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Original article

Brain computer interface with the P300 speller: Usability for disabled people with amyotrophic lateral sclerosis

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ABSTRACT

Objectives: Amyotrophic lateral sclerosis (ALS), a progressive neurodegenerative disease, restricts patients' communication capacity a few years after onset. A proof-of-concept of brain–computer interface (BCI) has shown promise in ALS and "locked-in" patients, mostly in pre-clinical studies or with only a few patients, but performance was estimated not high enough to support adoption by people with physical limitation of speech. Here, we evaluated a visual BCI device in a clinical study to determine whether disabled people with multiple deficiencies related to ALS would be able to use BCI to communicate in a daily environment.
Methods: After clinical evaluation of physical, cognitive and language capacities, 20 patients with ALS were included. The P300 speller BCI system consisted of electroencephalography acquisition connected to real-time processing software and separate keyboard-display control software. It was equipped with original features such as optimal stopping of flashes and word prediction. The study consisted of two 3-block sessions (copy spelling, free spelling and free use) with the system in several modes of operation to evaluate its usability in terms of effectiveness, efficiency and satisfaction.
Results: The system was effective in that all participants successfully achieved all spelling tasks and was efficient in that 65% of participants selected more than 95% of the correct symbols. The mean number of correct symbols selected per minute ranged from 3.6 (without word prediction) to 5.04 (with word prediction). Participants expressed satisfaction: the mean score was 8.7 on a 10-point visual analog scale assessing comfort, ease of use and utility. Patients quickly learned how to operate the system, which did not require much learning effort.
Conclusion: With its word prediction and optimal stopping of flashes, which improves information transfer rate, the BCI system may be competitive with alternative communication systems such as eye-trackers. Remaining requirements to improve the device for suitable ergonomic use are in progress.

1. Introduction

Amyotrophic lateral sclerosis (ALS) is a rare, rapidly progressive and devastating fatal neurodegenerative motor neuron disease affecting mostly older people; the disease is clinically characterized by a combination of lower and upper motor neuron degeneration symptoms, with widespread distribution in bulbar, cervical, thoracic, and lumbosacral regions. It commonly starts with focal onset and spreads inexorably to other anatomical areas [1], leading in a few years to a very severe condition of muscle weakness including limbs, thoracic and bulbar functions.

The disease incidence is about 2 to 3/100,000 in Western countries and prevalence about 4 to 6/100,000 (2). The creation of multidisciplinary ALS centers has greatly improved clinical care in the past decade and enhanced the survival and quality of life of patients.

In 25% to 30% of affected individuals in the early stage of ALS, dysarthria occurs as a first or predominant sign [2]. It affects up to 70% of patients with limb-onset disease, who gradually lose the ability to communicate orally or by writing, as do all patients with bulbar-onset disease when limbs eventually become affected. We

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have no hard evidence (only grade IV evidence) regarding speech and language management strategies for patients with ALS. The European Federation of the Neurological Societies–ALS guidelines [3] suggest, as a good practice point, assessing communication every 3 to 6 months and the use of appropriate communication support systems. Various oral communication devices and non-verbal strategies used consist of low-tech and high-tech augmentative and alternative communication (AAC) systems.

In this study, we investigated the usability of a brain computer interface (BCI) system for typing text for people with ALS. The principle of a BCI is to interpret the electric signals of the brain and translate them into commands. The feasibility of BCI communication has been reported in the past few years for individuals with ALS [4–10]. We evaluated BCI communication in a population of 20 severely disabled patients followed in the ALS Center of Nice University Hospital. The BCI system consisted of a virtual keyboard called the P300 speller [11,12] equipped with optimal stopping of flashes and word prediction, which are expected to improve performance in terms of information transfer rate (ITR). All patients underwent 2 sessions including 3 operating modes of progressively increasing complexity to investigate the usability of the system in terms of effectiveness, efficiency and satisfaction as recommended by the International Organization for Standardization (ISO 9241-1998) [13,14].

2. Materials and methods

2.1. Population studied

This was a non-invasive non-randomized prospective single-center study promoted by Nice University Hospital in accordance with the legal national regulations (approval by the local ethics committee CPP Sud Méditerranée III [ref.2013.01.03 ter] and registered at ClinicalTrials.gov [NCT01897818]).

After detailed information about the P300 speller and study, 20 patients who were routinely followed from disease onset in our center were included. Participants meeting the inclusion criteria and not the non-inclusion criteria in Appendix A were included. Oral communication disability was not considered critical to select patients because the goal was not to test BCI as an AAC in a target population but to test whether disabled people with multiple deficiencies related to ALS would be able, in a non-specific environment, to use BCI to communicate according to the concept of usability defined previously.

2.2. Experimental design

At inclusion, patients underwent assessment that included general neurological examination, ALS Functional Rating Scale–Revised (FRS-R) [15] and modified Norris bulbar scale [16]. Global cognitive impairment was measured with the mini mental state examination (MMSE) and the frontal assessment battery. Specific psychometric tests were administered to evaluate executive functions (Wisconsin card sorting test, phonemic verbal fluency, Symbol Digit Modalities Test and Trail Making Test A and B), attention (Symbol Digit Modalities Test) and language (French naming test DO80). Mood was evaluated by the State Trait Anxiety Inventory scale and depression by the Montgomery-Asberg Depression Rating Scale.

The initial use of the BCI device took place within 2 weeks after the initial assessment. An occupational therapist set up the system and provided explanations to the patient. All stages of the study were performed in a standard room. Participants sat in a comfortable chair or in their own wheelchair 90 cm from the LCD monitor.

Each patient participated in two identical P300 speller sessions 2 to 4 weeks apart. Each session lasted 60 to 90 min and consisted of 3 blocks: copy spelling (block 1), free spelling (block 2), and free use (block 3). At the beginning of each session, participants viewed a short audiovisual explanation about the subsequent experiments while they were wearing an EEG cap (ANT Neuro Waveguard^{TM}, with active electrodes), from which 12 electrodes (Fz, Cz, C3, C4, Pz, P3, P4, Oz, O1, O2, P7, P8, grounded to AFz, average reference) were connected to a Refa8 amplifier (256-Hz sampling rate). Conductive gel was applied to each electrode, with impedances $<$ 10 kOhms. Ability to stare at a screen and execute the instructions to use the device and evocation of a reliable visual P300 response were tested at that time. During calibration, participants successively focused on 10 letters, flashing 20 times. The recorded calibration data was used to train spatial filters and the linear discriminant analysis (LDA) classifier [17].

During the copy-spelling task (block 1 of each session), participants used the P300 speller to type two 10-letter words they overtly chose from a list (Appendix B, Table A1); while typing, participants were provided with cues (each keyboard letter to type briefly highlighted in blue) and feedback (letter highlighted in green if correctly selected by the P300 speller and in red otherwise). During typing, the word was progressively displayed under the keyboard, including possible typing errors. In this task, participants were instructed not to correct possible errors, so that the accuracy metrics were homogeneous.

During the free-spelling task (block 2 of each session), participants used the P300 speller to type two 5-letter words (or one 10-letter word) they covertly chose from a list (Appendix B, Table A2); they did not receive any cues or feedback and were again instructed not to correct possible errors.

The free-use task (block 3) was optional, depending on the patient's fatigue and motivation. Participants who chose to perform this block could use the P300 speller freely to type words and sentences of their choice, including punctuation marks, and were also offered the possibility to use word prediction. In word prediction mode, participants could spell character-by-character or select full words suggested on the screen. Error correction was possible by using a backspace key.

After each session, patients were asked to answer a questionnaire about satisfaction with the usefulness, comfort, and ease of use of the system on a 10-point visual analog scale (VAS).

2.3. P300 speller system

The P300 speller system was designed at Inria Sophia Antipolis [17]. It consisted of an EEG acquisition and real-time processing software using the OpenViBE platform [18] and a separate keyboard-display control software, both software running on a Windows 7 laptop with a One Intel Quad Core processor i7-3740QM (2.70 GHz, 6 MB cache). The laptop monitor was used to monitor the EEG signal quality, and a separate 22″ 1680 $\times$ 1050 LCD monitor was used to display the keyboard. The keyboard had 43 symbols including punctuation marks and a backspace key. A choice of AZERTY (French layout) or ABCDE layout was available.

As for all P300 speller keyboards, characters flashed in order to elicit a P300 response for the attended character. Here, the flashing consisted of briefly covering the character with a "smiley face", as this has been shown to elicit stronger P300 responses than simply highlighting the character [19]. The flash duration was 116.7 ms, and the inter-stimulus interval was 183.3 ms. Instead of row-column flashing, characters were flashed in pseudo-random groups, designed to minimize the consecutive flashing of the same characters, and the simultaneous flashing of neighbor characters [20].