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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

Francesca Schettini, PhD,[a,b,*] Angela Riccio, PhD,[a,c,*] Luca Simione, PhD,[a,d] Giulia Liberati, PhD,[a,e] Mario Caruso, MS,[b] Vittorio Frasca, MD,[f] Barbara Calabrese, PhD,[g] Massimo Mecella, PhD,[b] Alessia Pizzimenti, MSc,[h] Maurizio Inghilleri, MD, PhD,[f] Donatella Mattia, MD, PhD,[a] Febo Cincotti, PhD[a,b]

From the [a]Neuroelectrical Imaging and BCI Lab, IRCCS Fondazione Santa Lucia, Rome, Italy; [b]Department of Computer, Control, and Management Engineering Antonio Ruberti, "Sapienza" University of Rome, Rome, Italy; [c]Department of Psychology, "Sapienza" University of Rome, Rome, Italy; [d]Institute of Cognitive Sciences and Technologies, CNR, Rome, Italy; [e]Institute of Neuroscience, Université Catholique de Louvain, Louvain-la-Neuve, Belgium; [f]Department of Neurology and Psychiatry, "Sapienza" University of Rome, Rome, Italy; [g]Department of Experimental and Clinical Medicine, "Magna Graecia" University of Catanzaro, Catanzaro, Italy; and [h]Crossing Dialogues Association, Rome, Italy.
** Schettini and Riccio contributed equally to this work.*

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.

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

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.

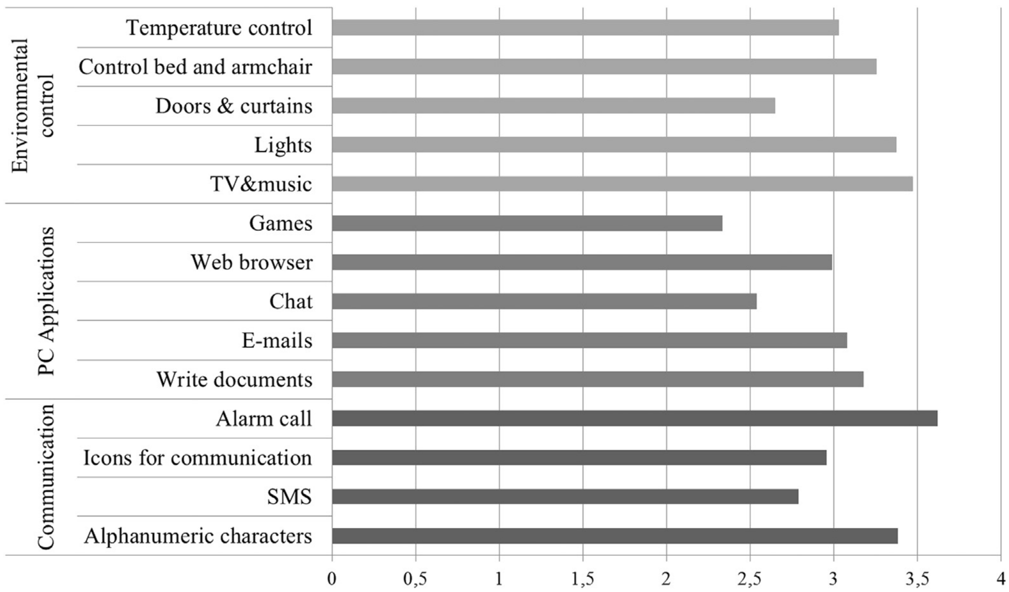

Fig 1 Results of the preliminary user survey. Bars denote the mean score values (x-axis) for functionalities (y-axis) ranked on a scale ranging from 0 (useless) to 4 (very useful). Abbreviation: SMS, short message service.

Hardware and software

To ensure portability and affordability, the AT prototype was developed on a 10-in tablet, and the software was written in Java[a] and Visual C++[b] running on the Windows operating system.[c] As it concerned the BCI modality, a specifically developed software program allowed visual stimuli (green grids in this case) necessary to generate evoked potentials to be overlaid on the user interface. Stimulation timing and data acquisition were managed by the BCI2000[d] framework,[18] and stimuli were delivered by a proxy application that managed the communication between the BCI2000 and the prototype user interface. All components of the software BCI ran on the tablet, as well as the other software components (including the user interface) of the prototype.

Participants

Eight end-users with ALS (5 men, 3 women; mean age ± SD, 60±12y; mean time ± SD since diagnosis, 24±26.6mo; range, 2−84mo) were recruited from the ALS Center (Department of Neurology and Psychiatry, "Sapienza" University of Rome). All participants (or legal guardians when needed) gave their written informed consent for participation in the study, which was approved by the local ethical committee of IRCCS Fondazione Santa Lucia Rome, Italy. Demographic, clinical, and neuropsychological descriptions of the end-users are reported in table 1. Functional muscular impairment was assessed by means of the ALS Functional Rating Scale−Revised (ALSFRS-R[19]). All

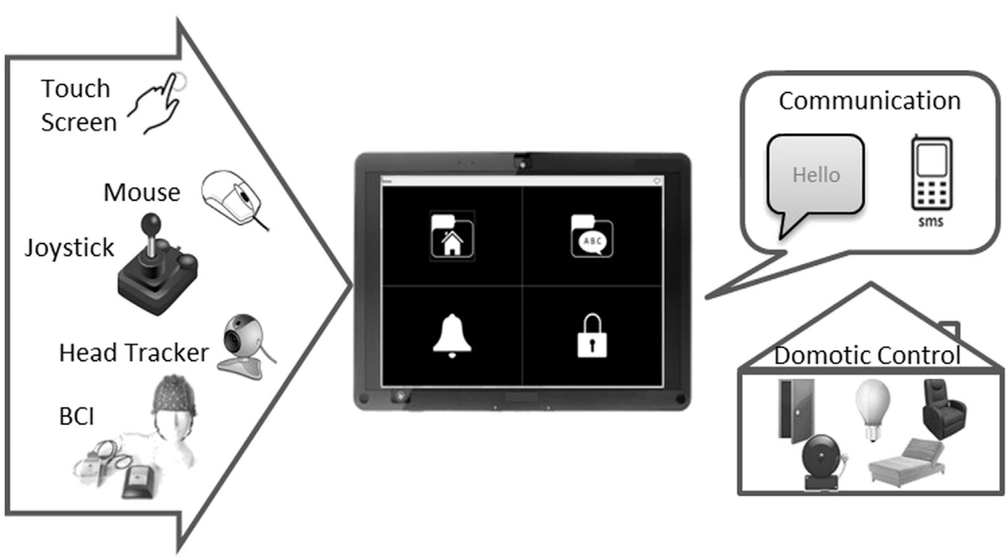

Fig 2 Schematic illustration of the AT prototype. Multimodal access inputs (ie, touchscreen, mouse, keyboard, buttons, switches, head tracker, including a P300-based BCI), interface (ie, the core system), and controlled options (application for interpersonal communication and environmental functionalities). Abbreviation: SMS, short message service.

Table 1 Demographic, clinical, and neuropsychological description of end-users

Subject No.	Sex	Age (y)	ALSFRS-R	Onset	Time Since Diagnosis (mo)	Conventional/Alternative Input Device	WCST	SA	WM
1	M	55	13	Spinal	84	Automatic scanning—1 button	=	=	=
2	M	59	37	Spinal	31	Touch screen	↓↓	↓	↓
3	M	47	34	Bulbar	8	Mouse	=	=	=
4	F	75	38	Bulbar	10	Mouse and keyboard	↓↓	=	↓
5	F	72	34	Bulbar	12	Mouse	↓↓↓↓	=	↓
6	M	40	31	Spinal	12	Scanning—2 buttons	↓↓↓↓	=	=
7	M	61	28	Bulbar	34	Scanning—2 buttons	=	=	=
8	F	72	41	Bulbar	2	Mouse	↑	↓	↓

NOTE. ALSFRS-R is a validated scale monitoring the progression of disability in patients with ALS, with scores ranging from 0 to 48. An equal sign indicates performance within normal range. Up and down arrows indicate performance above and below (ie, pathologic) normal range, respectively. The number of down arrows indicates the severity of the deficit, ranging from mild (1 arrow) to severe (5 arrows).
Abbreviations: F, female; M, male; SA, selective attention; WCST, Wisconsin Card Sorting Test; WM, working memory.

enrolled participants showed the presence of a severe impairment in communication (score ≤2 on item 1, "word articulation," or item 4, "writing ability," of the ALSFRS-R) or environmental control (score ≤2 on item 5, "ability to cut food/use tools," or item 6, "hygiene/personal care," of the ALSFRS-R), and all were using a conventional/alternative input device. Five end-users showed a deficit of executive functions (as assessed by means of the Wisconsin Card Sorting Test[20]). A deficit of selective attention and of working memory, both assessed by means of the computerized Test for Attentional Performance,[21] was found in 2 and 4 participants, respectively.

Experimental protocol

The overall usability of the AT prototype was evaluated by comparing 3 different experimental conditions performed in 3 different experimental sessions (1/wk), each lasting about 90 minutes. In conditions I and III (see next 3 sections), scalp EEG signals were recorded (g.MOBIlab,[e] 256Hz) from 8 Ag/AgCl electrodes (Fz, Cz, Pz, Oz, P3, P4, PO7, and PO8, referenced to the right earlobe and grounded to the left mastoid[22]) placed according to the 10-10 standard.

Condition I: P300-speller

In condition I, the participants were asked to control a stand-alone P300-based BCI (P300-speller[23]); the aim was to test the baseline end-users' ability to control a BCI system and to subsequently compare the performance obtained with the BCI with that observed while controlling the AT prototype with the BCI channel. The P300-speller consisted of a 6×6 matrix containing 36 alphanumeric characters, which were randomly intensified by rows and columns for 125 milliseconds, with 125 milliseconds of interstimulus interval. End-users had to spell 7 predefined words of 5 characters (so-called copy mode). The selection of a character occurred after a train of stimuli (trial), during which every row and column of the matrix were intensified 10 times. Characters were cued at the beginning of each trial. No feedback was provided to the users while spelling the first 3 words. This EEG—data set was used to extract the BCI classifier parameters by applying a stepwise linear discriminant analysis.[24] The extracted parameters (features weights) determined the online feedback (ie, the selected character) during the spelling of the remaining 4 words.

Condition II: AT prototype controlled with conventional/alternative input device

Condition II aimed at introducing the AT prototype to the users, who operated it via a conventional or an alternative input device (eg, mouse, buttons) that best matched their residual motor abilities (see table 1, Conventional/Alternative Input Device column). The experimenter showed the applications integrated in the AT prototype to the end-users, who were then encouraged to explore them until they felt "confident enough." Throughout the session, the users performed 2 preestablished tasks that mimicked everyday life actions and required a minimum of 8 selections each. The end-users received instructions only on the final goal of the required task; that is no details were given about how to solve it. Hence, they were left free to develop their own strategy to cope with possible mistakes. We will refer to these tasks as "self-managed tasks."

- *Self-managed environmental control task:* The users had to perform sleep-time actions; that is, starting from the home menu of the visual interface, they were required to lower the backrest of the motorized bed, turn off the light, and go back to the home page.
- *Self-managed communication task:* The experimenter asked the participants, "How is the weather today?" and the users had to answer "BELLO" ("fine" in Italian) by writing it on the virtual keyboard and vocalizing it via the vocal synthesizer.

Condition III: AT prototype controlled with P300-based BCI input

In the third session, the AT prototype was controlled via the P300-based BCI (our main experimental condition). The prototype visual interface consisted of several menus with a minimum of 4 items (2×2 matrix) and a maximum of 36 items (6×6 matrix). Stimulation timing and number of stimulus repetitions for each item were the same as in condition I (P300-speller). Each end-user carried out a total of 6 calibration runs (no feedback provided): 2 with a 2×2 matrix, 2 with a 4×4 matrix, and 2 with a 6×6 matrix. During each calibration run, the users were required to attend 4 items prompted by the experimenter. Classifier parameters were calibrated as described for condition I on the ensemble of the calibration runs. During the subsequent online runs, the end-users were asked to perform 2 tasks consisting of a well-defined sequence of actions that were cued step by step by the experimenter (in case of a wrong selection, the experimenter also suggested how to fix the error). These tasks allowed a direct comparison with condition I. We will refer to these tasks as "copy tasks."

- *Copy—environmental control task:* The end-users had to perform wake-up actions; that is, starting from the home menu, they were required to turn on the light, raise the seatback of the motorized bed, and then go back to the starting menu.
- *Copy—communication task:* The experimenter asked the participants, "How is the weather today?" and the end-users had to answer "PIOVE" ("it rains" in Italian) by writing it on the editor and vocalizing it via the vocal synthesizer.

Finally, each subject performed the same 2 self-managed tasks described in the Condition II section.

AT prototype usability assessment

As in previous studies,[7,13] specific performance metrics were considered for each of the 3 usability domains: effectiveness, efficiency, and satisfaction.[11] Metrics such as the time for correct selection and the written symbol rate (WSR[25]) were considered as in between the efficiency and effectiveness domains.

Effectiveness

Effectiveness was quantified in terms of the following:

1. *BCI online copy accuracy:* Expressed in terms of the percentage of correct selections for the online copy tasks of conditions I and III. It was calculated by dividing the number of correct selections by the number of total selections.
2. *BCI offline accuracy*: Expressed in terms of accuracy for stimulus repetition and assessed by means of a 7-fold and 6-fold cross-validation on the copy-mode words spelled in condition I and on the calibration runs of condition III, respectively. For each round of crossvalidation, 6 runs (condition I) or 5 runs (condition II) were used as training data set, whereas the remaining run was used as testing data set. The number of stimulus repetitions allowing for the highest WSR and the corresponding accuracy value for each end-user were assessed on the results of cross-validation related to condition III.
3. *AT prototype online accuracy during self-managed tasks*: Expressed in terms of the percentage of correct selections and calculated by dividing the number of correct selections by the number of total selections of the self-managed tasks performed in conditions II and III. Since the same number of stimulus repetitions was applied for all end-users during the online task of condition III (ie, no optimization was performed), we also reported the accuracy value corresponding to the maximum WSR as estimated offline. In the following, this condition will be referred to as condition III*.

Efficiency

Efficiency was quantified in terms of the following:

1. *BCI offline WSR:* The WSR was assessed as a function of the number of stimulus repetitions delivered in a given trial of the copy tasks performed in conditions I and III.
2. *AT prototype time for correct selection:* The total time (in seconds) to complete the task divided by the number of correct selections, as calculated for the self-managed tasks of conditions II and III. In a separate analysis (in condition III*), we performed an offline optimization of the time per correct selection. In fact, the number of stimuli per trial of online BCIs is usually calibrated to maximize communication speed. In our study, sequences of 10 stimuli were used for all participants to allow a more accurate group analysis. In the offline simulation, for each subject, the number of stimulus repetitions was set as the value that maximized the WSR.
3. *Workload:* Measured by means of the National Aeronautics and Space Administration—Task Load Index.[26]

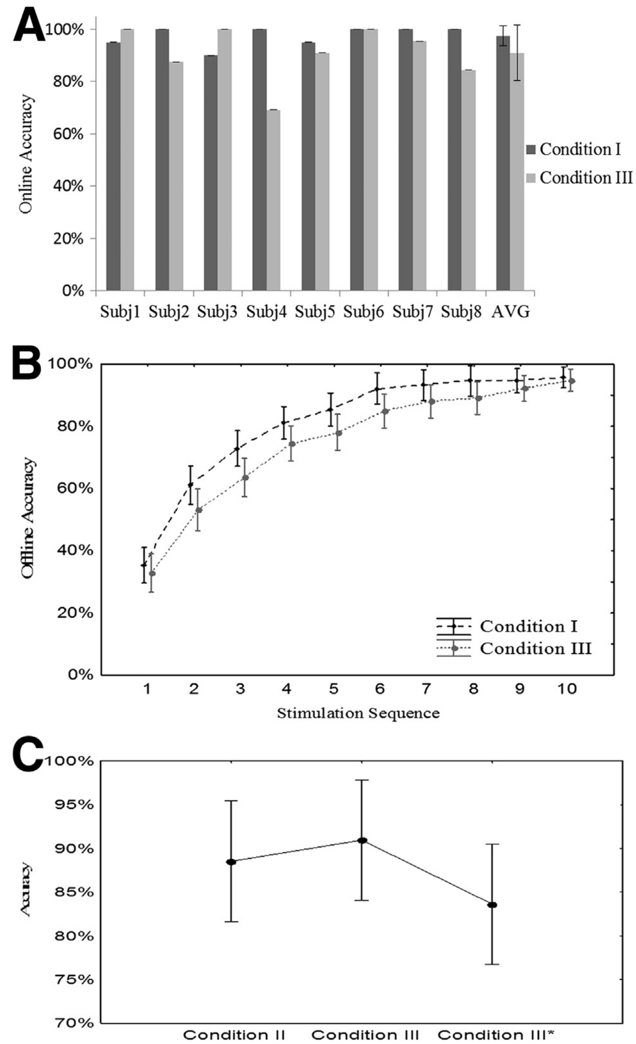

Fig 3 (A) Online accuracy percentage values for the copy tasks of conditions I and III. (B) Mean accuracy values as a function of the number of stimulus repetitions delivered in conditions I and III and assessed by means of offline cross-validations. (C) Online accuracy on average computed during the self-managed tasks, under conditions II and III. Condition III* denotes values corresponding to the maximum end-users' WSR, optimized for condition III. Abbreviations: AVG, average; Subj, subject.

Satisfaction

Satisfaction was reported by means of the following:

1. *VAS scores:* End-users were administered a visual analog scale (VAS, 1—10) to assess the overall satisfaction experienced with

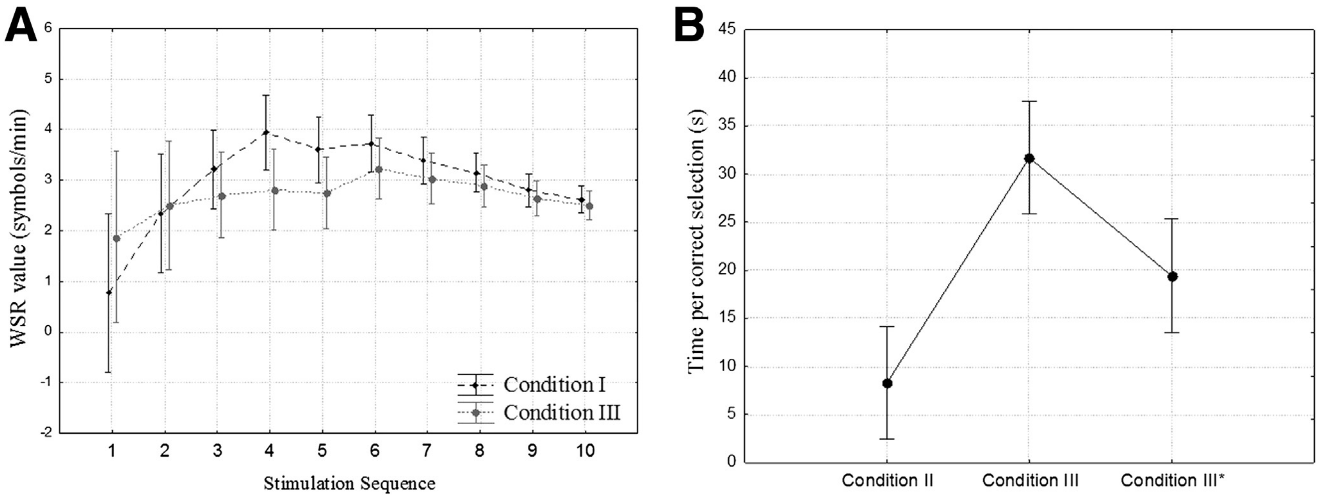

Fig 4 (A) WSR mean values for conditions I and III assessed by means of offline cross-validations. (B) Time per correct selection detected online during self-managed tasks in conditions II and III. Condition III* refers to the time per correct selection obtained considering the number of stimulus repetitions associated with the maximum value of WSR.

the P300-speller (in condition I) and the AT prototype (in conditions II and III).

2. *System usability scores:* End-users filled out the System Usability Scale (SUS, 1–100), which investigated end-users' satisfaction in terms of pleasure experienced using the P300-speller (in condition I) and the AT prototype (in conditions II and III).

The self-reported questionnaires (National Aeronautics and Space Administration–Task Load Index, VAS, SUS) were administered by a psychologist at the end of each session.

Results

Effectiveness

1. *BCI online copy accuracy:* We compared BCI online copy accuracy values obtained in conditions I and III (fig 3A). Since the distribution of these values for condition I violated the assumption of normality, a Wilcoxon matched-pairs test was applied. The analysis did not reveal significant differences ($Z=1.18$, $P=.23$). The distribution of the differences (accuracy condition I minus accuracy condition III) was normal (Shapiro-Wilk test, $W=.95$, $P=.78$; mean value ± SD, 6.6%± 12%). Thus, we can conclude that accuracy in condition I is on average less than 7% higher than in condition III. This difference was not significantly different from 0 as assessed by a 1-sample *t* test ($P=.19$).
2. *BCI offline accuracy:* A repeated-measures analysis of variance (ANOVA) was performed with conditions (I, III) as the factor and the BCI offline accuracy per number of stimulus repetitions as the dependent variable. Even though condition I exhibited a higher accuracy than condition III, such a difference was not significant ($F_{9,792}=1.053$, $P=.35$) (fig 3B).
3. *AT prototype online accuracy during self-managed tasks:* The values obtained in conditions II, III, and III* were also compared by means of a 1-way ANOVA (fig 3C). No significant differences were found between the 3 conditions ($F_{2,21}=1.26$, $P=.30$).

Efficiency

1. *BCI offline WSR:* The BCI offline WSR scores obtained in conditions I and III were compared, and no significant difference was found as assessed by a repeated-measures ANOVA with condition as the factor and WSR value per stimulation sequence as the dependent variable ($F_{9,792}=1.33$, $P=.21$) (fig 4A).
2. *AT prototype time for correct selection:* The AT prototype time for correct selection for conditions II, III, and III* was compared by means of a 1-way ANOVA. Condition II exhibited a significantly lower time per correct selection (8.31±6.81s on average) with respect to condition III (31.69±7.59s on average) and condition III* (19.43±9.3s on average) ($F_{2,21}=17.2$, $P<.01$) (fig 4B).
3. *Workload:* On average, the workload was perceived as highest in condition I (table 2). The total workload scores obtained in the 3 conditions were compared by means of a nonparametric Friedman ANOVA. No significant differences between the 3 conditions were found (Friedman $\chi^2=3.2$, $P=.19$).

Satisfaction

1. *VAS scores:* The VAS score was higher in condition III with respect to condition II.
2. *System usability scores:* The system usability score was higher in condition II with respect to conditions I and III.

None of these differences, however, reached significance as determined by means of 2 nonparametric Friedman ANOVAs performed for both the VAS (Friedman $\chi^2=.24$, $P=.88$) and SUS scores (Friedman $\chi^2=4.06$, $P=.13$).

Discussion

The aim of this study was to test the feasibility and to evaluate the usability of an AT prototype which was intended to provide people with severe motor impairment caused by ALS with several applications to support communication and environmental control. The AT prototype was endowed with several accessibility options, ranging from conventional/alternative input devices to a BCI device.

Table 2 Scores of self-reported questionnaires (satisfaction VAS, SUS, NASA-TLX) of end-users (N=8) along the 3 conditions

	Satisfaction VAS (0–10)			SUS (0–100)			Workload (NASA-TLX, 0–100)		
Subject No.	Condition I	Condition II	Condition III	Condition I	Condition II	Condition III	Condition I	Condition II	Condition III
1	9.8	10	10	77.5	57.5	85	44	30.33	37.66
2	10	9	8.3	82.5	84.28	55	14.33	10.66	27.66
3	8.6	7.8	9	80	92.5	90	27.33	22.66	29.66
4	9.7	10	10	42.5	70	70	60.33	56	32.28
5	9.7	7	9	100	85	77.5	62.33	55.33	39.66
6	10	10	10	95	100	92.5	17	29	13.33
7	9	10	9	85	100	90	39	20.3	62.33
8	9.6	9	9,3	82.5	85	82.5	28,33	27	15.66
Mean ± SD	9.5±0.5	9.1±1.1	9.3±0.6	80.6±17.2	84.3±14.5	80.3±12.6	36.6±18.2	31.4±16.2	32.3±15.3

Abbreviation: NASA-TLX, National Aeronautics and Space Administration—Task Load Index.

The prototype features met the end-users' requirements mainly by targeting everyday communication (such as asking for the caregiver's attention) and basic environmental interactions (such as turning on/off lights and controlling the television; see fig 1).

We demonstrated the feasibility and usability of the system, designed and developed to provide a multimodal access for communication and environmental control applications. Usability was assessed applying metrics derived from the UCD and adapted to evaluate BCI technology. No differences were found in terms of effectiveness between the 3 conditions. We found that using a P300-based BCI to control a complex user interface (condition III) did not affect both system accuracy and WSR as compared with the control of a stand-alone BCI (P300-speller, condition I) with a static menu interface. With respect to efficiency, the access to the proposed AT was faster when conventional/alternative input devices (condition II) were used as compared with the BCI (condition III) access mode. This finding was not, however, reflected by the workload perceived by end-users that was similar among the 3 conditions. Finally, end-users reported a high level of satisfaction in both conditions with BCI input (conditions I and III). Despite no significant differences being found, the satisfaction perceived with BCI input overtook the satisfaction perceived with conventional/alternative input (condition II). We can speculate that this higher level of satisfaction might be related to the greater challenge associated with the use of a BCI that, in case of success, can feel more satisfying. On the contrary, usability displayed an opposite trend, being higher when the AT prototype was accessed via conventional/alternative inputs. This trend could be attributed to the generally lower speed of the BCI channel and the need for calibration that might affect the overall system usage with respect to conventional/alternative input devices.

Also interesting is that all end-users were able to access the prototype via the BCI input channel, even in the presence of cognitive impairment.

In conclusion, a BCI endowed as an input channel in an AT system is a step forward for the process of translation from the laboratory to daily life. Providing end-users with a usable aid, projected according to UCD principles, could potentially positively influence their perception of quality of life.

Study limitations

This feasibility study was conducted under controlled conditions (ie, experimental setting) and involved 8 end-users who were still able to use conventional inputs. This prevented us from properly evaluating the proposed system with standardized instruments to assess computer task performance.[27] These instruments need to be applied in a longitudinal study with a larger cohort of end-users using the system along the time course of the disease in an ecological environment.

Conclusions

Even though further testing is required, this study demonstrates the feasibility of an AT for communication and control that is endowed with multiaccess including BCI. According to the principles of UCD adapted for the design and development of the prototype, the BCI is not considered the only option for end-users (stand-alone BCI) but as an additional channel to access a whole system providing a large range of options. Excluding the speed, the usability of the BCI-controlled AT (ie, effectiveness, efficiency, and satisfaction) was not reduced with respect to the conventional/alternative input devices.

Suppliers

a. Java; Oracle Corp.
b. Visual C++; Microsoft Corp. Available at: www.microsoft.com/Visual-Studio.
c. Windows operating system; Microsoft Corp.
d. BCI2000; Schalk Lab, Center For Medical Sciences. Available at: www.bci2000.org.
e. g.MOBIlab; g.tec Medical Engineering GmbH.

Keywords

Amyotrophic lateral sclerosis; Assistive technology; Brain-computer interfaces; Event-related potentials; P300; Rehabilitation

Corresponding author

Francesca Schettini, PhD, Neuroelectrical Imaging and BCI Lab, IRCCS Fondazione Santa Lucia, Via Ardeatina, 306, I-00179 Rome, Italy. *E-mail address:* f.schettini@hsantalucia.it.

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