ELECTROPHYSIOLOGICAL CONTROL SIGNALS FOR PERSONS WITH NEURODEGENERATIVE CONDITIONS: BLENDED CONTROL SIGNALS

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Abstract: Severe neurological conditions may considerably affect one's functional capabilities. Special computer interfaces and access methods have been developed in attempt to provide a mean to overcome the functional disabilities experienced by persons in these conditions. In this paper, a case study on the usage of a brain-body interface by a young man with Amyotrophic Lateral Sclerosis is presented. From the study different ways of interacting with the computer, beyond the traditional direct selection and scanning methods, emerge. These resort to control signals that combine binary and continuous features, *blended control signals*. Such control signals may provide more flexible and efficient ways of interacting with Assistive Technology systems, especially for those individuals with neurodegenerative conditions.

1 INTRODUCTION

Various diseases or conditions may impose severe limitations in one's motor abilities and consequently lead to communication disorders. These diseases and conditions can be divided in *progressive* and *static or improving* (Glennen and DeCoste, 1996). Examples of progressive conditions are neurodegenerative diseases, as Amyotrophic Lateral Sclerosis (ALS), Multiple Sclerosis or Parkinson, and some oncological conditions. Brainstem strokes, traumatic brain injuries or spinal injuries are included in static or improving conditions, as they remain unchanged or improve over time.

Assistive Technologies can be defined by "*any item, piece of equipment or product system whether acquired commercially off the shelf, modified, or customized that is used to increase or improve functional capabilities of individuals with disabilities*." (United States Congress, 1998). Although there are many definitions for AT, *the main objective of assistive technologies (equipments and services) is to contribute to a better quality of life of the many persons affected by disabilities worldwide, through the integration of technological aspects in equipments, services and contexts* (Azevedo, 2006).

This paper is focused in AT systems, based on computer interaction, for persons with neurodegenerative conditions, i.e. progressive conditions caused by neurodegenerative diseases. In this context, individuals experience progressive decline in motor functioning, which dramatically affects their quality of life. Neurogenic communication disorders are a common consequence of neurodegenerative conditions as individuals progressively loose their ability to write and/or speak. Through computer interaction these persons may access to communication aids for writing or speaking.

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AT selection for people with neudegenerative conditions is a big challenge since the progression of the disease must be "previewed", as well as other factors related to the individual's context. The progression of these diseases will lead to different needs and capabilities along the different stages of the disease. Flexibility is thus an utmost important characteristic for AT systems, which have to respond to individuals needs during all stages and conditions.

Considering AT systems based on computer interaction, user interface is an important part of the system, which translates users input signals into control signals. The most common user interfaces for severe neurodegenerative conditions are the ones using eyetracking techniques and the ones based on electrophysiological signals (Felzer and Nordmann, 2006). User interfaces are much dependent on the input signals that the user can control. The problem of the type of electrophysiological control signals that persons with neurodegenerative conditions can generate to access to AT devices, from early to late stages of disease, is addressed in this paper.

The paper is organized as follows. In Section 2, a brief description of user interfaces and typical selection methods used in AT systems context are exposed. The use of electrophysiological signals as control signals for AT systems is addressed in Section 3. Section 4 contains a description of a case study, which aims at evaluating the use of a brainbody interface by a young man with ALS to access to a computer as a communication device. This case study is discussed in Section 5 stressing the types of control signals the user was able to generate and proposing a new class of control signals – *blended control signals*. Paper conclusions are presented in Section 6.

2 USER INTERFACES

One of the critical elements of AT systems for persons with neurodegenerative conditions is the User Interface (UI). The UI receives user's input and translates it into control signals to access to the AT devices. These signals can be generated by various movements, such as hands, eyes or head movements, or even by other body sources as, for example, electroencephalograph signals. Control signals are then very dependent and conditioned by user's physical and context conditions.

A general representation of a UI for AT Systems is proposed in (Cook and Hussey, 2002) as shown in Figure 1.

Figure 1: User Interface of an AT System.

The Selection Method defines the way the user will select each element of selection set. Typically, AT devices provide Scanning or Direct Selection methods. Direct selection is possible if the user can generate at least as many control signals as the selection set. Otherwise, user has to resort to an indirect selection method (e.g. scanning) to pick an element of the selection set.

For example, given the task of writing in a computer, one may use a direct selection method pressing each key on the keyboard (AT device); however, if the person is not able to directly select each key, she needs to use a scanning method controlling it with one or more binary signals. Scanning method is much slower that direct selection method. However, there are many strategies that try to make this selection method more efficient according to users' abilities (Cook and Hussey, 2002).

This traditional strict division of selection methods ignores the possibility of having other kinds of interaction, based on control signals richer than simple on/off signals though not rich enough to control a 2-axis interaction (as showed in Figure 2 for the example of access to a virtual keyboard).

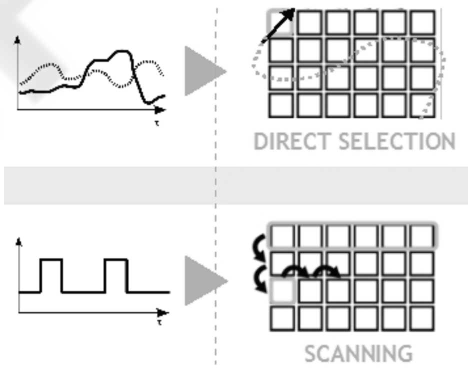

Figure 2: Example of access to a virtual keyboard. Traditional division for selection methods consider direct selection (continuous control signals for 2-axis control) or scanning method (based on one or two binary control signals).

When focusing on progressive conditions, AT systems must consider different kinds of access, being flexible to adapt to users' functionality. In this paper, the search for other kind of selection methods, based on electrophysiological control signals is discussed.

3 ELECTROPHYSIOLOGICAL CONTROL SIGNALS

Technology development in the field of biosensors has shown that individuals can generate and control various kinds of output signals that can therefore be used as control signals. In particular, todays control signals that are generated within the individual body can be used for man-machine interface.

When evaluating a person in a later stage of a neurodegenerative condition, often the main problem is to find *one* control signal that the user is able to intentionally generate. Even one single control signal supports an indirect access method, allowing a selection within a given set. The use of electrophysiological signals brings new perspectives on the number and type of control signals that a user with severe neurodegenerative conditions may generate.

At the skin surface level, two different types of signals can be captured: electric (e.g. electromyography, electrocardiography) and non-electric information (e.g. temperature, blood pressure) (Allanson, 2002). Typically, the former are the ones used for AT control systems, as it is the case of the AT system presented in this paper.

In case of individuals with neurodegenerative diseases, especially in later stages of the disease, these signals can be an efficient way of generating control signals. For example, an individual with very low motor control, who can't press a switch, can be able to generate control signals captured by an EMG sensor. In fact, an electrophysiological signal can provide a motor independent control signal even for persons in *locked in* state (Wolpaw et al., 2002; Wills and MacKay, 2006). However, an important issue to consider is that, due to its physiologic nature, electrophysiological information depends on the physical and environment conditions of each individual (such as diseases, fatigue, humour, environment temperature, familiar context, etc.). Thus, it is important to know the physiological mechanisms that produce the signals and how these signals are affected by referred conditions.

Therefore, in AT systems design, each case is a singular case, influenced by individuals' unique conditions and particular disease progression.

4 CASE-STUDY

A *Small Number Design* methodology (Iacono, 1992)(Stevens and Edwards, 1996) was used in order to evaluate the interaction of an individual with ALS with a brainbody interface (™Brainfingers Cyberlink). This brainbody interface consists on a headband with three surface electrodes placed on the forehead. The control signals generated by this interface are based on muscle and brain potentials, and are called *brainfingers* (Junker, 1995).

The individual that voluntarily participated in the study is in a later stage of the disease for some years. He can control very few movements and uses a pressing switch activated by slight head movements as the control interface to his communication aid. He is thus able to control a scanning process in software *The Grid©* for communication purposes and Internet access. With this system, this person wrote a published poetry book.

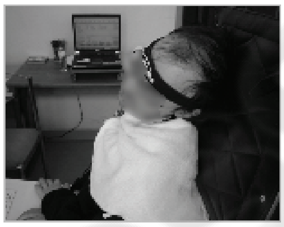

Figure 3: User studied using ™Brainfingers Cyberlink interface in a training session.

The motivation for this case study was twofold: are there alternative ways (and more efficient) for this individual to interact with an AT system?; is it possible for him (using ™Brainfingers Cyberlink interface) to generate more control signals or "richer" than binary control signals?

4.1 Test Design

A protocol for evaluation was developed and tested aiming at studying the control signals that the user was able to generate with the interface. Starting from the binary signal that the user used before, "richer" signals where progressively attempted. The tests followed the four steps described below.

a) One binary control signal

To gain confidence with the system, the user was firstly asked to use the AT system by means of his pressure switch, as he is used to. Then, the mechanical switch was replaced by the brainbody interface. Different sources of muscle potencial were essayed as a binary control. The signal generated by opening the jaw was found to be more efficient. In fact, this is the gesture that user does to communicate to his close friend and physiotherapist as a 'yes'.

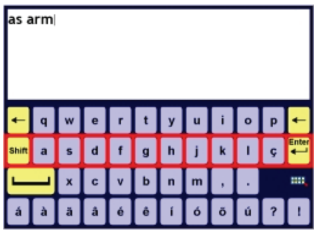

Figure 4: Virtual keyboard used to evaluate interaction using a binary control signal to write a sentence by a scanning method.

b) One continuous control signal

After getting used to access to computer using a binary *muscle signal*, the user was challenged to play a game where he had to move a bar in one axis to catch a ball. The bar could be controlled by user regulation of the *muscle signal* amplitude.

c) One "continuous and discrete" control signal

After being able to generate one *binary* control signal and one *continuous* control signal, the user was asked to access to his communication software using the combination of these two control signals. For that, a special one-row keyboard was designed (see Figure 5) and the user had to select each cell in a specific order. In order to do that, a continuous signal had to be controlled between two thresholds to move the selection bar. When this bar is in the desired position, the signal should be raised above the second threshold, thus making the selection (see Figure 4). In the designed application, the continuous signal amplitude within the two thresholds controlled the movement within the row, and the second threshold was used to generate a binary control signal for selection of the highlighted cell.

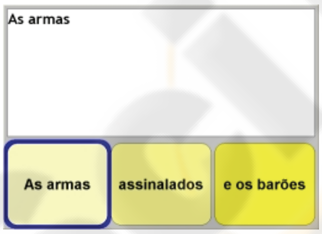

Figure 5: Virtual keyboard used to evaluate interaction with one continuous control signal to move mouse cursor in one-axis and one binary control signal to make key selection.

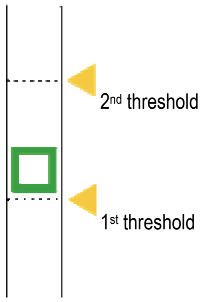

Figure 6: Representation of the technique used to combine two different control signals. By moving the bio-signal amplitude (the square) between the two thresholds, the user will move one object in one direction. When overcoming the 2nd threshold, the user makes a selection.

d) Two continuous control signals

Then user was asked to use two continuous control signals to navigate through rows and columns, in a keyboard as shown in Figure 7. Two different brainfingers (control signals generated by the studied user interface) were used. The source of these signals were muscle potencial generated by opening jaw and one brainfinger potencial (Junker, 1995) generated by subtle forehead movements.

Control was based on these two control signals: the first (described in Figure 6) to control x-axis, and the second to control y-axis.

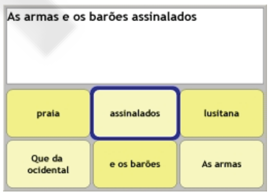

Figure 7: Virtual keyboard used to evaluate interaction using two continuous control signals to move mouse cursor in two-axis and one binary control signal to make key selection.

5 RESULTS

The user was able to control the UI using different selection methods. Qualitative and quantitative data were analysed, giving together a more complete evaluation of the results (for more details, please refer to (Londral, 2007).

The main problems related to control signals were low SNR, involuntary generated control signals and delay in generating the control signal. The latter was due to the difficulty in raising and lowering the amplitude of the control signals. After some minutes of training, the involuntary impulses were almost suppressed. When writing using a scanning access method, and after five minutes training, user was able to do 3,18 key selections per minute. Considering that user is able to do 5,16 key selections per minute with his usual UI (a pressing switch) and that this result was reached in just one short session of training, it is expected that this performance will improve with training.

The user could also generate one continuous control signal using it to move the mouse cursor in one axis successfully. Resorting to a control signal that combines continuous and binary features, as described in Section 4.1-c, the results obtained were 4,36 key selections per minute, thus improving the performance attained with one binary control signal. However, it is important to note that this selection method was tested just with a small selection set (smaller than the one used for the previous result).

When testing the use of two continuous control signals, in order to control the mouse cursor in two axis (as described in Section 4.1-d), the performance was only 1,71 key selections per minute. This selection method was difficult for the user, especially in managing the control of the different thresholds. Therefore, more training is necessary to validate this technique.

From this case study, it is clear that the user was able to generate various types of control signals that could provide more *flexibility* to a UI, thus making it more adaptable to the user progressive conditions.

5.1 Blended Control Signals

Traditionally, control interfaces generate binary control signals (used to control scanning methods) or continuous control signals in 2-axis (used to control direct selection). Based on the various types of electrophysiological signals that the individual in this study could generate, a new class of control signals is proposed – *blended control signals* - that combine in a single signal discrete and continuous features. Based on these signals, different access methods can be designed. Beyond traditional selection methods, these signals can potentially fill the *gap* between scanning and direct access methods, as discussed in Section 2. In fact, the interaction described in Section 4.1-c) is neither direct nor scanning.

From this study was demonstrated that users may have potencial to generate control signals with more information than just for a binary control, though not enough to direct selection.

In progressive conditions, users experiment different needs and abilities along different stages. The more information the user interface can collect from users' abilities, the faster may be the access to AT systems.

The use of blended control signals, based on user's electrophysiological signals, allows a better adaptation to neurodegenerative conditions, broadening the possibilities of ways of interaction and enabling persons with severe neurodegenerative disorders to interact more efficiently with AT systems.

6 CONCLUSIONS

In this paper a case study demonstrating the use of electrophysiological control signals by a young man with ALS was presented.

The user was able to “upgrade” the control signals by progressive steps. Starting by a binary control signal using a scanning method, he was progressively able to generate continuous control signals, as well as combinations of these – *blended control signals*. The case study here presented clearly shows that other selection methods should be sought taking advantage of the control signals that this kind of users may be able to generate, in a sense richer than binary signals, although poorer than a continuous signal.

This kind of signals may provide more flexible and efficient ways of interaction with AT systems, if multimodal selection methods are designed. Moreover, resorting to blended control signals, AT systems may become more user friendly and adaptable, reducing the rate of AT abandonment, especially among people with neurodegenerative conditions.

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