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ORIGINAL ARTICLE

Assistive Device With Conventional, Alternative, and Brain-Computer Interface Inputs to Enhance Interaction With the Environment for People With Amyotrophic Lateral Sclerosis: A Feasibility and Usability Study

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Abstract

Objective: To evaluate the feasibility and usability of an assistive technology (AT) prototype designed to be operated with conventional/alternative input channels and a P300-based brain-computer interface (BCI) in order to provide users who have different degrees of muscular impairment resulting from amyotrophic lateral sclerosis (ALS) with communication and environmental control applications.

Design: Proof-of-principle study with a convenience sample.

Setting: An apartment-like space designed to be fully accessible by people with motor disabilities for occupational therapy, placed in a neurologic rehabilitation hospital.

Participants: End-users with ALS (N=8; 5 men, 3 women; mean age ± SD, 60±12y) recruited by a clinical team from an ALS center.

Interventions: Three experimental conditions based on (1) a widely validated P300-based BCI alone; (2) the AT prototype operated by a conventional/alternative input device tailored to the specific end-user's residual motor abilities; and (3) the AT prototype accessed by a P300-based BCI. These 3 conditions were presented to all participants in 3 different sessions.

Main Outcome Measures: System usability was evaluated in terms of effectiveness (accuracy), efficiency (written symbol rate, time for correct selection, workload), and end-user satisfaction (overall satisfaction) domains. A comparison of the data collected in the 3 conditions was performed.

Results: Effectiveness and end-user satisfaction did not significantly differ among the 3 experimental conditions. Condition III was less efficient than condition II as expressed by the longer time for correct selection.

Conclusions: A BCI can be used as an input channel to access an AT by persons with ALS, with no significant reduction of usability.
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Amyotrophic lateral sclerosis (ALS) is a progressive neurodegenerative disease that affects both upper and lower motor neurons, with an annual incidence in Europe of 2 to 3 people per 100,000 of the general population older than 15 years.[1] People with ALS experience increasing muscular weakness and atrophy

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that progressively limit independence and communication in their daily life. This condition can be temporarily compensated for by adopting an assistive technology (AT) tailored to the current functional deficit. Accordingly, augmentative and alternative communication is a valuable means by which people with severe motor disabilities can extend/replace their communication abilities by adopting solutions ranging from low-tech (eg, eye-transfer board) to high-tech (eg, eye-tracker) communication aids.[2]

In the absence of muscular contraction, the brain-computer interface (BCI) may represent a solution since it exploits neurophysiological signals as input commands to control external devices.[3,4] Although the number of studies on BCI applications has been recently growing exponentially,[5] those including target end-users with severe motor impairment are still scarce.[6-10]

The "user-centered design" (UCD; International Organization for Standardization 9241-210[11]), according to which the end-user has a central and active role in the technology design and development iterative processes, has also been introduced in the BCI field of research.[12-15] The adoption of the UCD principles has provided the initial step to bridge the existing gap in translating the BCI technology from the laboratory to the real-life usage scenario.[12] In this regard, several studies[7,13,14] are available showing the feasibility of the BCI technology to serve as an additional channel to access commercial AT devices, thus paving the way to a wider applicability of the BCI technology.

One of the studies[7] evaluated the usability of a commercial AT software controlled by a P300-based BCI in a group of 4 end-users with motor disabilities. In a second study,[14] an unmodified commercial AT was functionally operated through a BCI keyboard. The authors demonstrated that using a BCI to control an unmodified commercial AT did not affect BCI performance in a group of 11 end-users with ALS and 22 participants without motor disabilities.

One of the fundamental steps in the UCD cycle is to evaluate technology design against the user's requirements.[11] Following the adoption of the UCD, an effort has been made to apply objective metrics derived from the UCD to evaluate BCI-controlled applications.[7] A preliminary framework of these metrics has been recently proposed[15] and applied to evaluate the usability of communication and entertainment applications operated via electroencephalographic (EEG)-based BCIs.

In the present study, we aimed to evaluate the feasibility and usability of a previously implemented AT prototype[16] operated via the P300-based BCI channel according to the metrics derived from the UCD approach. As such, the prototype provided the end-users with functionalities that were seamlessly accessible through several conventional/alternative devices including a P300-based BCI (for a review, see Kleih et al[17]), and it was meant to enhance or even to allow basic needs for communication and environmental interaction. The multimodal accessibility, which also included an exclusive BCI control, rendered this AT prototype adaptable to cope with a progressive impairment up to a loss of muscular function (such as in the case of ALS).

A comparative experimental design was adopted in which the use of the AT prototype operated via the P300-based BCI was contrasted against 2 conditions:

1. A widely validated stand-alone P300-based BCI. This (control) condition allowed us to investigate whether the dynamic interface of the AT prototype, consisting of dynamically resized matrices to enable access to a range of different applications (virtual keyboard, domotic control, etc), would affect system usability with respect to a static interface (ie, single matrix).
2. The same AT prototype operated via conventional/alternative channels based on residual muscular abilities. Herein, our investigation focused on whether the limits in speed and accuracy of the BCI channel could affect usability with respect to conventional/alternative input devices.

Methods

AT prototype design

The functionalities to be included in the AT prototype were selected according to the results of a preliminary survey and 2 focus groups. The survey involved 3 classes of primary and secondary users: 7 end-users (ie, people with ALS), 13 caregivers, and 20 professional stakeholders (ie, experts in ATs). Participants were asked to rate how useful the inclusion of further functionalities in the domains of interpersonal communication, environmental interaction, and personal autonomy would be (fig 1). The 2 focus groups involved end-users, caregivers, and stakeholders and were carried out in order to discuss the potentialities and the limits of a BCI system as AT. Four main topics emerged from the 2 focus groups: (1) the need for more information on BCIs and their potential applications; (2) the importance of having a modular system customizable to end-users' needs, and able to follow end-users throughout the progression of the degenerative disease; (3) the relevance of emotional aspects in the relationship with the technology; and (4) the importance for end-users to remain active (G. Liberati, PhD, unpublished data, 2012).

Prototype description

Functionalities

Concerning interpersonal communication, the AT prototype (fig 2) provided 3 main applications: (1) an alarm bell to draw the attention of the caregiver; (2) a simple text editor for both face-to-face and remote (e-mail, short message service) communication; and (3) an interface to select predefined sentences or keywords for quick communication. For the environmental control, simple functionalities were required by end-users, such as television control, movement of motorized armchair/bed, light switching, and door opening.[16] These were implemented by using the KNX standard to control the electronic devices available at an apartment-like space designed for occupational therapy and fully accessible by people with motor disabilities.

List of abbreviations:

ALS	amyotrophic lateral sclerosis
ALSFRS-R	ALS Functional Rating Scale−Revised
ANOVA	analysis of variance
AT	assistive technology
BCI	brain-computer interface
EEG	electroencephalographic
SUS	System Usability Scale
UCD	user-centered design
VAS	visual analog scale
WSR	written symbol rate