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Adaptive inputs in an interface for people with Dyskinetic Cerebral Palsy: Learning and usability

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Abstract. This study concerns the difficulty in accessing computers faced by people with Dyskinetic Cerebral Palsy (DCP). Thus diminishing their opportunities to communicate or learn. This population usually needs an alternative input human-computer interface (HCI). The paper presents an alternative multimodal HCI that incorporates a head-mounted interface and superficial electromyography sensors (sEMG). The aim of the study is to assess the usability and the suitability of these two HCI devices. Six non-disabled subjects and ten subjects with DCP participated in the iterative process in which each test follows an improvement of an input. The results indicated that for both systems, the improvements in the usability are remarkable when there were previous training programmes with both interfaces. These tests allowed the identification of the main difficulties associated with disability: poor control of the voluntary muscle contraction, which affects the EMG signal, and abnormal postures, which affect the head-mounted interface control. Regarding the EMG signal, the characterisation of the involuntary patterns of muscle contractions may prevent false positives. In the case of the inertial interface, a relative mode control (based on the velocity of the movement instead of posture) may be a solution to increasing the usability and task performance.

Keywords: Cerebral palsy, dyskinesia, usability, augmentative and alternative communication, human-machine interaction, assistive technology, user-adaptation, sEMG, inertial sensors, motor disorders

1. Introduction

Cerebral Palsy (CP) is a non-progressive condition caused by an injury in the brain in early stages of pregnancy, through birth, to early childhood, and results in motor and sensitivity impairments [1,2]. CP is classified as "non-progressive", meaning the condition does not get worse with time [3]. However, specific symptoms can change with the individual's body growth and development [4].

Dyskinetic Cerebral Palsy (DCP) is a permanent condition that causes severe motor impairments (i.e.

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changes in muscle tone and posture, and involuntary movements) and speech disorders (i.e. anarthria and dysarthria) which greatly limit physical and social activity. DCP affects over 125.000 people in Europe and there are 1.500 new cases each year [5–7]. It is caused by a non-progressive interference, lesion, or abnormality of the developing/immature brain (before, during or shortly after birth). Over the last years, the prevalence of CP has increased due to the increase in the survival rate of prematurely born infants. The estimated lifetime cost per CP patient is nearly one million euros [8].

Despite the fact that 78% of DCP children have normal intelligence, 96% have been classified as "educationally subnormal". This discrepancy between their intellectual potential and their actual development is to a large degree caused by their impaired communication and interaction abilities, which hamper their learning processes. Indeed, this lack of communication channel does not only affect learning but other key processes such as rehabilitation therapies, diagnostic and health management, gaming, social relationships or environment control. In fact, this lack of communication combined with limited mobility leads to increased dependency, loneliness, social exclusion, reduced quality of life, and eventually the premature death of people with DCP [9–11].

Improvements in health and rehabilitation treatments and new communication systems have increased considerably their quality of life and extended their life expectancy. The autonomy of people with DCP is considered a primary target as the compensation of their multiple and severe limitations (speech and motor control) can allow them to reach their maximum potential [11–13].

The majority of people with DCP cannot communicate through written language because they have very limited fine motor control. Consequently, they need to use Augmentative and Alternative Communication (AAC). The American Speech-Language-Hearing Association (2014) defines AAC as any kind of communication mechanisms (other than oral speech) that is used to declare thoughts, ideas, wants and needs. People with severe speech or language problems rely on AAC to complement existing speech or replace speech that is not functional. Special augmentative aids, such as picture and symbol communication boards and electronic devices, are available to help people express themselves. This is expected to support social interaction, improve school performance, and increase self-esteem ("American Speech-Language-Hearing Association", s.f.) [14].

An AAC system consists of a package of techniques and technologies that makes up 'total communication' for one specific individual. This system is based on the communication medium, a system that represents meaning, means of access and strategies for interacting (Royal College of Speech and Language Therapists (RCSLT) 2006) [15].

- Communication medium refers to the way of transmitting the message. This might be via unaided or aided systems. The UNE-EN ISO 9999 defines assistive products for face-to-face communication in letter and/or symbol sets and boards, communication amplifiers, dialogue units and software for face-to-face communication [16].
- The system of representing meaning, ideas and concepts includes body language, pictures, gestures, facial expressions, paintings, words, line drawings or Bliss symbols.
- The means of access to the communication medium introduces the tools to interact with the assistive devices, for example, keyboard, touch screen or a switch to scan from an array of letters/words/pictures and are included in the UNE-EN ISO 9999 [16].
- The term strategy comprises any plan to use symbols, aids, and techniques to improve communication. For example, being able to start up a conversation, maintain a conversation by turn-taking and using questions, and reparation strategies when communication breaks down (RCSLT 2006; UNE-EN ISO 9999:2011) [16].

The support devices for the AAC can be accessed via two basic strategies: direct selection and scanning. The direct selection approach allows the user access to all possible symbol choices at all times. This kind of selection can be carried out with keyboards, joysticks or switches installed on the wheelchair, light and optical pointers or eye-gaze [17,18]. For users with reduced mobility, especially in their hands, direct selection systems generally are not a good alternative. These kinds of users use scanning as means of alternative access [19].

Lee and Thomas [20] describe four general scanning techniques:

- Automatic scanning: A cursor or marker automatically moves in sequence across items or groups. The marker pauses at each group/item for a predefined time. When the user holds down the switch, the highlighted item is selected. Usually, users are trained to focus on the target item and press the switch whenever the target is highlighted.

- Step scanning: In this technique, the scan and selection of an item is completed in several steps (i.e. rows and columns of icons). Even though more switch activations are required, this strategy can actually be faster than automatic scanning. In any case, the advantage of this approach is that the user can go at their own pace according to their physical and cognitive limitations.
- Inverse scanning: The cursor or marker advances by maintained switch activation. While the switch is activated, the highlight pauses at each item for a scan interval. The item is selected when the user releases the switch.
- Directed scanning: Separate switches are used to control the direction of cursor movements. The switches can be in step or inverse mode [20].

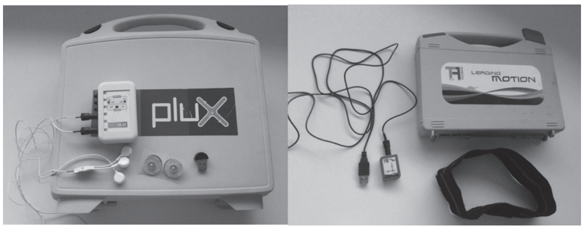
Each scanning technique and pattern requires different physical, cognitive and perceptual abilities from the user. For this reason, the scanning mode has to be chosen according with the user needs and limitations [21,22].

Nowadays, scanning solutions are being adapted to the specific characteristics of users. Some proposed solutions for scanning are focused on switching by head movements, pressure sensors, electromyography or mechanomyography [23]. In general, DCP users need an input interface to select and point at the desired concept. However, their lack of movement and posture control restrains the possible use of interfaces. Typical keyboards, a mouse or touch screens cannot be used by most of DCP users, and they have similar problems with more natural interfaces such as speech, gesture or eye tracking commands [24].

A head-mounted interface has been used in infants with CP and evaluated as a useful tool for communicating, learning and therapy [25]. In addition, some approaches use a combination of different technologies such as the EMG signals from muscles in the face and point of gaze coordinates produced by an eye-gaze tracking system with non-disabled people [26].

In the framework of the ABC project (European Project 287774: ABC "Advanced BNCI Communication", financed by the Seventh Framework Programme, corresponding to the FP7-ICT-2011-7 call), the usability of a multimodal Human-Computer Interface (HCI) fusing the EMG and the inertial head-mounted interface as the input device was investigated for people with DCP including when they acted as social partners in the process design [27,28].

This study aims to assess the usability and suitability of the two devices analysed (EMG and inertial head-mounted interface) to determine the most appropriate for each subject and to identify the improvements in efficiency during use.



(a) (b)

Fig. 1. (a) EMG interface and (b) head-mounted interface.

Fig. 2. The instrumentation for EMG with the communicator prototype.

2. Materials and methods

2.1. Materials

2.1.1. Inputs

Two input devices (Figs 1(a) and (b)) were studied simultaneously because they provide complementary functions. The assessment is based on generating messages from a communicator developed in the framework of the ABC project.

EMG

The EMG signal was recorded by two surface electrodes placed on the appropriate muscle and one reference electrode placed following the SENIAM, Surface Electromyography (SEMG) for non-invasive assessment of muscles procedures [29]. The bioPLUX system (Fig. 1(a)) allow wireless recording of a broad range of (bio) signals [30]. EMG signals were plugged into the bioPLUX device, and connected to channels 1 and G, which transmits the data to a computer over Bluetooth (Fig. 2).

Fig. 3. The instrumentation for head-mounted interface.

Fig. 4. ABC Communicator prototype.

The EMG signal was filtered to smoothen out short-term fluctuations with a moving average as the mean of 500 samples each of 0.05 seconds. EMG data was sampled at a frequency of 500 Hz. In order to differentiate voluntary and involuntary contractions, a threshold (minimum value) was selected for each user and each test.

Head-mounted interface

Although all areas of the motor function can be limited, limbs are usually more affected than the head motion in infants with severe CP [31]. This is the reason why the inertial interface is a head-mounted device.

The interface is based on a head-mounted interface (Fig. 1(b)) that integrates a three-dimensional (3D) accelerometer, a 3D gyroscope and a 3D magnetometer mounted on a commercial helmet. A calibrated head-mounted interface measures 3D acceleration (caused by motion and gravity), 3D angular velocity and 3D earth magnetic field. This system (Fig. 3) tracks the user's head movements and translates them into the displacements of the mouse pointer on the screen. The angular orientation of the head-mounted interface had an accuracy of about 1°, and was related to the performance [25]:

- Throughput value 1.5 bits/s.
- SD 0.5 bits/s.

2.1.2. *ABC communicator prototype*

The ABC system consists of two main subsystems: The Signal Server and the User Interface.

The Signal Server collects the information from each input device in the ABC system. This information is processed in order to generate high-level commands to the communicator. In the case of the head-mounted interface, an "absolute mapping" between head posture and pointer location is implemented. That means that there is a point-to-point relation between head angle and pointer location. In the case of the EMG, when the electromyographic signal reaches a specific threshold personalised for each subject, the ABC system turns it into a click. Figure 4 shows the ABC Communicator prototype.

2.2. *Methods*

Our study involves an iterative process in three stages. Each test is finished with an improvement in the inputs of the following test. Firstly, a pilot study was performed with non-disabled people to identify usability problems. Secondly, an initial test with subjects with DCP incorporated the improvements identified in the pilot study and the configuration of the input devices was the same for each subject. The final test with subjects with DCP incorporated the improvement of the EMG signal recordings according to individual muscle tone and a previous training period with the head-mounted interface.

2.2.1. *Subjects*

Six non-disabled subjects (3 males and 3 females with an age range of 23 to 43 and a median age of 30.4, SD = 6.5) participated in the pilot study. Six subjects with DCP (2 males and 4 females with an age range of 26 to 45 and a median age of 36.83, SD = 6.36) participated in the initial test. Seven subjects with DCP (4 males and 3 females with an age range of 32 to 39 and a median age of 35.5, SD = 2.88) participated in the final test, and three of the subjects; (001, 002, 006) did the two tests. Details of the subjects are summarised in Table 1. Ethical approval was obtained for all measurements before conducting the experiments.

2.2.2. *Task and procedures*

Two different input devices were used: superficial electromyography (sEMG) for clicking and the head-mounted interface to control the mouse pointer (direct selection).

According to the DCP subjects' characteristics, these two inputs were combined with the activation of

Table 1
Gross motor function classification system score (GMFCS) for DCP subjects

	Subject code	Gender	Age	GMFCS	CP type
Pilot test	P001	Male	35	Healthy	Healthy
	P002	Male	25	Healthy	Healthy
	P003	Male	25	Healthy	Healthy
	P004	Female	23	Healthy	Healthy
	P005	Female	24	Healthy	Healthy
	P006	Female	30	Healthy	Healthy
Initial test	*001	Male	39	IV	Dystonic-spastic tetraparesis
	*002	Female	34	V	Dystonic tetraparesis
	003	Female	26	IV	Dystonic tetraparesis
	004	Female	38	V	Spastic tetraparesis hypertonic
	005	Male	45	V	Dystonic-spastic tetraparesis
	*006	Female	39	V	Dystonic-spastic tetraparesis
Final test	*001	Male	39	IV	Dystonic-spastic tetraparesis
	*002	Female	34	V	Dystonic tetraparesis
	*006	Female	39	V	Dystonic-spastic tetraparesis
	007	Male	33	V	Spastic tetraparesis hypertonic
	008	Male	37	V	Dyskinetic cerebral palsy (choreo-athetoid) and spastic tetraparesis
	009	Female	32	IV	Dystonic tetraparesis
	010	Male	38	V	Spastic cerebral palsy tetraparesis G-80/G-82

*The three subjects participated in both studies.

the click by a dwell time of one second and the automatic scanning. Therefore, the three ways of functioning were configured as automatic scanning + EMG, head-mounted interface + EMG and head-mounted Interface + dwell time.

In the pilot study, six non-disabled subjects tested the three modes of control. The test consisted of nine tasks with the communicator prototype.

The tasks were organised into three groups: searching and selecting concepts, creating phrases and management of messages. In addition, two libraries of pictograms were created: the first one was destined for those tasks related to the concepts and the second was used for the creation of phrases and the management of messages. Moreover, an assessment was done following a protocol in which the opinion of the subjects and the time, the nature of the mistake and its frequency were evaluated.

In the initial test with subjects with DCP, six of them participated, two subjects using each combination of inputs: automatic scanning + EMG, head-mounted interface + EMG, head-mounted Interface + dwell time.

During the familiarization process, which was based on five minutes of free use of the system, one subject with automatic scanning + EMG decided not to continue before beginning the tasks because was tired and stressed. Therefore, one subject of automatic scanning + EMG and two subjects of head-mounted interface + dwell time also participated in the final test.

The tasks were initially intended to be the same as in the pilot study with the three modes of control but, in order to avoid fatigue and stress for the subjects, we only analysed the first five tasks of searching and selecting concepts and the subjective assessment in the initial test with subjects with DCP. This initial test was useful to confirm the decision tree for the configuration of the sample.

In the final test with subjects with DCP, three subjects used the automatic scanning + EMG: two males and one female. These had done the test previous to the final test. Two different subjects were used for the head-mounted interface + EMG: one male and one female. Both of these were doing the test for the first time. Finally, two subjects used the head-mounted interface + dwell time: one male and one female. These had already done the test before. The protocol was finally reduced to five tasks consisting of searching and selecting concepts.

The subjects who tested the head-mounted interface had trained with it for eight days before the test. However, in the case of the sEMG-based system, only the last subject of the automatic scanning + EMG had trained before the tests for fifteen minutes. The others, including the two subjects with head-mounted interface + EMG, did not train for this part. The amplitude of EMG contraction was evaluated in order to find the most appropriate contraction threshold. Details of the tasks are summarised in Table 2.

All of the procedures were carried out according to ISO 9241-9:2000 [32]. In the case of the EMG click, the procedure followed was that recommended by SENIAM [30] regarding muscle instrumentation.

Table 2
Methodological procedure

Test parameters	Pilot test	Initial DCP test	Final DCP test
HCI mode of function	6 subjects with automatic scanning + EMG 6 subjects with head-mounted interface + EMG 6 subjects with head-mounted interface + dwell time	Subjects 002, 004 with automatic scanning + EMG Subjects 003, 005 with head-mounted interface + EMG Subjects 001, 006 with head-mounted interface + dwell time	Subjects 002, 007, 008 with automatic scanning + EMG Subjects 009, 010 with head-mounted interface + EMG Subjects 001, 006 with head-mounted interface + dwell time
EMG muscle*	All the healthy subjects did the task with the masseter muscle	Subject Muscle 002 Rectus femoris 005 003 Extensor carpi ulnaris 004 Sternocleidomastoid	Subject Muscle 002 Rectus femoris 007 010 008 Occipito-frontalis 009 Biceps brachii
EMG threshold data (mV) mean	10.1, SD = 6.0	18.33, SD = 12.5	19.8, SD = 7.39
Dwell time activation configuration		1 second	
Tasks	Nine tasks of searching and selecting concepts, creating phrases and management of messages	Five tasks of searching and selecting concepts using the communicator	

*The subjects that were tested with scanning + EMG and the head-mounted interface + EMG had EMG sensors placed in the muscle with the best control. The subjects without any muscular control tested the head-mounted interface + dwell time.

2.2.3. Data analysis

According to standard ISO 9241-11, each task has been measured as follows:

- Effectiveness: Assess whether the user is able to successfully complete the task or not. To complete the task means to achieve the required pictogram selection (the pictogram appears in the text field) before a maximum time of 2 minutes is exceeded.
- Efficiency: Number and kind of mistakes.
- Satisfaction: Comments from think-aloud protocol.
- The System Usability Scale (SUS): [33] Applied through ten-item scale giving a global view of subjective assessments of usability.

3. Results

This study has provided three kinds of outputs and some improvements have been identified and implemented during the entire test. The results obtained in each input device detail the number of completed tasks, the mistakes found, their frequency and the improvement proposals outlined by the participants. Moreover, the different subject experiences have been used to develop a decision tree to assign the most suitable input device for each user.

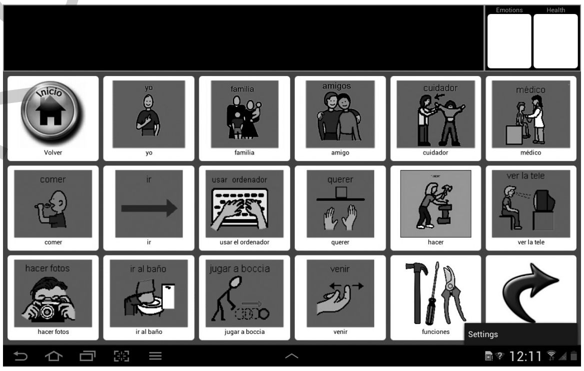


Fig. 5. Screen configuration with 3 rows and 6 columns. Scanning made by row/columns.

3.1. Improvements addressed

After the tests carried out in the pilot study, we did a series of improvements based on the experiences to be applied in the usability DCP tests.

The configuration of the screen was modified by increasing the pictogram size, they were organised in3 rows and 6 columns and also increasing the information architecture of the communicator prototype (see Fig. 5). In the automatic scanning + EMG a new control option was implemented and allowed the scanning by row/columns shown in Fig. 5.

We created another page inside the library intended for the management of functions (see Fig. 6). We also included a message asking the user if he/she wants to

Table 3
Improvements addressed in methodological procedure

Test parameters	Pilot test	Initial DCP test	Final DCP test
Scanning type configuration	Cell scanning	Row/column scanning	
Library screen configuration	5 rows/4 columns 2 pages	3 rows/6 columns 2 pages	
EMG click delaying	None	None	2 seconds after first click
Acquainting process	Five minutes of free use		Familiarisation process of fifteen minutes with EMG. Eight previous training days with head-mounted interface

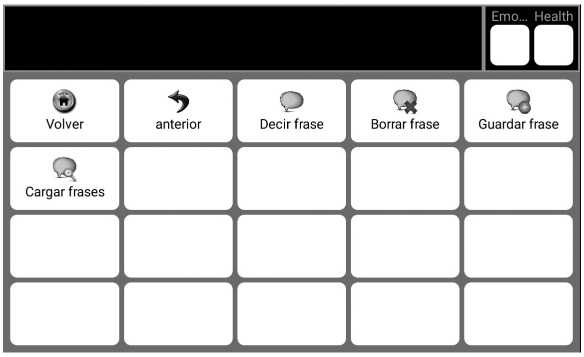


Fig. 6. Functions. From top to bottom and from left to right: come back home, return, say phrase, save phrase, delete phrase, load saved phrases and erase the last pictogram.

delete the complete phrase that has been created and also he or she wants to save it.

After the initial test, we achieved a series of improvements to increase the training period with the EMG and head-mounted interface input devices (see Table 3).

The subjects using the head-mounted interface had trained with it for 8 days before the test, but in the case of subjects using the EMG, they only trained before the tests for 15 minutes. The amplitude of the EMG signal was used to calculate the most appropriate threshold.

3.2. *Pilot study*

All of the non-disabled subjects completed the tasks with the two input devices and the modes of control in a randomised experimental design. The problems identified regarding the interfaces and the communicator allowed the improvements in our system to reduce fatigue and stress during the DCP tests.

A limitation of the EMG input is the low frequency filtering that produced a delay during clicking and caused the selection of the previous or next pictogram instead of the desired one. In addition to this, a standard configuration of the EMG threshold initially made the clicking with an involuntary selection more complicated. A limitation with the head-mounted interface is related to the lack of a visual feedback (seeing the movement of the head reflected as a cursor) on the screen.

3.3. *Usability DCP tests*

3.3.1. *Automatic scanning + EMG*

The usability assessment in comparing tests assigned a score of 54 in the initial test and 60 in the final test in a scale of 0 to 100 proposed by the SUS scale. The main differences that increase the score in the final test are the well integration of functions, the quickness in use and the confidence in the system.

In the initial test, due to a severe spastic tetraparesis and difficulties at voluntary the contracting the muscle to click, Subject 004 became stressed and decided to not continue the test.

Subject 002 needed more time (about 30 seconds) to relax the muscle after each contraction and the traditional detector based on the amplitude of the EMG signal detected several false clicks during this period. Consequently, involuntary repetitive clicks were performed during the task. Therefore, the subject was only able to complete two tasks.

Accordingly, the EMG control was adjusted to the muscle spasticity taking only the first peak of contraction and delaying the next click for two seconds. Additionally, a previous familiarisation of fifteen minutes for performing muscle contractions and adjusting the correct threshold was scheduled for next tests.

Three subjects participated in the final test and only one of them repeated the experience. Figure 7 shows the electromyographic pattern of these three subjects before performing the test that allowed adjusting the EMG threshold.

The categories and the frequency of the mistakes found in the final test is markedly lower and the subjects were able to complete almost three tasks with less physical and verbal assistance than the initial test. Table 4 shows the mean of mistakes for each test.

3.3.2. *Head-mounted interface + EMG*

Subject 005 presented an extensor pattern so when

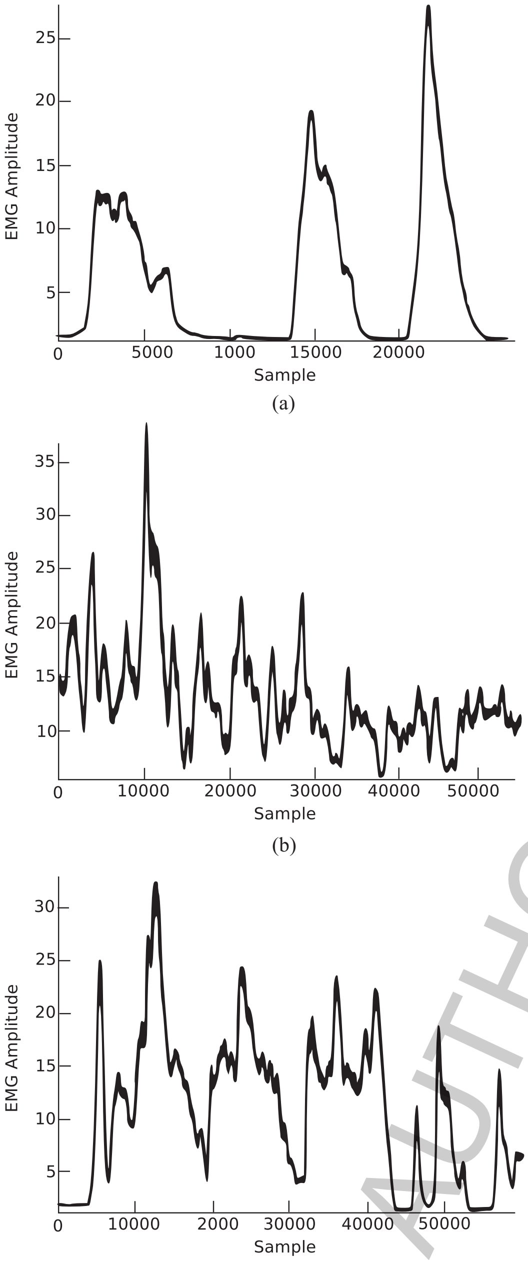


Fig. 7. EMG patterns study on the final test: (a) EMG pattern of the rectus femoris during activation in three voluntary contractions before doing the test. (b) EMG pattern of the occipitofrontalis. Due to a severe spastic and choreo – athetoid tretraparesis it was difficult to register voluntary contractions. (c) EMG pattern of the rectus femoris during activation in voluntary contractions.

he tried to reach pictograms placed above the others; he had to complete a cervical extension that activated the rectus femoris and consequently the click for the selection.

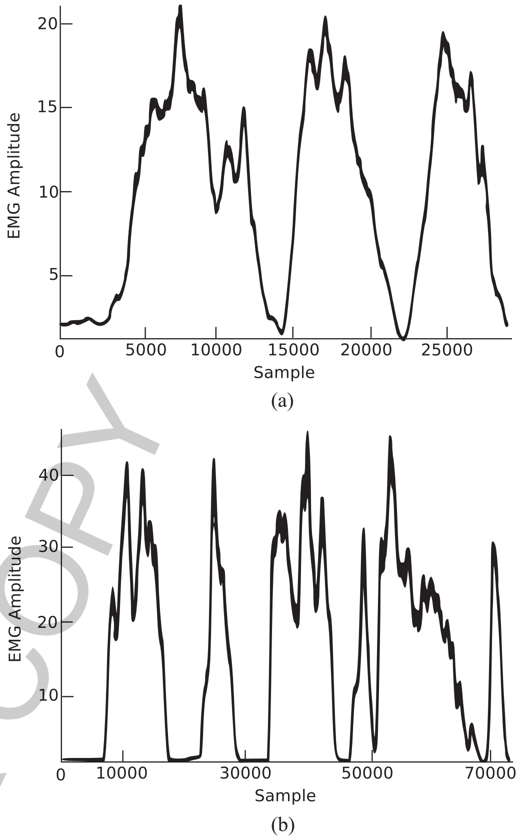


Fig. 8. EMG patterns study on the final test with the head-mounted interface. (a) EMG pattern of the biceps brachii during activation in voluntary contractions. (b) EMG pattern of the rectus femoris during activation in voluntary contractions.

The other identified limitations were the same as those of the EMG signal recording previously described in the automatic scanning + EMG section. Figure 8 shows the EMG patterns study on the final test with the head-mounted interface.

In the final test, the sample was adjusted and two other subjects performed the test. The number of completed tasks increased and the subjects were able to complete more tasks with less physical and verbal assistance than during the initial test. Table 5 shows the mistake mean and tasks completed.

3.3.3. Head-mounted interface + dwell time

Despite the fact that the two subjects of this mode of control declared that this strategy was appropriate for them, in the initial test, they were not able to complete the tasks. Both subjects had problems with the head-mounted interface: they were not able to recover the home position and the pictogram was not selected by the dwell time.

Table 4
Mistake categories, mistake mean and tasks completed for automatic scanning + EMG for all DCP subjects

	Initial test	Final test
Automatic scanning + EMG	24 Mistakes/subject 2/5 Tasks completed	7 Mistakes/subject 2.3/5 Tasks completed
	Categories of mistakes (in both tests)	
	Not selecting pictogram because the muscle did not contract in the required time. Involuntary contraction that activates the click in a pictogram that is not the required by the task. Multiple selection because of muscle spasticity and not immediate relaxation. Incorrectly selected pictogram because of incorrectly selected row.	

Table 5
Mistake categories, mistake mean and tasks completed for head-mounted interface + EMG for all DCP subjects

	Initial test	Final test
Head-mounted interface + EMG	9 Mistakes/subject 2/5 Tasks completed	9 Mistakes/subject 3.5/5 Tasks completed
	Categories of mistakes (in both tests)	
	*Cephalic control but has an extensor pattern, so in the pictogram that is above, the cervical extension is produced and the musculature is activated and also the EMG click for the selection. Selection of the following pictogram because of the contraction is produced but not the immediate relaxation. Multiple selection of pictograms because of the muscle spasticity and no muscular activity relaxation.	

*This mistake appears only in the initial test.

Table 6
Mistake categories, mistake mean and tasks completed for each mode of function for all DCP subjects

	Initial test	Final test
Head-mounted interface + Dwell time	9 Mistakes/subject 0/5 Tasks completed	3.5 Mistakes/subject 4.5/5 tasks completed
	Categories of mistakes (in both tests)	
	Not selected pictogram because of the impossibility of coming back to the neutral position of the calibration. Incorrectly selected pictogram because of the impossibility of coming back to the neutral position of the calibration.	

In the final test, after the eight days of training, both subjects reduced remarkably the number of mistakes made and were almost able to complete the five tasks. Table 6 shows the mistakes' mean and tasks completed.

3.4. Decision tree

The two stages of the validation with DCP have provided a general result that facilitates the selection of the most suitable mode of control for each user profile. The decision tree shown in Fig. 9 proposes an allocation process for the communicator access that is very useful for professionals.

This tree has been created according to knowledge of professional caregivers concerning the individual motor control of each DCP user involved in the project and the user's experience of alternative devices to computer access. It allows taking a decision about the best mode of control according to the functional profile of each user.

Three essential functional requirements are established for the use of the system:

1. Voluntary muscular control is understood as the following:
   a. Intentional relaxation and shrinkage of a muscle or group of muscles
   b. A muscle signal can be registered
   c. Carrying on usability criteria
   d. With a delay between the command and execution inferior to 3 seconds.

   If these requirements are not accomplished, the user must be excluded from the system. Unfortunately, the user is not able to access to the communicator through any device.
2. Cephalic relative control is understood as one or more of these:
   a. Making movements with the head in the X and Y axes
   b. At least with a range of 5 centimetres
   c. Movement in the horizontal plane is not necessary
   d. Precision is not required but it is necessary for the system one orientation identified.

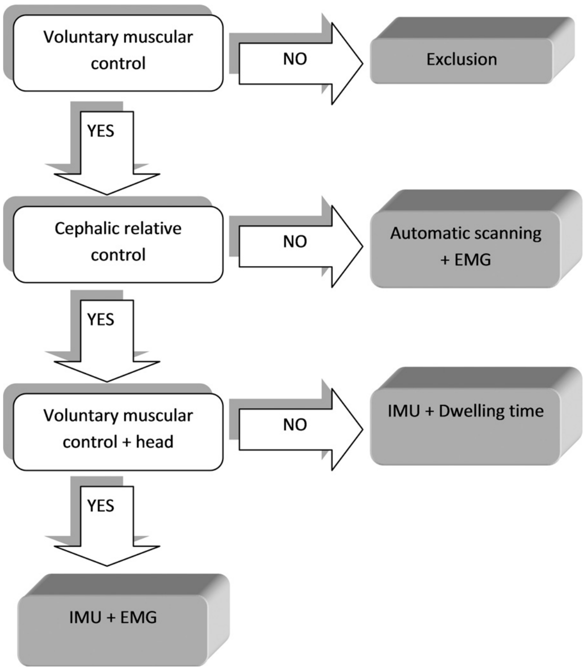


Fig. 9. Decision tree for an individual's inclusion criteria.

   If these requirements are not accomplished, the user must be change the way of functioning. The user is able to access the communicator through EMG selection and automatic scanning.

3. Voluntary muscular control + cephalic relative control is understood as the possibility of make the two actions independent, i.e. doing the selection through a voluntary movement (EMG) without it affectings the position/mobility of the head. If these requirements are not accomplished, the user must access the communicator through the head-mounted interface and select the pictogram with a dwelling time. If these requirements are accomplished, the user must access the communicator through the head-mounted interface and select the pictogram with the EMG.

4. Conclusions and future work

This study concerns the difficulty in accessing computers faced by people with Dyskinetic Cerebral Palsy (DCP), thus diminishing their opportunities to communicate or learn. The studies presented in this paper aim to assess the usability and the suitability of two input devices for people with DCP to open the possibility of increasing the autonomous communication and interaction with their environment. Although there are a wide variety of advanced interfaces for disabled people, few studies are focused on controlling an interface with the distinctive pathological movements of the DCP, filtering the involuntary motion and fixing the EMG signal recording for spastic muscles.

An iterative process reduced the time needed to redesign the prototype and allowed us to know the impact of each improvement done in the system usability. The input devices and the communicator prototype were adapted for the initial test with people with DCP after the evaluation of the tests performed by nondisabled subjects. In the initial test we validated the improvements achieved and identified new limitations based on the lack of experience or training in the system management. This reasoning led to the final test where the subjects trained and were acquainted with the system.

This study proves the feasibility of using alternative methods to improve communication for people with DCP and the relevance of a training programme to increase usability. It was, for instance, the characterization of the EMG pattern during voluntary contractions that is required.

These tests allowed the identification of several problems. Firstly, regarding the EMG signal the user must have control of the voluntary muscle contraction. Secondly, with regard to the head-mounted interface, there is a difficulty returning to the calibration position. Finally, regarding the HCI based on the head-mounted interface, a relative mode control, which allows subjects to reach the centre of the screen from any head angle, might improve the usability.

According to the decision tree, the sample selection of the subjects with DCP must be based on an individual's inclusion criteria according to voluntary muscular control, cephalic relative control and voluntary muscular control remaining the head position without any pattern of alteration (e.g. extensor pattern).

This study showed the utility of filtering, calibration and biofeedback systems to improve system efficiency. Progress must be focused on intelligent systems that detect dyskinetic patterns, and testing the devices in real life conditions to analyse the effect of stress and muscle overloading during extended use.

Future research in the development of devices aimed at DCP subjects should improve their robustness to minimise current difficulties, such as the limited control of muscle contraction-relaxation, the pace of movement, and the difficulty of keeping the posture acquired during prolonged use.

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Conflict of interest

The authors have no conflict of interest to report.

References

[1] Holm VA. The causes of cerebral palsy: A contemporary perspective. JAMA 247; 1982: 1473-1477.

[2] Odding E, Roebroeck ME, Stam HJ. The epidemiology of cerebral palsy: Incidence, impairments and risk factors. Disability and Rehabilitation 28; 2006: 183-191.

[3] Badawi N et al. What constitutes cerebral palsy? Dev Med Child Neurol 40; 1998: 520-527.

[4] Panteliadis CP. Cerebral Palsy: Principles and Management. Thieme, 2004.

[5] Winter S, Autry A, Boyle C, Yeargin-Allsopp M. Trends in the prevalence of cerebral palsy in a population-based study. Pediatrics 110; 2002: 1220-1225.

[6] Jones MW, Morgan E, Shelton JE, Thorogood C. Cerebral palsy: introduction and diagnosis (part I). J Pediatr Health Care 21; 2007: 146-152.

[7] Johnson A. Prevalence and characteristics of children with cerebral palsy in Europe. Developmental Medicine & Child Neurology, 2002: 633-640.

[8] Honeycutt AA, Grosse SD, Dunlap LJ, Schendel DE, Chen, H, Brann E, al Homsi G. Economic costs of mental retardation, cerebral palsy, hearing loss, and vision impairment. Using survey data to study disability: results from the National Health Interview Survey on disability. London, England: Elsevier Science Ltd, 2003: 207-28.

[9] Madrigal A. La parálisis cerebral. IMSERSO, 2004. http://sid.usal.es/idocs/F8/FDO8993/paralisis_cerebral.pdf. Accessed 10 November 2015.

[10] Evans PM, Evans SJ, Alberman E. Cerebral palsy: why we must plan for survival. Arch Dis Child 65; 1990: 1329-1333.

[11] Strauss D, Shavelle R, Reynolds R, Rosenbloom L, Day S. Survival in cerebral palsy in the last 20 years: signs of improvement. Dev Med Child Neurol 49; 2007: 86-92.

[12] Kübler A, et al. Patients with ALS can use sensorimotor rhythms to operate a brain-computer interface. Neurology 64; 2005: 1775-1777.

[13] Hutton JL, Cooke T, Pharoah PO. Life expectancy in children with cerebral palsy. BMJ 309; 1994: 431-435.

[14] American Speech-language. Hearing Association (ASHA): Augmentative and Alternative Communication (AAC) http://www.asha.org/public/speech/disorders/AAC.htm, 2014.

[15] Royal College of Speech and Language Therapists. Communicating Quality 3: RCSLT’s guidance on best practice in service organisation and provision, 2006.

[16] Assistive products for persons with disability: Classification and terminology. ISO 9999. International Standard ISO, ISO 9999:2011.

[17] Guerrier Y, Kolski C, Poirier F. Towards a communication system for people with athetoid cerebral palsy. Human-Computer Interaction – INTERACT 2013 – 14th IFIP TC 13 International Conference, Cape Town, South Africa, September 2-6, 2013, Proceedings, Part IV, Springer, Lecture Notes in Computer.

[18] Glennen S, DeCoste DC. The Handbook of Augmentative and Alternative Communication. Cengage Learning, 1997.

[19] Light J, Drager K. AAC technologies for young children with complex communication needs: state of the science and future research directions. Augment Altern Commun 23; 2007: 204-216.

[20] Lee KS, Thomas DJ. Control of computer-based technology for people with physical disabilities: an assessment manual. Univ of Toronto Pr. 1990. ISBN 978-0802066954.

[21] Treviranus J, Tannock R. A scanning computer access system for children with severe physical disabilities. Am J Occup Ther 41; 1987: 733-738.

[22] Ottenbacher KJ, Angelo J. Comparing scanning modes for youths with cerebral palsy. Final Report, Department of Education, Washington, DC. 1994.

[23] Alves N, Chau T. The design and testing of a novel mechanomyogram-driven switch controlled by small eyebrow movements. Journal of NeuroEngineering and Rehabilitation 7; 2002: 22.

[24] Betke M, Gips J, Fleming P. The camera mouse: visual tracking of body features to provide computer access for people with severe disabilities. IEEE Trans Neural Syst Rehabil Eng 10; 2002: 1-10.

[25] Raya R, Roa JO, Rocon E, Ceres R, Pons JL. Wearable inertial mouse for children with physical and cognitive impairments. Sensors and Actuators A: Physical 162; 2010: 248-259.

[26] Chin CA, Barreto A, Cremades JG, Adjouadi M. Integrated electromyogram and eye-gaze tracking cursor control system for computer users with motor disabilities. J Rehabil Res Dev 45; 2008: 161-174.

[27] Hornof A. Working with children with severe motor impairments as design partners. Proceedings of the 7th International Conference on Interaction Design and Children, 2008: 69-72.

[28] Poveda R, López-Vicente A, Barberà-Guillem R, Sánchez-Lacuesta J, Prat J. Cómo obtener productos con alta usabilidad Guía práctica para fabricantes de productos de la vida diaria y ayudas técnicas. Instituto de Biomecánica de Valencia, 2003.

[29] Hermens HJ, Freriks B, Merletti R, et al. European recommendations for surface electromyography. Roessingh Research and Development, Enschede, 8(2); 1999: 13-54.

[30] Biosignal plux: http://www.biosignalsplux.com/. Accessed 10 November, 2014.

[31] Wichers M, Hilberink S, Roebroeck M, Nieuwenhuizen OV, Stam H. Motor impairments and activity limitations in children with spastic cerebral palsy: a dutch population-based study. Journal of Rehabilitation Medicine 41; 2009: 367-374.

[32] ISO 9241-9:2000. Ergonomic requirements for office work with visual display terminals (VDTs) – Part 9: Requirements for non-keyboard input devices.

[33] Brooke J, et al. SUS-A quick and dirty usability scale. Usability evaluation in industry 194; 1996: 4-7.