Advanced Augmentative and Alternative Communication System Based on Physiological Control

Instituto de Biomecánica de Valencia

Doctoral Thesis

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To my children and my
wonderfull wife

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Abstract

Dyskinetic Cerebral Palsy (DCP) is mainly characterized by alterations in muscle tone and involuntary movements. Therefore, these people present with difficulties in coordination and movement control, which makes walking difficult and affects their posture when seated. Additionally, their cognitive performance varies between being completely normal and severe mental retardation.

People with DCP were selected as the objective of this thesis due to their multiple and complex limitations (speech problems and motor control) and because their capabilities have a great margin for improvement thanks to physiological control systems.

Given their communication difficulties, some people with DCP have good motor control and can communicate with written language. However, most have difficulty using Augmentative and Alternative Communication (AAC) systems. People with DCP generally use concept boards to indicate the idea they want to communicate. However, most communication solutions available today are based on proprietary software that makes it difficult to customize the concept board and this type of control system.

This is the motivation behind this thesis, with the aim of creating an interface with characteristics, able to be adapted to the user needs and limitations. Thus, this thesis proposes an Augmentative and Alternative Communication System for people with DCP based on physiological control. In addition, an innovative system for direct control of concept boards with EMG is proposed. This control system is based on a physical model that reproduces the muscular mechanical response (stiffness, inertia and viscosity). It allows for a selection of elements thanks to small pulses of EMG signal with sensors on a muscle with motor control. Its main advantage is the possibility of correcting errors during selection associated with uncontrolled muscle impulses, avoiding sustained muscle effort and thus reduced fatigue.

This thesis has been carried out within the European Project 287774: ABC “Advanced BNCI Communication” funded by the European Commission under the 7th Framework program.

Resumen

La Parálisis Cerebral de tipo Discinésica (DCP) se caracteriza principalmente por las alteraciones del tono muscular y los movimientos involuntarios. Por ello, estos pacientes presentan dificultades en la coordinación y en el control de movimientos, lo cual les dificulta el caminar y afecta su postura cuando están sentados. Cabe resaltar que la capacidad cognitiva de las personas con DCP puede variar desde completamente normal, hasta un retraso mental severo.

Las personas con DCP han sido seleccionadas como objetivo de esta tesis ya el margen de mejora de sus capacidades es amplio gracias a sistemas de control fisiológico, debido a sus múltiples y complejas limitaciones (problemas de habla y control motor).

Debido a sus dificultades de comunicación, algunas personas con DCP se pueden comunicar con lenguaje escrito, siempre y cuando tenga un buen control motor. Sin embargo, la mayoría tienen dificultades para usar sistemas de Comunicación Aumentativos y Alternativos (AAC). De hecho, las personas con DCP utilizan generalmente tableros de conceptos para indicar la idea que quieren transmitir. Sin embargo, la mayoría las soluciones de comunicación disponibles en la actualidad están basadas en software propietario que hacen difícil la personalización del tablero de conceptos y el tipo de sistema de control.

Es aquí donde surge esta tesis, con el objetivo de crear una interfaz con esas características, capaz de adaptarse a las necesidades y limitaciones del usuario. De esta forma, esta tesis propone un sistema de comunicación aumentativo y alternativo para personas con DCP basado en control fisiológico. Además, se propone un Sistema innovador de control directo sobre tableros de conceptos basado en EMG. Este Sistema de control se basa en un modelo físico que reproduce la respuesta mecánica muscular (basado en parámetros como Rigidez, Inercia y Viscosidad), permitiendo la selección de elementos gracias a pequeños pulsos de señal EMG con sensores sobre un músculo con control motor. Sus principales ventajas son la posibilidad de corregir errores durante la selección asociado a los impulsos musculares no controlados, evitar el esfuerzo muscular mantenido para alcanzar un nivel y reducir la fatiga.

Esta tesis se ha realizado en el marco del Proyecto Europeo 287774: ABC “Advanced BNCI Communication” financiado por la Comisión Europea durante el Séptimo Programa Marco.

Resum

La Paràlisi Cerebral de tipus Discinèsica (DCP) es caracteritza principalment per les alteracions del to muscular i els moviments involuntaris. Per açò, aquests pacients presenten dificultats en la coordinació i en el control de moviments, la qual cosa els dificulta el caminar i afecta la seua postura quan estan asseguts. Cal ressaltar que la capacitat cognitiva de les persones amb DCP pot variar des de completament normal, fins a un retard mental sever.

Les persones amb DCP han sigut seleccionades com a objectiu d'aquesta tesi ja el marge de millora de les seues capacitats és ampli gràcies a sistemes de control fisiològic, a causa dels seus múltiples i complexes limitacions (problemes de parla i control motor).

A causa de les seues dificultats de comunicació, algunes persones amb DCP es poden comunicar amb llenguatge escrit, sempre que tinga un bon control motor. No obstant açò, la majoria tenen dificultats per a usar sistemes de Comunicació Augmentatius i Alternatius (AAC). De fet, les persones amb DCP utilitzen generalment taulers de conceptes per a indicar la idea que volen transmetre. No obstant açò, la majoria les solucions de comunicació disponibles en l'actualitat estan basades en programari propietari que fan difícil la personalització del tauler de conceptes i el tipus de sistema de control.

És ací on sorgeix aquesta tesi, amb l'objectiu de crear una interfície amb aqueixes característiques, capaç d'adaptar-se a les necessitats i limitacions de l'usuari. D'aquesta forma, aquesta tesi proposa un sistema de comunicació augmentatiu i alternatiu per a persones amb DCP basat en control fisiològic. A més, es proposa un sistema innovador de control directe sobre taulers de conceptes basat en EMG. Aquest sistema de control es basa en un model físic que reprodueix la resposta mecànica muscular (basat en paràmetres com a Rigidesa, Inèrcia i Viscositat), permetent la selecció d'elements gràcies a xicotets polsos de senyal EMG amb sensors sobre un múscul amb control motor. Els seus principals avantatges són la possibilitat de corregir errors durant la selecció associat als impulsos musculars no controlats, evitar l'esforç muscular mantingut per a aconseguir un nivell i reduir la fatiga.

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Chapter 1
Introduction

Dyskinetic cerebral palsy (DCP) is a chronic pathology where the cognitive performance varies between being completely normal to severe mental retardation. It is characterized by the presence of involuntary movements which may be athetoid (writhing movements, spasticity of fingers, hands, head and tongue) and/or dystonic (rigid posturing) and/or choreic (rapid and jerky movements). The cognitive skills can be masked by the motor limitations and the communication difficulties, which leads to deficient learning possibilities and social exclusion.

The Augmentative and Alternative communication systems increase the possibilities of communication for people with cerebral palsy. These support systems contribute positively to the improvement of their personal autonomy and independent life, their social integration and, therefore, their quality of life. While great efforts have been made to improve its usability and functionality, existing systems must adapt even more to the specific needs of the users and their disabilities.

The aim of this thesis is to propose an augmentative and alternative communication system based on physiological signals adapted to the end-user needs of people with Dyskinetic Cerebral Palsy.

This thesis has been conducted within the framework of the European Project 287774: ABC “Advanced BNCI Communication” financed by the Seventh Framework Program, corresponding to the call FP7-ICT-2011-7. ABC project aims to develop a novel modular and interoperable system, based on smart processing of Brain-Neural Computer Interface (BNCI) signals to provide augmented communication, emotion management and environment control to persons with Dyskinetic Cerebral Palsy (DCP).

People with DCP have been selected as the objective of the project because they present a high potential to improve their capabilities with physiological control systems, while being hampered by their multiple and severe limitations (speech and motor control problems). In addition, the system has a high potential for enhancing the capabilities of people with other physical disabilities and/or speech problems or for children with developmental disorders, as well as for wider applications (eg games, learning, safety at work or assistance in driving).

Figure 1.1 shows the proposed ABC system and its modules: (M1) The BNCI system (Brain Neural Computer Interface) will integrate different physiological signals (EEG, EMG, IMU, etc.) to develop a robust control system adapted to user needs and daily use. (M2) The health monitoring module will use the physiological parameters to support self-understanding and decision making in health management. (M3) The emotions module will interpret physiological signals to understand user's emotional states and to provide support and guidance of emotional understanding and management. (M4) The communicator is the user interface integrating the different functionalities of the system.

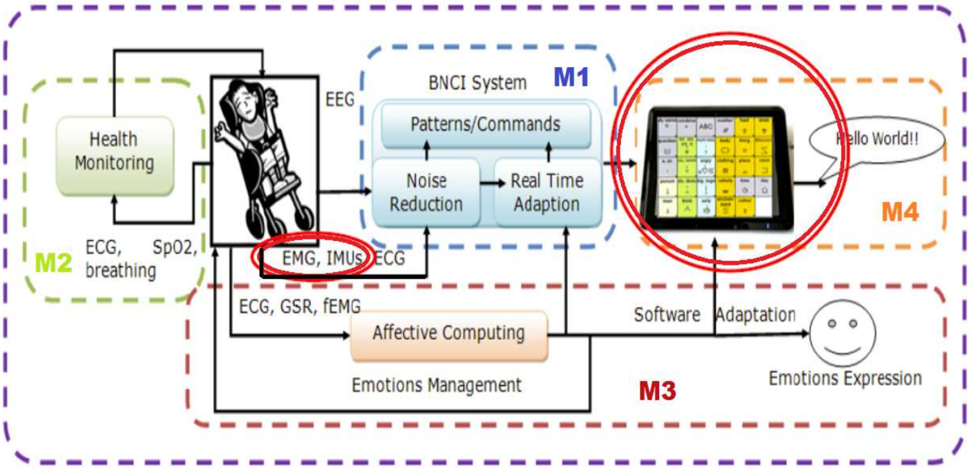


Figure 1.1. Modules of the ABC system and focus in this thesis.

The following premises motivate this thesis:

- The variability of characteristics in DCP demands adaptive interfaces and services specific to each user.
- Many users with DCP have difficulties in selecting elements of a grid by controlling a pointer.

Thus, the activities of this thesis are focused on the design of the communicator system and the definition and set-up of an innovative solution of direct control over grids of concepts based on physiological control and the specific DCP user needs.

Developed methodologies and results of this thesis are being used in another national project called LICOM (DPI2015-67064-R), funded by the Ministerio de Economia y Competitividad. The LICOM project (Communication systems for people in a locked-in syndrome state) is focused on the development of a low-cost, domestic use application to provide a communication tool for locked-in patients. This project is based on one of the premises of this thesis: a system must be easily configurable and adaptable to the needs of each patient.

There are several publications based on the results of the thesis. They are presented in the section 6.3.

Chapter 2
State of the Art

In this chapter, the most relevant literature in the field of cerebral palsy and especially about the type Dyskinetic (DCP) is reviewed.

Firstly, we have studied the information about the difficulties of people with DCP to understand the particularities of this type of pathology.

Secondly, the augmentative and alternative communication systems (AACS) have been reviewed. Their characteristics, usability issues, use cases and adaptability to user needs were studied.

Finally, a comprehensive review about the use of physiological systems as a tool to interpret the emotions or control system was done.

2.1 Disability and Dyskinetic Cerebral Palsy.

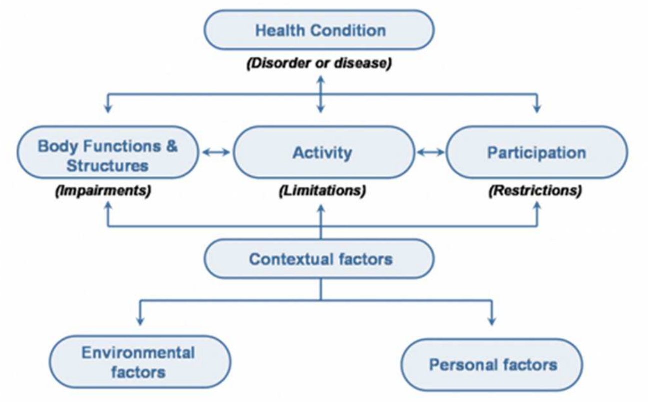
The view of disability has changed over time. In the second half of the twentieth century, the dominant model was the rehabilitation model, which sees disability as an expression of the disease and therefore a fundamentally personal factor, just needing medical treatment. Efforts were focused on restoring the affected body structures and functions (Impairments), working under the assumption that medical advances would eventually control the factors causing disability (illness), aiming to minimize them. In 1980, the WHO published the International Classification of Impairments, Disabilities and

Handicaps (ICIDH) (World Health Organization, 1980). Although this model started to consider contextual factors, it is essentially a lineal cause-effect model between handicap, disability and impairment.

Human functioning is diverse and varies throughout life. Therefore, it requires a systemic model to explain the diversity of human functioning, disability and health status. In 2001, the World Health Organization published The International Classification of Functioning, Disability and Health (World Health Organization, 2001), with the aim of unifying the conceptualization of human functioning and health.

The linear model of interpretation (impairment-disability-handicap) evolves to a multivariate model relating human performance and health status, gaining importance the contextual factors (both personal and environmental ones) (Figure 2.**1**). In this way, human functioning is a continuous variable that cannot be divided between what is "normal" and what is not. It is important to highlight that environmental factors can be considered as facilitators or barriers, depending on how they are related to the improvement of functional or structural alteration, the performance of an activity or the performance of a social role. These environmental factors are, among others, the design of environments, services and products in general, and specifically the assistive technologies (technical aids).

ICF						
Parts	**Functioning and disability**				**Contextual Factors**	
Components	Body structures and functions		Activities and Participation		Environmental Factors	Personal Factors
Domains	Body structures Body functions		Life areas (tasks, action)		External influences	Internal influences
Qualifiers or constructs	Changes in body structures (anatomical)	Changes in body functions (physiological)	Capacity (executing tasks in a standard environment)	Performance (executing tasks in the current environment)	Facilitators and Barriers	Impact of attributes of person



Source: (World Health Organization, 2007)

Figure 2.1. ICF overview.

ICF has been designed like a common language for describing health, functioning, and disability. It can primarily be used in clinical settings, health services or for a survey at the individual or population level to compare data coming from different individuals, or groups of individuals, and to code their characteristics. Nevertheless, due to its all-inclusive nature, ICF can serve as a framework to describe disability. In fact, ICF is not by itself an evaluation tool, but rather a standard language and framework for the description of health and health-related states (Rosenbaum & Stewart, 2004).

2.1.1. Cerebral Palsy

The definition of Cerebral Palsy (CP) has been a challenge since 1843 when William Little proposed the first description (Little, 1843). He suggested a link between abnormal parturition, difficult labor, premature birth, asphyxia neonatorum, and physical deformities. Later, he introduced the term tenotomy instead of deformity (Little, 1862). Thereafter, Freud considered CP in terms of clinical neurological syndromes. Freud proposed CP to be caused not just at parturition but also earlier in pregnancy because of "deeper effects that influenced the development of the fetus" (Freud, 1897).

The complexity of what composes cerebral palsy is underlined by its numerous definitions and the variety of its classifications systems. In 1959, members of the Little Club proposed that "cerebral palsy is a persisting but not unchanging disorder of movement and posture, appearing in the early years of life and due to a non-progressive disorder of the brain, the result of interference during its development" (Mac Keith, MacKenzie, & Polani, 1959). (Bax, 1964)) redefined this as 'a disorder of movement and posture due to a defect or lesion of the immature brain' and recommended "exclude from cerebral palsy those disorders of posture and motion which are 1) short-term, 2) due to a progressive disease, 3) exclusively due to mental retardation".

Since then, several authors have been suggested other definitions for CP (Kurland, 1957; Mutch, Alberman, Hagberg, Kodama, & Perat, 1992; Nelson & Ellenberg, 1978) like "an umbrella term covering a number of syndromes with motor deficiency, non-progressive, but often changing, secondary to brain lesions or anomalies appearing in the early stages of brain development". This last definition was remained quite unchanged for 40 years. However, this does not imply that this definition is exempt from important limitations, both theoretical and practical (Dan & Cheron, 2004; Ferrari, 2010; Ferrari & Alboresi, 2010).

To solve some definition issues, like the exclusion of the perceptive, cognitive, and behavioral aspects, an international multidisciplinary team met in Bethesda (MD, USA) in July 2004. A revised definition was then produced by the Executive Committee of the team and published in 2006 (Cioni & Paolicelli, 2010):

"Cerebral palsy (CP) describes a group of disorders of the development of movement and posture, causing activity limitation, that are attributed to non-progressive disturbances that occurred in the developing fetal or infant brain. The motor disorders of cerebral palsy are often accompanied by disturbances of sensation, cognition,

communication, perception, and/or behavior, and/or by a seizure disorder" (Rosenbaum et al., 2007).

In any case, CP affects children since they are born and it severely limits their physical and social activity. Depending on the location and severity of the brain injury, the effects of CP can be very different for each patient. Motor disorders caused by CP are often accompanied by epilepsy; by disturbances of sensation, perception, cognition, communication, and/or behavior; and by secondary musculoskeletal problems.

Different classification types of CP are proposed according with the clinical description of the type, topographical distribution and severity of the motor impairment (Alberman, 1984; Howard et al., 2005; Ingram, 1984; Stanley, Blair, & Alberman, 2000).

By the type of motor impairment, CP classification can also change between authors. Some authors classify the CP as Spastic, Dyskinetic, Ataxic and Hypotonic (Delgado & Albright, 2003; Sanger, 2003; Stanley et al., 2000); The World Health Organization's (WHO), in the International Statistical Classification of Diseases and Related Health Problems (10th Revision), propose his classification in Spastic quadriplegic/tetraplegic, Spastic diplegic, Spastic hemiplegic, Dyskinetic (dystonic and athetoid), Ataxic and a group for the mixed cerebral palsy syndromes (World Health Organization, 2010); and the Surveillance of Cerebral Palsy in Europe proposes a classification grouped in Spastic bilateral, Spastic unilateral, Ataxic, Dyskinetic dystonic and Dyskinetic choreo-athetonic (Cans, 2000). In any case, Spastic is the most common type of motor impairment with about 80 per cent of reported cases and it is characterized by increased tone (hypertonicity), high stiffness (spasticity), pathological reflexes (e.g. hyper-reflexia, spasticity) and high incidence of intellectual disability. Ataxic CP presents loss of muscular coordination, disturbed balance, tremor and movements with abnormal force, rhythm or accuracy. Hypotonic CP is characterized by abnormally low tone, in the trunk and limbs that must be distinguished from weakness. Dyskinetic CP is found more often in conjunction with spasticity than alone. It is characterized by the presence of involuntary movements which may be athetoid (writhing movements, spasticity of fingers, hands, head and tongue) and/or dystonic (rigid posturing) and/or choreic (rapid and jerky movements)(Stanley et al., 2000).

The topographical classification of CP is associated to the affected limbs. *Quadriplegia* denotes the involvement of all limbs with the arms being equally or more affected than the legs; *diplegia* is used to describe more severe involvement of the legs than the arms; and Left or Right *hemiplegia* is the involvement of one side of the body only, with the upper limb more affected than the lower limb.

The classification of CP by severity of motor impairments assigns scales like mild, moderate and severe (Balf & Ingram, 1955) or defining their own levels (Krägeloh-Mann et al., 1993; Palisano et al., 1997; Wood & Rosenbaum, 2000). The most useful development in the classification of CP based in the severity of motor impairments has been the development of the Gross Motor Function Classification System (GMFCS).

This classification is a five-level ordinal grading system based on the assessment of self-initiated movement with emphasis on function during sitting, standing and walking. Distinctions between different levels are based on functional limitations, the need for walking aids or wheeled mobility and quality of movement. Unlike other classification methods, the GMFCS has been shown to be a valid, reliable, stable and clinically relevant method for the classification and prediction of motor function in children with CP between the ages of 2 and 12 years (Howard et al., 2005; Palisano et al., 1997; Rosenbaum, Palisano, Bartlett, Galuppi, & Russell, 2008).

The GMFCS has been validated (Morris & Bartlett, 2004; Palisano, Cameron, Rosenbaum, Walter, & Russell, 2006) and is the most accepted classification in the recent years. Some studies have been carried out to compare the different types of classification providing conclusions like “the classification of CP by topographical distribution is useful for clinical and epidemiological purposes, the value of their subgroups (quadriplegia, diplegia, hemiplegia) as an indicator of mobility is limited in comparison with the classification of severity with the GMFCS” (Gorter et al., 2004).

Advances of the science to classify the CP more accurately are still in progress. Bax et al. propose 4 components to be considered in the CP classification (Bax et al., 2005; Rosenbaum et al., 2007):

- Motor abnormalities:
  - Nature and typology of the motor disorder: The observed tonal abnormalities assessed on examination (e.g. hypertonia, hypotonia) as well as the diagnosed movement disorders present, such as spasticity, ataxia, dystonia, athetosis.
  - Functional motor abilities: the extent to which the individual is limited in his or her motor function, including oromotor and speech function.
- Associated impairments:

  The presence or absence of associated non-motor neurodevelopmental or sensory problems, such as seizures, hearing or vision impairments, or attentional, behavioral, communicative, and/or cognitive deficits, and the extent to which impairments interact in individuals with CP.
- Anatomic and radiological findings:
  - Anatomic distribution: the parts of the body (such as limbs, trunk, or bulbar region) affected by motor impairments or limitations.
  - Radiological findings: the neuroanatomic findings on computed tomography or magnetic resonance imaging, such as ventricular enlargement, white matter loss, or brain anomaly.

- Causation and timing:

  Whether there is a clearly identified cause, as is usually the case with postnatal CP (e.g. meningitis or head injury) or when brain malformations are present, and the presumed time frame during which the injury occurred, if known.

Communication problems are associated with all classification types of cerebral palsy. However, the Dyskinetic Cerebral Palsy (DCP) is one of the most affected groups by this kind of problems (Bax, Tydeman, & Flodmark, 2006; Odding, Roebroeck, & Stam, 2006). This communication barrier is an important difficulty for people with CP during their social, cognitive and academic development by the limitations to express their thoughts or emotions.

Speech problems associated with CP are related with poor control of respiration, phonation, nasality and articulation, as a result of muscular weakness, larynx or palate dysfunction, and articulation that result from imprecise movement of the oral-facial structures. The incidence of anarthria and dysarthria (difficulties in articulating words due to emotional stress or to paralysis, incoordination, or spasticity of the muscles used in speaking) varies in relation to the type and degree of motor impairment. Moreover, other communication disorders like hearing loss, language delay or disorder may also be associated with CP (Lindsay, 2008).

Children with CP may experience delayed language development as part of their cognitive disturbance, or as a result of their lack of interaction with their world and reduced world experience. The motor limitations can affect the production of speech, facial expressions, gestures or body movements and reduce children's ability to act as effective senders of communication signals. Children with CP take very little control over conversation and their conversation patterns put at risk of becoming passive communicators. Moreover, they often fail to develop a full range of communication skills having a risk of exclusion (Lindsay, 2008; Pennington & McConachie, 2001).

2.1.2. Dyskinetic Cerebral Palsy

Dyskinetic cerebral palsy (DCP) represents the 10-20% of the incidence of CP (Madrigal Muñoz, 2004; Robaina Castellanos, Riesgo Rodríguez, & Robaina Castellanos, 2007). In general, DCP is mainly characterized by muscle tone alterations and a varying element of involuntary movement. Therefore, these patients present lack of coordination and movement control affecting gait performance and postural control in seating position. Face and tongue muscles are also affected leading to involuntary facial expressions and drooling. Although, primitive reflexes persist and spasticity is often present, it is not a dominating feature. Muscle tone fluctuations disappear while the subject is asleep and worsen with emotional stress (Hernandez-Reif et al., 2005). Some cases of DCP have associated dyskinetic eye movements. In these cases the visual function is slow, variable and highly inefficient which further limits the communication skills (Roulet-Perez & Deonna, 2002; Wadnerkar, Pirinen, Haines-Bazrafshan, Rodgers, & James, 2012).

A European study carried out with data of children with DCP born between 1976 and 1996 showed that 16% of the children walked without aids, 24% with aids and 59% needed a wheelchair. Severe learning disability was present in 52%, epilepsy in 51% and severe visual and hearing impairment in 19% and 6%, respectively (Himmelmann et al., 2009).

The presence of anarthria or dysarthria is also common in DCP due to inferior intelligence level or uncoordinated phonatory muscles, making necessary the use of alternative communication aids. These problems are accompanied by other impairments as learning disability. Moreover, growth is often hampered due to feeding difficulties and enhanced energy costs (Himmelmann, Hagberg, Wiklund, Eek, & Uvebrant, 2007).

Cognitive performance in DCP varies between being completely normal and severe mental retardation. This heterogeneity depends on several factors, including the type of paralysis and associated cerebral lesions (e.g. extrapyramidal motor system, pyramidal tract, basal ganglia) as well as the methods used for the neuropsychological assessment (Pueyo-Benito & Vendrell-Gómez, 2002). However, according to international statistics, most of DCP users (96%) are classified as “educationally subnormal” (Evans, Evans, & Alberman, 1990) while the intelligence level of CP persons is normal in a range of 50-70% (Pueyo-Benito & Vendrell-Gómez, 2002) and up to 75% for DCP (Madrigal Muñoz, 2004). Cognitive skills of children with DCP can be masked by limitations of motor control and by the lack of communication abilities, which leads to deficient learning possibilities for the most children with DCP.

These physical and cognitive disorders derived in a heterogeneous group of problems related with daily living, affecting to all developmental stages: childhood, scholarship and adulthood. During childhood, the “Early childhood intervention” (a healthcare program oriented to children with DCP since they are diagnosed until they are six years old) is crucial to children development, providing stimuli to enhance the development of child capabilities, learning abilities, knowledge of the environment and social behaviors (Madrigal Muñoz, 2004). Therefore, inefficient early childhood intervention or existence of delays for its performance will limit the developmental capability of the child.

Children with DCP have a high impact on the family environment, which varies depending on the severity, and it will be present along all life of the subjects. On the one hand, the parents must help the child in the performance of most daily living activities, leading parents to emotional interdependence and burning out. The first one, emotional interdependence, is related with work absenteeism and disregarding of other family members and friends due to guilty feel. The second one, burn out, provokes important health problems (Madrigal Muñoz, 2007). In addition, brothers think that parents do not pay enough attention to them, deriving in behavior changes such as hyperactivity, aggressiveness or low school performance (Madrigal Muñoz, 2004).

During scholarship, most of DCP children require an individual learning program to overcome their difficulties. Depending on the disability degree, they can attend a conventional school or a specialized learning center (Singhi, 2004). The main difficulties at this stage are focused on learning process (Madrigal Muñoz, 2004). Their intelligence level is not evaluated correctly (Evans et al., 1990) due to their motor disabilities, speech and perceptual disorders (Pennington, Goldbart, & Marshall, 2008; Singhi, 2004). Specifically, DCP children have a normal intelligence but have problems with eye movements and communication that hamper learning processes (Singhi, 2004).

Therefore, a key objective in learning program adaptation is to enable an effective and efficient communication to facilitate learning capacity and dexterities acquisition. Moreover, along this stage, the communication will be critical for participating and playing with other children, interacting with the environment, developing as much as possible their cognitive, social, physical and affective capabilities to reach an independent life (Madrigal Muñoz, 2007).

During adulthood, the aforementioned factors are also important, but the key processes are related with socialization, decision-making and the possibility of performing a job. Their communication skills together with parents' attitudes will also be a key aspect on these processes. Negative attitudes or overprotection will restrict child development (Romero & Celli, 2009). The parents should not assume responsibilities of their sons (corresponding to their age and capabilities) but they should enhance decision making and independent living of their sons.

During the last 60 years, the improvement and advancements of healthcare services and rehabilitation methods together with the development and use of Augmenting and Alternative Communication (ACC) Languages (which have enabled their interaction with the world and substantially improved their quality of life) have doubled the life expectancy of the DCP collective, now reaching 40-50 years on average.

2.2 Augmentative and Alternative Communication Systems and Languages

The American Speech-Language-Hearing Association defines the Augmentative and Alternate Communication (AAC) as any kind of communication mechanisms (other than oral speech) that are used to declare thoughts, ideas, wants and needs. People with severe speech or language problems rely on AAC to supplement 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 may increase social interaction, school performance, and feelings of self-worth (« American Speech-Language-Hearing Association », s. d.).

Communication commonly combines verbal and non-verbal techniques to send a message from one person to another (Alant, Bornman, & Lloyd, 2006). The mode of communication chosen relies on the person's skill, the context of the conversation, who they are communicating with and the intent of the message (Light & Drager, 2007).

There are several options when people cannot use speech to communicate effectively in all situations. These options are classified into two groups: unaided and aided communication systems. Unaided communication does not require equipment use outside of the body, for example the manual signs and communication boards or sign language (Fosset & Mirenda, 2009). Aided communication involves external digital devices equipped with a pre-formatted symbol or letter screen of which can be accessed on a computer-based format or personal laptop based on users' cognitive and physical capabilities (Rocon, 1999). Most AAC users combine both aided and unaided techniques for their communication needs according with the context across a range of interlocutors (American Speech-Language-Hearing Association, 2004).

An AAC system consists of a package of techniques and technologies that constitute the 'total communication' for a specific individual. This system is based on the communication medium, a system of representing meaning, a means of access and strategies for interacting (Royal College of Speech and Language Therapists, 1996).

- Communication medium refers to the way to transmit the message. This might be via unaided or aided systems. The UNE-EN ISO 9999 brings assistive products for face-to-face communication (UNE-EN ISO, 2012) in letter and/or symbol sets and boards, communication amplifiers, dialogue units and software for face-to-face communication.
- The system of representing meaning, ideas and concepts includes body language, pictures, gestures, facial expressions, paintings, words, line drawings or Bliss symbols.
- A mean of access to the communication medium refers to tools to interact with the assistive products, for example, keyboard, touch screen or a switch to scan from an array of letters/words/pictures and are also included in the UNE-EN ISO 9999.
- Strategies are plans to efficiently utilize symbols, aids, and techniques to improve communication. For example being able to start up a conversation, maintaining a conversation by turn-taking and using questions, repair strategies when communication breaks down (C.-G. Kim, Kwak, Tak, & Song, 2011).

There is a wide range of augmentative and alternative languages using pictograms or images. Some of them are proprietary software like MinSpeak, Pictured Communication Symbol (PCS), DynaSyms, Picture Exchange Communication System (PECS), Pictogram Ideogram Communication (PIC), Widgit or Pixon. Besides, there are several languages in free open-source format like Blissymbolic, ARASAAC or IMPACTE2. The most extended alternative and augmentative languages are PCS, Minspeak and Blissymbolics. However, other non-commercial purpose solutions have been recently developed and are available for future applications like ARASAAC or IMPACTE2.

PCS was developed by Mayer Johnson (1981) and it is composed by 3000 symbols that can be completed with characteristic symbols from the own user cultural symbols (« Magatzem d'icones catalanes », s. d.). Symbols represent the concept to transmit because this language is addressed to people with simple and expressive language and a limited vocabulary. Users can build sentences following the color code (e.g. yellow for people and green for verb) of Fitzgerald (1954). The main limitations are its poor communication capability and it is proprietary software (« Pictured Communication Symbol », s. d.).

The symbols of Minspeak (developed by Bruce Baker, 1982) do not have a pre-established meaning but it is defined by the user and the speech therapist, allowing user personalization. Moreover, the symbols can have several meanings (semantic compaction) so users can express multiple messages with a reduced set of symbols. However, this is also a proprietary software (« Minspeak », s. d.). Its owner also commercializes several conceptual boards for its implementation (e.g. Deltatalker with 2 million of messages).

Blissymbolics language (Bliss, 1949, 1978) was not specifically designed for people with speech disabilities but as an auxiliary international language. Despite, it has two main advantages compared to previous one: (i) free open-source and (ii) higher communication capability. It has 2000 symbols and users can create new symbols combining existing symbols. It allows generating symbols to distinguish, among others, singular/plural or verbal forms. Users should be able to understand this visual symbolic representation, which is complex for users with cognitive damage or for users used to written or spoken languages. Its main problem is that it is difficult to understand by non-experienced users (e.g. therapists, rehabilitators, teachers, family members). However, it can be solved using current translators or a speech synthesizer.

The Center for Special Care and Rehabilitation (CARE) developed IMPACTE2 (Imágenes PAra ComunicarTE), a collection of images in digital format to facilitate communication among people with some kind of speech problem. The last version has 800 images including the most commonly used vocabulary. Although these designs are not a communication system, IMPACTE2 is designed in such a way that it meets the characteristics to fulfill its purpose.

Aragonese Portal of Augmentative and Alternative Communications (ARASAAC) is a pictographic system developed in 2008 by Centro Aragones de Tecnologias para la Educación (CATEDU), a non-profit organization that develops educational materials for people that have special communication requirements. Today the ARASAAC pictographic system is formed by more than twenty thousand full-color and black-and-white pictograms, which are classified into forty-one categories. Unlike PCS, ARASAAC does not have the orthographic representation of the image and is distributed under a Creative Commons license.

Some alternative languages like PECS or PIXON propose their own methodology for learning processes. PECS is characterized by the fact that it does not require any demanding prerequisite and it start with the teaching of requesting for preferred items and activities. Teaching functional verbal operants with prompting and reinforcement strategies carries out learning process in PECS. Verbal prompts are not used, thus building immediate initiation and avoiding prompt dependency (Lancioni et al., 2007; « PECS (The Picture Exchange Communication System) », s. d.). PIXON is based on the selection and use of high frequency core vocabulary and organized by Part-of-Speech (POS) categories. The objective of PIXON is to propose a curriculum for the systematic development of language with children using AAC strategies. The curriculum being developed involves the creation of modules for the systematic introduction of vocabulary, using normal language development as one model for vocabulary selection. While the modules are not in a strict developmental order, they are driven by the goal of providing words and language functions developed in children by the age of 3. Each module builds upon the previous module, until the child has, at a minimum, access to 150 core words with words from a full range of word groups. The words selected for each module were based on the decision that the child with complex communication needs requires a system that will allow his/her language to grow (Van Tatenhove, 2008).

When planning an AAC intervention, it is important to select a system of representation that the individual can understand. People who are dependent of an AAC generally use a variety of types of symbols throughout their lives, therefore, the objective of an initial symbol evaluation is to select the type(s) of symbols that meet the current needs of communication and that require minimal time for learning. Over time, additional symbols assessments may also be performed to identify the symbols that may be used in the future. (Fosset & Mirenda, 2009)

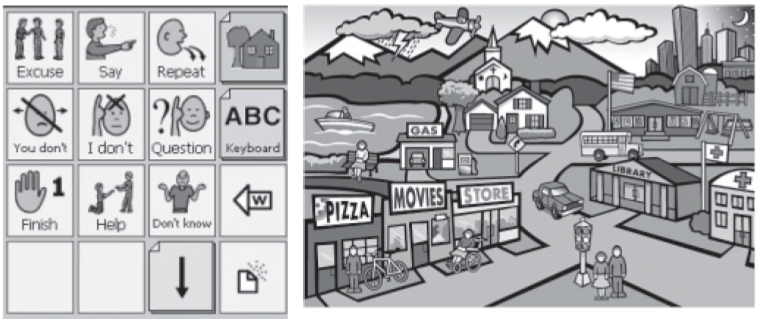
2.3 Assistive Products

Support devices can vary from paper sheets to electronic boards (which can be either static or dynamic). The static electronic boards (all symbols are simultaneously displayed) are limited to a single AAC code and its communication capability is limited to the number of physical symbols of the board. Dynamic devices can manage a higher number of symbols and allow modifying and adding new ones, enriching the code. Dynamic devices can be dedicated devices developed for communication purposes or non-dedicated devices such as tablets PC. Most of devices are dedicated but during the last years, there are different initiatives to develop communication software for non-dedicated devices.

The organization and layout of information can serve to facilitate or impede the accuracy and efficiency with which AAC users are able to locate, select, and functionally use the concepts (Light & Drager, 2007). Vocabulary in communication devices and software for AAC are often presented in a grid format (The Grid 2, Say-it! SAM, Liberator Vantage Lite, Dynavox). The vocabulary items may be organized by spoken word order, category, frequency of usage or using graphical scenarios (Visual Scene Displays – VSD).

(Light et al., 2004) carried out a research about the learning demands of different layouts and organizations of AAC technologies: (1) a taxonomic grid layout (i.e., symbols organized according to hierarchical categories and displayed in a row-column layout); (2) a schematic grid layout (i.e., symbols organized according to events or experiences and displayed in a row-column layout); (3) a schematic visual scene layout (i.e., a contextual scene of an event with concepts embedded under hot spots in the scene); and (4) iconic encoding (i.e., an encoding technique in which line drawings that are rich in semantic associations are used in combinations as codes to retrieve single words or phrases). Although the results depend on the age of participating children, this study provides several interesting conclusions. In general, the iconic encode was significantly difficult to learn by children between 4 and 5 years. Some children had trouble with all form of vocabulary arrangement on initial exposure, but after just one session performed significantly better with the visual scenes than a grid format. In general, VSDs look like an important representation form for beginning communicators compared to traditional grid displays. The main advantages of VSDs are the following (ACN, 2004; Drager et al., 2004; Light & Drager, 2007):

- The scenes provide familiar events or activities in the user's lives, maximizing the meaningfulness of the representations.
- Visual scene display present language concepts in context, providing support for user's understanding.
- Visual scene displays, by definition, organize language schematically according to event experiences. This approach is congruent with the organization of language concepts when a child is learning a language.
- Visual scene displays keep the conceptual and visual relationships between symbols that occur in life (i.e., location, proportionality of concepts, etc.).
- Visual scene displays enable communication partners to participate more actively in the communication process (providing social interaction). Communication partners assume a supportive role, if needed, to make interaction easier for beginning communicators and individuals with cognitive and linguistic limitations.



Source: (ACN, 2004)

Figure 2.2. Contrasting types of AAC displays. Traditional grid display and Visual scene display.

There are several solutions using VSD like Q-Talk, Lingraphica, Springboard-lite or Vmax+. The main differences between these devices are the pictures/symbols used, navigation mechanism, type of feedback to the user and weight of device.

2.3.1. Mean of access

There are two basic access methods for using AAC devices, direct selection and scanning.

Direct selections allow the user access to all possible symbol choices at all times. This kind of selection can be carried out with keyboards or switches, light and optical pointers or eye-gaze (Glennen, 1997).

Keyboards can be used by pressing the buttons with any body part (fingers, hands, head, eye-gaze, etc). Usually, interfaces with keyboards can be with mechanical pressure keys (e.g. Delta Talker, Alpha Talker, Sidekick, Chatbox), touch membranes or touch screen surfaces (e.g. Parrot, Dynavox-Maestro, Hawk, Speak Easy, Mercury). For those cases where the users have low muscle tone and are unable to apply enough pressure, membrane surfaces are a good solution by the very little pressure needed for activation. Moreover, several studies conclude about the importance of user feedback during keyboard interaction. Some proposed solutions for user feedback are the use of electrotactile or vibrotactile membranes, light touch or auditory signals (Glennen, 1997; Kaczmarek, Webster, Bach-y-Rita, & Tompkins, 1991). When physical capability affects the interaction with traditional keyboards, switches allowing very separate elements could be a solution. However, this solution limits the number of messages to be transmitted.

Light and optical pointers are methods for direct selection of elements onto the surface of a communication system. Typically, these kinds of pointers are mounted on user's head or glasses or held in a hand. This is a beneficial method for users with good fine motor control.

Direct selection pointing can also be achieved with Eye Gaze (Bates, Donegan, Istance, Hansen, & Räihä, 2007). This technique is based in fixation of gaze in objects or pictures on a panel or screen. There are non-technological solution like ETran (a clear plexiglass board) or more technological systems with dynamic screens with eye-tracking by cameras like Dynavox Eyemax System, Eye-com or Tobii communicator (Corno, Farinetti, & Signorile, 2002). Other solutions based on video analysis for direct selection are proposed. This consist of a visual tracking of parts of the body like pointer, for example, tracking eyes, nose, mouth or fingers (Betke, Gips, & Fleming, 2002).

For users with reduced movements, especially in their hands, direct selection systems generally are not a good alternative. This kind of users use scanning as a mean of alternative access (Light & Drager, 2007). Scanning is the sequential presentation of choices (letters, words, or pictures) and the user sends a signal when the desired item has been reached (activating or releasing one or more switches). In this type of selection, the options are usually highlighted by a cursor moving in an established pattern over an array of items on a screen. In some cases, with a large set of items, elements are arranged in groups. User first chooses the group associated to the desired item and then the item itself (Treviranus, 1997).

(Lee & Thomas, 1990) describe four general techniques of scanning:

- Automatic scanning: The scanning indicator moves through items by highlighting each item or groups of them. The scanner make selections when the scanning indicator (or cursor) is on the desired choice and the user activates the selection switch.
- Step scanning: With this technique, through steps the user has the control of scanning speed. Thus, more switch activations are required. When the desired item is reached, the user releases the switch. The absence of a switch press is the signal that a selection has been made. 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 highlight advances by maintain 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.

According with the way to present the items to the user, several scanning patterns are proposed. The most common are circular, linear and group item scanning. In linear scanning, the options are presented one at a time in a line-by-line pattern. Circular scanning operates in a similar way but the items are scanned in a circular pattern and they are arranged in a circle. In group item scanning, items are grouped and the scanning indicator will first scan by groups. When the user selects a group the scanning indicator will scan each item inside the group. The most used groups are row/column and block or quadrant scanning (Beukelman & Mirenda, 2005; Mizuko & Esser, 1991; Surdilovic & Zhang, 2006; Vinson, 2001).

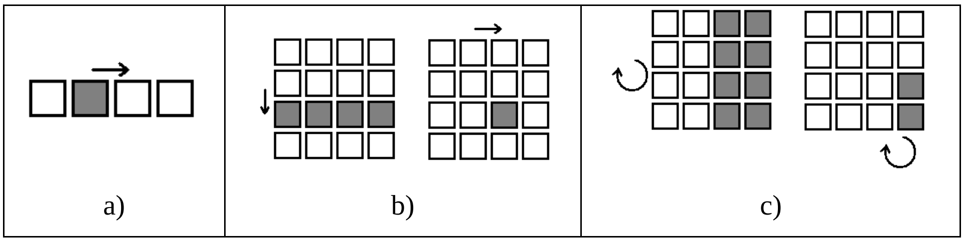


Figure 2.3. Most used scanning patterns. a) linear scanning, b) row/column scanning, c) block scanning.

Each scanning technique and pattern requires different physical, cognitive and perceptual abilities of the user (Treviranus & Tannock, 1987). For this reason, the scanning mode has to be chosen according with the user needs and limitations (Ottenbacher & Angelo, 1994).

Despite the benefits of scanning, this selection method is very slow and has high learning demands especially for user with cognitive and linguistic limitations. Therefore, several acceleration techniques have been developed which allow item selection to transmit larger quantities of information (Treviranus, 1997). Abbreviation expansion is an acceleration technique that translates one or a few selections into a longer message which would otherwise require many selections (Light, 1989; Vanderheiden & Kelso, 1987). A second technique known as linguistic prediction can complete the spelling of a word once a few letters have been entered (Swiffin, Arnott, Pickering, & Newell, 1987). McCarthy el al. propose a scanning method using animations and speech output with appropriate intonation. In this way, the lack of speed in learning and accuracy was improved (McCarthy et al., 2006).

To reduce access time to items in a grid for the different scanning patterns, (Kulikowski, 1985) proposed an ideal relationship between scanning dimensions and the selection set size as shown the Table 2.1. (Shein, 1997). The dimension 1 is the linear scanning pattern while row-column scanning has a dimension of 2. Quadrant scanning of an 8x8 matrix has a dimension of 3 and further groups or pages can generate additional dimensions.

Table 2.1. Ideal selection set with respect to scanning dimension.

Dimension	Selection Set Size
1	1
2	6
3	22
4	85
5	331
6	1288
7	5006
8	19449

Nowadays, scanning solutions are being adapted to specific characteristics of users. Some proposed solutions for scanning are focused in switching by head movements, pressure sensors, electromyography or mechanomyography (Alves & Chau, 2010; Belda-Lois et al., 2006; Dymond & Potter, 1996; C. Huang et al., 2006).

In general, DCP users need an input interface to select and point at the desired concept. However, their lack of movement and posture control restrain the possible interfaces to be used. Typical HMI such as 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 (Betke et al., 2002; Jilin Tu, Huang, & Hai Tao, 2005; Mauri, Granollers, Lorés, & García, 2006; Riby & Hancock, 2009). Most of DCP users use an scanning system combined with non-comfortable section/control systems such as pushing with their head or shoulder against a switch (Swinth, Anson, & Deitz, 1993) o sipping-puffing air through a small straw (Bonnat, 2010; Mazo et al., 2002), or being helped by a third person (caregivers or family). However, both approaches have low bit rate and high amount of errors due to delay between DCP users “intentions” and the actual “execution” of the action.

2.4 Brain-Neural Computer Interfaces

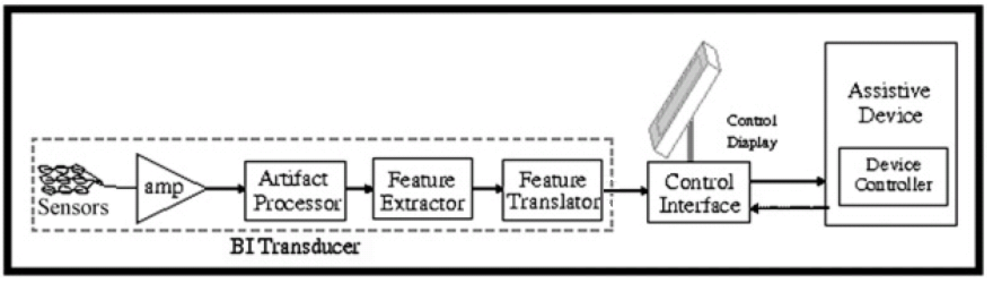
Brain-Computer Interfaces (BCI) are devices that are not dependent on actual movements. BCIs process directly the user intentions and translate the corresponding brain activity into messages for the environment by providing real-time feedback to the user (Dornhege et al., 2007; Wolpaw et al., 2002). **Brain-Neural Computer Interfaces** (BNCIs) are an extension of BCIs that also rely on: passive monitoring (which might assess workload or user fatigue without providing real-time feedback); information derived from the peripheral nervous system (such as motor unit action potentials that trigger muscle flexion); and indirect measures of neural activity (such as the electromyography: EMG) (J.C. Moreno et al., 2010).

Several neurological diseases such as muscular dystrophy, amyotrophic lateral sclerosis (ALS), high spinal cord injury or cerebral palsy may lead to severe motor impairment and paralysis making communication hard or even impossible. The ultimate goal of BNCI research is to provide a nonmuscular-driven communication channel for individuals who are no longer able to communicate due to severe physical impairment.

In 2003, Mason & Birch proposed a functional model of a BCI system. This model have been improved with the model of (Cook & Hussey, 2002) which include several concepts from the U.S. Institute of Medicine (IOM) model of disability (Engineering & Medicine, 1997). Their final model is shown in the Figure 2.4. The figure depicts a generic BCI system in which a person controls a device in an operating environment through a series of functional components. The Transducer translates the person's brain activity into usable control signals.

The sensors placed on the head of the user record the brain signal and convert it to electrical signals. The amplifiers (amp) amplify and bandpass filter the signals. The Artifact Processor removes the artifacts from the electrical signal. The Feature Extractor transforms the signals in feature values that correspond to the underlying neurological mechanism used by the user for control. The Feature Translator translate the outputs of the Feature Extractor into logical control signals.

A Control Interface translates the relatively low-dimensional transducer output into higher dimensional values. The Assistive Device (AD) component uses these control signals to perform a desired activity or function (Bashashati et al., 2007; S. G. Mason & Birch, 2003; S. Mason et al., 2005).



Source: (Mason et al., 2005)

Figure 2.4. Functional model of a BCI System.

There are several technologies to acquire brain activity. Currently, electroencephalogram (EEG) is the most common signal source for BCIs in humans. Unlike methods like MEG (magnetoencephalography) and FMRI (Functional Magnetic Resonance Image), the popularity of EEG is primarily due to its non-invasive nature, relatively low price, portability, and wide availability. Invasive recording technologies have a better signal-to-noise ratio, however, they also pose a considerably higher medical risk compared to the non-invasive EEG and are currently only employed for medical reasons other than BCI, such as pre-surgical epilepsy monitoring.

EEG signals are the differences in electric potential recorded from electrodes placed on the scalp and reflect the temporal and spatial summation of electrical inputs to large groups of neurons lying beneath the recording electrode. EEG signals have small amplitudes (10^{-6} Volt) which make EEGs very sensitive to noise and artifacts. Artifacts are signals that do not originate from the brain, but which may influence the BCI output. The most frequent artifacts generated by the user are muscle activities (which can be measured using the EMG) and eye movements (measured via the electrooculogram, EOG). Artificial noise is usually due to nearby electronic devices (e.g., 50 Hz power line interference). Indeed, the user's current mental or emotional state may also affect the measured EEG activity and cause transient distortions (Myrden & Chau, 2015).

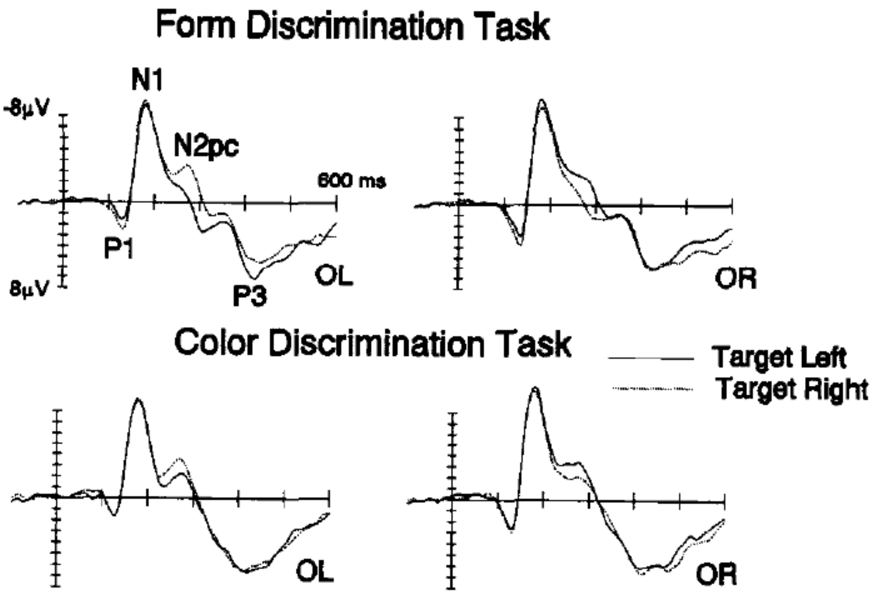
According with the neuromechanisms and recording technology to generate control signals, (Wolpaw et al., 2002) categorized the BCI systems as five major groups. These categories are <u>sensorimotor activity, P300 evoked potentials, Visual Evoked Potentials (VEP), Slow Cortical Potentials (SCPs) and Activity of Neural Cell (ANC)</u>. Additionally, to consider those BCI systems that use non-movement mental tasks as control mechanism, Bashashati et al. (2007) proposed two additional categories: <u>response to mental tasks</u> as changes in the brain rhythms with motor imagery (i.e. imagined movement) (Kübler et al., 2001; McFarland, et al., 2000; Pfurtscheller & Neuper, 1997) and <u>multiple neuromechanisms</u> as a combination of two or more neuromechanisms. Below there is a brief description of the different categories of BCI systems proposed by (Wolpaw et al., 2002):

- Sensorimotor Activity: When a person is not engaged in processing sensory inputs or producing motor outputs, he originates in the sensorimotor cortex Mu rhythms in the range of 8-12 Hz and beta rhythms in the range of 13-30 Hz. A movement or preparation for movement is typically accompanied by a decrease in the mu and beta rhythms. This decrease is called “event-related desynchronization” (ERD). Its opposite, rhythms increases, called “event-related synchronization” (ERS) occurs after a voluntary movement.

- Slow Cortical Potentials (SCPs): SCPs are slow, non-movement potential changes generated by the subject. This technique has to be trained in several sessions. The rhythms reflect changes in cortical polarization of the EEG lasting from 300 ms up to several seconds.
- P300 evoked potentials: P300 is a positive peak evoke in the EEG over the parietal cortex at about 300 ms after a controlled stimulus. This controlled stimulus can be an infrequent or particularly significant auditory, visual, or somatosensory stimulus, when interspersed with frequent or routine stimulus. A P300-based BCI has an apparent advantage in that it requires no initial user training: P300 is a typical response to a desired choice.
- Visual Evoked Potentials (VEPs): VEPs are small changes in the ongoing brain signal, over the visual cortex. They are generated in response to a visual stimulus and provides the direction of eye gaze, and thus to determine the direction in which the user wished to move a cursor (Wolpaw et al., 2002). If the flicker frequency of a visual stimulus are higher than 6Hz, a periodic sequence of VEPs is generated — a steady-state visual evoked potential (SSVEP)— which is frequency locked to the flickering target (Guangyu Bin, Xiaorong Gao, Yijun Wang, Bo Hong, & Shangkai Gao, 2009).
- The VEP-based communication systems depend on the user’s ability to control gaze direction. Moreover, for those user whose disabilities cause uncontrollable head and neck muscle activity, scalp EMG can impede reliable VEP measurement and reduce performance (Sutter, 1992).
- Activity of neural cells (ANC): This is an invasive category where intracortical electrodes are used. The firing rate of neurons in the motor cortex can reveal the direction of the movement. This category has been used to control the cursor movement to select icons or letters on a computer screen.

Operating with Event-Related Potentials (ERP) systems as P300/SSVEP-BCIs is generally easier than operating with event related changes in the oscillatory EEG activity (ERD/S-BCIs), because the elicitation and the detection of ERPs are time-locked to external visual stimuli (synchronous operation paradigm). ERD/S BCIs usually require longer training periods (from days to weeks) and achievable information-transfer-rates are lower. However, they allow autonomously and voluntarily modulating brain activity each time a message needs to be sent (asynchronous operation mode). Moreover, recent studies are improving solutions to reduce the learning time and the high mental workload to maintain concentration (D. Huang, Qian, Oxenham, Fei, & Bai, 2011).

Another available ERP is the N2PC which is a negative deflection in the EEG approximately produced 200 seconds after a visual stimulus (see Figure 2.5). The N2PC has been widely studied to determine its relationship with selective attention to locate stimulus in certain area of the visual field, giving as a result, stronger deflection amplitudes in the opposite area of the visual cortex where the stimuli is located. However, this potential has not been used yet to control BCI systems (Eimer, 1996; Kiss, Van Velzen, & Eimer, 2008; Sirvent Blasco, Iáñez, Úbeda, & Azorín, 2012). Sirvent Blasco et al., (2012) have used the N2PC together with the P300 like communication tool. Both evoked potentials were combined to increase the hit rate of the system. The main drawback is a higher number of electrodes required (16 electrodes) when compared with the P300 approaches (5 electrodes).



Source: (Eimer, 1996)

Figure 2.5. ERPs elicited in two tasks (form and color) with targets in the left side (straight lines) and the right side (dashed lines) at lateral occipital electrodes OL and OR.

A way to improve the performance of a BCI is the detection of the so-called Error-related Potentials (ErrPs) (Combaz et al., 2012). ErrPs were suggested to be generated in the anterior cingulated cortex (Ferrez & Millán, 2007) and related to the subject’s perception of an error (Holroyd & Coles, 2002). A mistake is followed by a positive potential centered at the vertex that peaks about 180 ms after the incorrect selection (Schalk, Wolpaw, McFarland, & Pfurtscheller, 2000). The ErrPs in the EEG are associated to errors made by the subject himself and when the user realizes that the interface failed to recognize properly his intention (Combaz et al., 2012). This technique is actually being improved. ErrPs improvements in BCI communication are focused on the current necessity of gathering enough training data, the importance of minimizing the amount of false positives in a single trial detection and the strong noisy component of the EEG signals (Combaz et al., 2012).

Providing on-demand control is crucial for BCI usability. One way to enable on-demand ERP-based access would be to present control commands on the screen and flash them all the time. Unless the user is intentionally attending to the flashes, no P300 is evoked and thus, no control command will be selected. Another option would be to combine the P300 system with an ERD/S-based BCI or other electrophysiological non-EEG signals (Hybrid BCIs). On-demand ERD/S based control is very difficult to achieve and so far are only a few groups reported on real-time systems (S. G. Mason & Birch, 2000; Millan & Mourino, 2003). This approach, however, would reflect the most natural way of interaction because user is in control of timing and speed.

One issue, which limits the practicality of non-invasive BCIs are the EEG sensors. Usually wet sensors are used which require scalp preparation, the use of electrolytic gels and need to be reapplied frequently to maintain a good signal quality. Lately reports on dry electrodes (Gramatica et al., 2006; Matteucci et al., 2007; Popescu, Fazli, Badower, Blankertz, & Müller, 2007; Ruffini et al., 2007) as well as active dry sensors (Fonseca et al., 2007; Zander et al., 2011) were published. Using these technologies, the first generation of such devices became commercially available recently (e.g. Emotive, Neurosky).

2.5 BNCI applications

The main and the most investigated applications of the EEG based BNCI are communication aids such as spelling devices (Neuper et al., 2006) and Internet-browsers (Mugler et al., 2008), the restoration and rehabilitation of lost motor function (Müller-Putz et al., 2005; Neuper et al., 2003; Pfurtscheller et al., 2003), the control of assistive devices in real and virtual environments (e.g. wheelchair (Galán et al., 2008)) and entertainment (e.g. arts performance or computer games (Halder et al., 2009)).

The Graz University of Technology developed an ERD/S BCI based spelling systems that enables user to communicate by selecting letters to form words and sentences (Scherer et al., 2004). One selection strategy is to split the alphabet iteratively according to a predefined procedure, until the desired letter is isolated. The simplest method uses a binary control signal, which requires two distinct mental activities. Patients with disability, included people with Cerebral Palsy, have learned to operate the virtual keyboard in this way (Christa Neuper, Scherer, Reiner, & Pfurtscheller, 2005; C Neuper et al., 2003). In contrast, P300 BCI can be used for spelling without previous training with a high success rate in Amyotrophic Lateral Sclerosis patients (F Nijboer et al., 2008; Sellers & Donchin, 2006).

Regarding to Internet access, there have been previous attempts to create a BNCI browser enhancing internet accessibility such as “Nessi”, “Descartes”, “BrainBrowser” (full review in (Mugler et al., 2008)). Although some of these systems achieved significant success, each of the existing systems has its important disadvantages, and none of them is a widely used application. Recently, the P300 based BCI internet browser was developed, which uses the P3Speller paradigm for selection of the desired links and allow the following browser functions: navigation (forward, back, reload, and home), data form entry, address bar entry, and scroll up and scroll down. These functional options are all presented as icons in an expanded 8-by-8 form of the traditional 6-by-6 P3Speller matrix in BCI2000. However, it is necessary to incorporate user-specific functions in the program and implementation of their personal suggestions and preferences.

Following this approach, there are also some specific applications such as Brain-Painting: SMR-BNCI (Halder et al., 2009) or P300 BCI based “Brain Painting”. The former uses the cursor task module of the BCI2000 software to present the painting menu to the user. The menu was modeled after the established hex-o-spell typewriter system developed by the Berlin BCI group (Krepki, Blankertz, Curio, & Müller, 2003). The latter, developed by the University of Tübingen, uses the P3Speller to present the painting matrix to the user. The rows and columns of the matrix are intensified in random order as with a P300 Speller System (F Nijboer et al., 2008). The use of the painting application has been successful in out-of-the-lab conditions (Kübler, Halder, Furdea, & Hösle, 2008).

In relation with other fields such as mobility, other ERD/S BCI applications have been proposed. The Graz University of Technology developed a 2-class ERD/S BCIs (called BrainSwitch) to operate a functional electrical stimulation (FES) system to control hand grasp for using at patients’ home (Gert Pfurtscheller et al., 2003); to control a wheelchair in a complex virtual environment; to operate the internet-based Virtual Google Earth application; or to play video games by using navigation commands “Rotate Left”, “Rotate Right” and “Move Forward” (Scherer et al., 2009). The latter two applications were based on the first BNCI able to detect motor imagery patterns in the on-going EEG, key for real-world applications were user require access to communication at any time.

2.5.1. Limitations of BNCI Systems

Over the past ten years it has been demonstrated that patients with severe motor disability are able to control a BCI (e.g. to select letters and thus to communicate) by regulating their slow cortical potentials (SCP) or sensory-motor rhythm (SMR) and ERD/S or with the P300-BCI (Birbaumer et al., 1999; Kübler et al., 2005; C Neuper et al., 2003; F Nijboer et al., 2008). However, BCI presents several limits that are associated to the type of application and the efficacy of implementation. The main constraints are:

- The <u>non-stationarity and the inherent variability of EEG brain signals.</u> Data from the same experimental paradigm but recorded on different days are likely to exhibit significant differences. Additionally, the noisy superposition of the electrical activity of large populations of neurons as measured on the scalp can mask the underlying neural patterns and hamper their detection. Besides the variability in neural activity, the user's current mental state may also affect the measured signals: stress, excessive workload, boredom, or frustration may cause temporary distortions of EEG activity. User adaptation to the BCI as well as the changing impedance of EEG sensors during the course of recording contributes to making the recorded signal statistically non-stationary

- Initial training time required to achieve BCI control. Typically, over 20 hours are reported in the literature (Kübler et al., 2005, 2001) except for VEP- or P300-based systems, which only require a short calibration at the beginning (F Nijboer et al., 2008).
- Data transfer rate, which has a current upper limit of between 25 and 50 bits per min (Krepki et al., 2003; Randolph, 2007; Wolpaw et al., 2002).
- Cumbersome preparation and de-preparation of the electrodes required for EEG recording (20 and 60 or even more minutes). De-preparation requires washing the hair. Solutions for this are the reduction of the number of electrodes or the use of dry electrodes. However, the quality of dry-electrodes, currently, is inferior to signals recorded from the classical gel-based electrodes (Zander et al., 2011).
- Effectiveness level is a key problem (Wolpaw et al., 2006). Depending on the application the consequence of the misclassification of a signal can cause frustration (and abandonment of the system). Choosing and fitting the system and the protocol is critical to adoption (Wolpaw et al., 2002).
- Lack of out-of-the-lab use of BCI systems. Up to now for successful BCI use, a user would need the supervision of a BCI expert over a long period. This greatly limits the number of potential users. Only a few laboratories are willing and experienced to visit people at home and supervise them (Jackson, McClendon, & Ozawa, 2010; Vaughan et al., 2006).
- BCIs have been tested and used mainly on adult patients with different degenerative neurological diseases. BCI research lacks the diversity of the targeted population. For example, up to now, there are no documented cases of children with DCP communicating by means of BCI.

Because of these and other limitations and challenges, only a few commercial BCI products are available on the market today (e.g. Guger Technologies OEG, Brain Products GmBH, Biosemi, BV, NeuroSky, Emotive Systems, BrianGate). Moreover, most of available products can be classified as a recording hardware for clinical and research purposes, and not as BNCI system ready for home use.

2.6 Other physiological signals and sensors for AAC

Motion and posture sensing, by means of inertial sensors can be used like input for a communication system (i.e. to control a joystick) or to identify emotional features. Since micro sensors such as gyroscopes and accelerometers have become generally available, human movement can be measured continuously outside a specialized laboratory with ambulatory systems. These sensors represent a real scientific breakthrough in the medical field, where there is a need for small ambulatory sensor systems for measuring the kinematics of body segments (Juan C Moreno, Rocon De Lima, Ruiz, Brunetti, & Pons, 2006; Verplaetse, 1996).

The interpretation of electrophysiological signal variations can distinguish some basic emotions. For that, biosensors have been developed that allow researchers to have a better understanding of the electrophysiological signals variations in the context of affective states. Signals such as Galvanic Skin Response (GSR), respiration and heart rate (HR) are the usually selected signals for monitoring emotional states since these signals are closely related to the autonomic nervous system (ANS) response to emotional stimulus. For example, GSR is controlled by sympathetic nervous system that sends outputs to sweat glands distributed on the skin, while HR is dually controlled by the sympathetic and parasympathetic branch of the ANS that may act independently. Moreover, respiration is also an election signal for affective states since its parameters map into an affective space dimensions:

- Galvanic Skin Response (GSR) represents variations of the skin electrical characteristics, i.e., GSR shows the electrical conductance of the skin (Bee, Prendinger, Nakasone, André, & Ishizuka, 2006). This feature varies with sudomotor glands, which are regulated by the sympathetic automatic nervous system in response to a cognitive stimulus (Gamboa & Fred, 2007; Li & Chen, 2006). Therefore, the skin electrical conductance decreases. Regarding GSR sensor, it is placed on the finger (or in the palm or the forearm) and the skin conductance is measured between two pre-defined points. This sensor is equipped with signal conditioning and amplification circuitry in order to provide accurate sensing capability and a high signal-to-noise ratio. As a result, it is possible to detect even the most feeble galvanic skin response events.
- The heart rate is a physiological parameter that can be measured from the ECG signal (electrocardiogram), which registers the heart electrical activity. Heart rate variability (HRV) parameters are obtained from the time and frequency analysis of heart rate (Rainville, Bechara, Naqvi, & Damasio, 2006). As an alternative to derive it from the ECG, the heart rate can be determined from the blood volume pulse (BVP) signal. The BVP sensor determines the amount of blood running though the vessels and it is placed on the finger. This sensor is based on photopletysmography (PPG) and consists of measuring the changes in volume through measuring the amount of infrared light absorbed by the blood.

The changes in volume are caused by variations in blood pressure in the vessels occurring during each cardiac cycle.

- The respiration has also been reported as being a signal that can help to distinguish emotional states since frequency of breathing and regularity of breathing cycles can reflect the person's emotional state, for example, when the subject cries, smiles or screams (Haag, Goronzy, Schaich, & Williams, 2004). This way, coupling the deep breathing with its frequency, one can analyze the emotional state (Hadjileontiadis, 2006; Hristova & Grinberg, 2009). The respiration sensor can be applied to the chest in order to measure abdominal or thoracic respiratory cycles. This sensor integrates an air pressure sensor to measure the pressure differences within a sealed chamber.

Electromyographic activity (EMG) is the electrical signal produced by muscles. This signal is used to control AAC systems, for example to activate a switch (Prinz, Zeman, Neville, & Livingston, 2006) or to control a cursor (Belda-Lois et al., 2006). While EMG activity may have value for assistive communication for users with sufficient muscle control, this signal is a noise source for BCI systems. In this way, this signal is being also used as artifact detection and elimination in BCIs. Thus, any practical system of EEG-based communication must incorporate means for preventing non-EEG activity from interfering with the EEG-based communication (i.e. body or eye movements and eye blinks) (Vaughan, Wolpaw, & Donchin, 1996).

The mechanical index of muscle contraction (mechanomyogram - MMG) is also used as switch or to control a cursor in AAC systems (Alves & Chau, 2010). MMG is generated from gross lateral movement of the muscle at the initiation of a contraction, smaller subsequent lateral oscillations at the resonant frequency of the muscle, and dimensional changes of active muscle fibers (Barry & Cole, 1990). Unlike EMG, MMG is not influenced by skin impedance changes and does not require skin preparation, the sensors are smaller and the measurement is not dependent on the alignment along the muscle fiber axis. MMG may be measured by microphones, piezoelectric contact sensors, accelerometers or laser distance sensors on the surface of the skin (Alves & Chau, 2010).

The blood volume and blood oxygenation are another physiological signal used for communication with BCI. These signals are used in the "Kokoro Gatari" functional Near Infrared (fNIR) imaging system developed by Hitachi Ltd. The measures are carried out via a small, flat sensor consisting of an emitter/detector placed on the user's forehead. The emitter shines infrared light into the brain, and the detectors determine the amount of light that is reflected, determining brain activity under the sensor. The sensor is placed close to the language center in the brain (Broca area). Currently, the device is configured to allow the user say "yes" or "no" depending on a pattern of activation in response to auditory cues (Jackson et al., 2010).

2.7 Physiology and Emotions: affective computing

Emotions theories have evolved along the history. Regarding the nature of emotions, some researchers have found evidences that emotions are inborn (Ekman & Friesen, 1971; Izard, 1971; Lutz & White, 1986) while others found also evidence of their dependence on social rules (Ekman & Friesen, 1971; Lutz & White, 1986). This has derived into two theories: Nativist theory, based on Neo-Darwin view, which defends innate nature; and Cognitive Model (Ortony & Turner, 1990) that defends that social "labels" and rules condition the emotional state. However, for emotional analysis both approaches should be taking into account (Ekman, 1993).

Analogously, some authors define emotions as physiological changes (James, 1992; Lange & Kurella, 1887) but other ones relate emotions with cognitive processes (Cannon, 1927)(Laparra-Hernández, Belda-Lois, Medina, Campos, & Poveda, 2009). More recently, this distinction has evolved relating emotions with somatovisceral patterns (Ekman et al., 1983; Levenson, 1988; Levenson et al., 1990) and with cognitive assessments (Schachter & Singer, 1962). Currently, many authors defend that both theories are partially valid because emotions are both.

Emotions "color and define" processes as decision making or learning (Fredrickson, 2003; Goleman, 2006; Schwarz & Clore, 1996), have a key role on health (Gross & Levenson, 1997), and is related with to some other cognitive processes such as perception (Bower, 1981), memory (Bower, 1981), preferences (Zajonc, 1984); making decision (Damasio, 2006), taking attention and concentrate (Derryberry & Tucker, 1992), communication (Derryberry & Tucker, 1992), motivation and efficiency during task performance (Yerkes & Dodson, 1908), intention (Frijda, 1986) and strategic planning (LeDoux, 1992).

Moreover, depending on emotions processing, some researchers defend that emotions are discrete elements and that there is a basic set of emotions (Ekman et al., 1986; Leidelmeijer, 1991; Mowrer, 1960; Ortony & Turner, 1990; Plutchik, 1980; Tomkins, 2008): categorical approach, however there is no consensus agreement on the number and name of this set of emotions. On the other hand, dimensional approach describe emotions as points that could be represented on multidimensional spaces (2 or 3 dimensions), two of most accepted are arousal-valence space (Cacioppo, Berntson, Larsen, Poehlmann, & Ito, 1993) and arousal-withdrawal (James A Coan & Allen, 2004).

Emotion detection could be obtained through questionnaires, physiological response, and behavior analysis, but an effective detection requires a multidimensional approach (Berridge, 2003). Questionnaires are the most used technique, because of their simplicity (Harmon-Jones, Amodio, & Zinner, 2007), but they have some inconveniences as when users are unable to understand or express what they feel, such as for example DCP users.

Within behavioral analysis, body posture and facial gesture can determine some emotions (Duclos, Laird, Schneider, & Sexter, 1989; Fazio, 1987; Flack, Laird, & Cavallaro, 1999) but some emotions, such as happiness, do not have a clear postural pattern (Flack, Cavallaro, Laird, & Miller, 1997; Flack et al., 1999; Flack, Williams, Cavallaro, & Laird, 1994). Pressure on feet and hands (Clynes, 1978), gait analysis (Lewis & Haviland-Jones, 2004), gaze for guilty and love emotions (Schnall et al., 2000), breathing for stressful situations (Healey & Picard, 2000) or voice and speech (Bezooijen, 1984), have also been used for emotion detection. However, most researchers highlight the difficulty to get patterns for each emotion. These patterns become more complex and difficult to extract on DCP users due to their damage between Central Nervous System and Motor Control System, deriving on lack of postural control, uncontrolled and involuntary movements (include facial expressions and gaze fixation) and irregular breathing patterns.

The emotional response is partially processed unconsciously and the physiological response analysis allow to access to the unconscious emotional response of users. Along last decades, different body signals have been used depending on context and emotions, the most used are galvanic skin response (GSR), heart rate (HR), facial electromyography (fEMG), electroencephalography (EEG) and blood pressure (BP).

Many studies have reported relations between GSR and the level of arousal (Bradley et al., 2001a, 2001b; Lang, 1995)(Bradley, Codispoti, Cuthbert, et al., 2001; Bradley, Codispoti, Sabatinelli, et al., 2001; Lang, 1995) other studies related fear with high levels on GSR (Lanzetta & Orr, 1986). In ECG signal, arousal is related with heart rate variability and valence is related with deceleration-acceleration pattern of heart rate (Bradley & Lang, 2007; Greenwald, Cook, & Lang, 1989). Analogously, asymmetry of EEG signals is also related with valence and with withdrawal (Cacioppo et al., 1993). Inside EMG facial, activity on zygomaticus major or orbicularis muscle (Bradley, Codispoti, Cuthbert, et al., 2001; Ekman et al., 1983) is related with positive emotions, and activity on corrugator supercilii is related with negative emotions (Brown & Schwartz, 1980; Schwartz, Fair, Salt, Mandel, & Klerman, 1976a, 1976b), but it does not exist agreement if it is possible or not to relate with arousal (Cacioppo, Petty, Losch, & Kim, 1986; Witvliet & Vrana, 1995).

EEG measures have been used to assess alertness, fatigue, workload, information overload, or errors (Allison et al., 2010; Ferrez & Millán, 2008; Trejo et al., 2005). Information from heart activity can also be used for passive monitoring, either alone or in combination with EEG activity. HR and EEG have also recently been validated in a BCI environment (Pfurtscheller et al., 2005, 2010). Passive monitoring of the user's cognitive and emotive state contributes to affective computing, in which the system adjusts according to the user's state by, for example, providing more or less information, changing the way information is presented to the user, or altering the options available at that time).

A recent study showed that it is possible to determine the emotional state of a person based on the measurement of brain activity alone. The group used an online support vector machine (SVM) to recognize two discrete emotional states, such as happiness and disgust from fMRI signals, in healthy individuals that were instructed to recall emotionally salient episodes from their lives (Sitaram et al., 2007).

The abovementioned signals have advantages and disadvantages depending on context and emotion "type", but it is necessary to combine different measurements to improve results (Cacioppo et al., 1993; Ekman et al., 1983; Healey & Picard, 2000; Larsen, Norris, & Cacioppo, 2003). However, DCP users can have affected the response of Autonomous Nervous System, for example, modifying their HR variability (Yang et al., 2002) altering emotional response, so it is necessary to adapt current approaches and emotion detection/classification algorithms to these changes on emotional response.

Controlling the emotional states could improve the communication in children with cerebral palsy. For example, the use of humor has been shown to enhance conversation in children who use aided communication, encouraging social interaction (Waller et al., 2009).

Several studies of emotional states with BCIs have shown their importance for a well communication process. These studies propose that a person's mood and motivation are related to BCI performance (Neumann & Birbaumer, 2003; Femke Nijboer et al., 2008; Femke Nijboer, Birbaumer, & Kübler, 2010). An example of the influence of the emotional state in the BCI performance was described by (Kleih, Nijboer, Halder, & Kübler, 2010), where the motivation increased the P300 amplitude within an ERP-BCI. In this way, Nijboer et al., (2010) propose that motivational factors and well-being should be assessed in standard BCI protocols.

2.8 Conclusions after the state of the art

The review of the bibliography has allowed to draw different conclusions and emphasizes the need to deepen in some scientific-technical subjects:

- DCP is a chronic pathology where the cognitive performance varies between being completely normal and severe mental retardation. It has associated motor deficits and severe language disorders, causing limitations in physical and social activity. DCP affects approximately 125,000 people in Europe with about 1,500 new cases each year.
- 75% of children with DCP have a normal intelligence level. However, 96% of DCP are classified as educationally degraded. Communication and interaction deficits are the causes that restrict their capacity for learning and development. This communication barrier combined with motor/mobility problems increases dependence, social exclusion and deteriorates their quality of life.
- An AAC system consists of a package of techniques and technologies that constitute the 'total communication' for a specific individual: the way to transmit the message, the system to represent the ideas or concepts, the mean of access and the strategies. There are a wide range of AAC languages and the

choice should be done based on current needs. People who are dependent of an AAC generally use a variety of types of symbols throughout their lives.

- Assistive products can vary from paper sheets to electronic boards. An important parameter for accuracy and efficiency in the communication is related to the organization and layout off information. The main differences between assistive devices are the pictures/symbols used, navigation mechanism, type of feedback and weight.
- There are two basic access methods to use AAC devices, direct selection and scanning. The most suitable method and type of technique is chosen based on end-user needs and limitations. Some proposed solutions for scanning are focused in switching by head movements, pressure sensors, electromyography or mechanomyography. The lack of movements and posture control of DCP users retrain the possible interfaces to be used. Typically, existent input interfaces to select and point a desired concept have low bit rate and high amount of errors due to delay between intentions and executions of the action.
- Brain-Neural Computer Interfaces (BNCIs) are an extension of BCIs that also rely on: passive monitoring; information derived from the peripheral nervous system; and indirect measures of neural activity. The objective of BNCI research is to provide a nonmuscular-driven communication channel for individuals who are no longer able to communicate due to severe physical impairment.
- BCI system can be categorized in five major groups according with their neuromechanisms and recording technology to generate control signals: sensorimotor activity, P300 evoked potentials, Visual Evoked Potentials (VEP), Slow Cortical Potentials (SCPs) and Activity of Neural Cell (ANC).
- Applications of the EEG based BNCI are communication aids, the restoration and rehabilitation of lost motor function, the control of assistive devices in real and virtual environments and entertainment. Some BCI control techniques are being used by patients with severe motor disability. However, BCI solutions present several limits that are reducing the development of home-use products: variability of EEG signals, initial training time required, data transfer rate, time required to install electrodes, effectiveness, invasiveness and the user specifics needs.
- Other physiological indicators are used, as control system (EMG, MMG, etc.) or as emotional change indicator (GSR, HRV, BVP, PPG, etc.). Emotion detection with physiological signals are especially interesting when the users are not able to understand or express their emotions. Control systems with physiological signals (EMG or movements) are limited when there are uncontrolled or involuntary movements, tremor, or lack of precision.

Chapter 3
Hypotheses and objectives

3.1 Presentation of hypothesis.

Based on State of the Art concepts, 2 hypotheses have been proposed:

1. Based on Dyskinetic Cerebral Palsy (DCP) user needs, it is possible to design a satisfactory concept of communication systems.

2. Our innovative approach of physiological control, based on a physical model, allows better communication performance than proportional control. This is applicable to direct selection systems over a grid of concepts.

3.2 Objectives.

The main objective of this thesis is to propose a communication system based on the intelligent processing of physiological signals, augmentative communication, expression of emotions, and interaction capabilities of people with Dyskinetic Cerebral Palsy (DCP). Thus, their social inclusion, independent living and quality of life can be improved.

To reach the main objective, the following sub-objectives were defined:

1. To compile the characteristics and limitations of DCP people and the principles of good design to define the preliminary requirements.

2. To prototype a concept of communication system considering the features for the users and for the caregivers.
3. To identify the functions of the communicator that users like and dislike.
4. To detect which aspects related to the handling of the communicator can be complex or inopportune for the user.
5. To identify which design aspects are more and less appreciated by the users.
6. To define methods for signal processing as control systems adapted to DCP users.
7. To compare the proposed methods for direct control system and their benefits for DCP users
8. To analyze the effect of the size and the distances between buttons on the selection performance over a grid of concepts.
9. To define the requirements of the concept grids to be used by physiological signals with direct control.

3.3 Work plan.

Figure 3.1 shows the work plan followed to reach the objectives of section 3.2 and to validate the 2 hypotheses of this thesis.

The workplan is grouped into 4 phases:

1. State of the art: compilation of the DCP user needs and main features of the existing augmentative and alternative communication systems.
2. Analysis and selection of design characteristics of the ABC system: based on user needs, selection of principles of design and prioritization of characteristics of the ABC system.
3. Design of experiences and tests: prototyping and evaluation of the communication system concept; fine tuning and evaluation of direct selection systems by physiological control
4. Data processing and analysis: data analysis and validation of the concept of the communication system and physiological control systems.

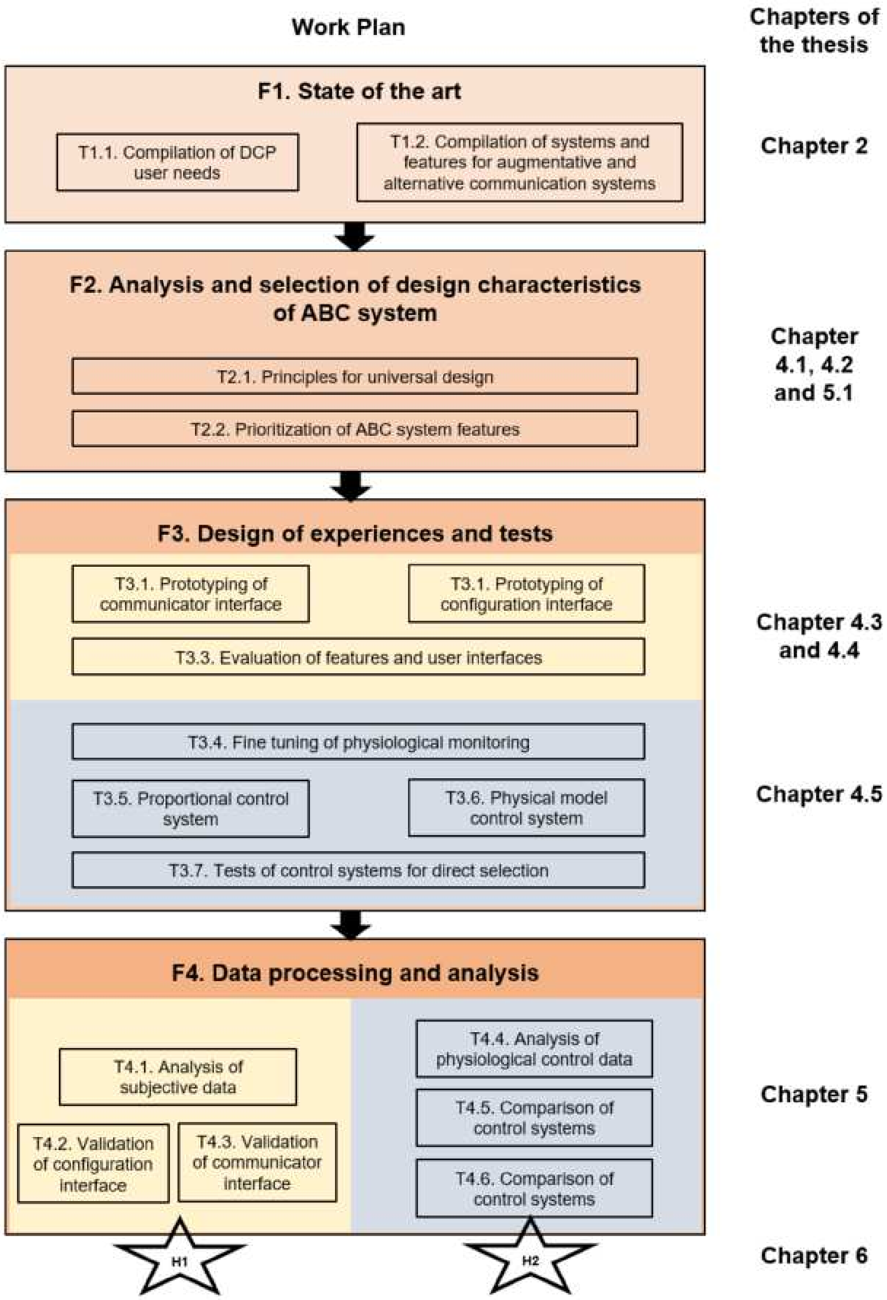


Figure 3.1. Work plan of the thesis (“Hx”: Hypotheses; “Tx.x”: Tasks). Task description is grouped by phases. On the right side, each phase is related to the chapters of this thesis.

Chapter 4
Materials and Methods

In this chapter, the methodology and materials are introduced. These tools were used to accomplish the objectives established in Chapter 3.

Section 4.1 presents the principles used for the design of the solutions presented in this thesis. Section 4.2 presents the methodology followed to prioritize the ABC system features.

Section 4.3 presents the prototypes developed for the configuration interface and the communicator. They were used as the base for the evaluation processes.

Section 4.4 presents the methodology used to test the user interfaces using the developed prototypes.

Finally, section 4.5 presents the methodology used to test our innovative approach of direct control based on EMG.

4.1 Conceptual design of the ABC System.

The conceptual design of the ABC system is based on the principles of Usability, Accessibility and Universal Design (Appert, Beaudouin-Lafon, & Mackay, 2003; Apple Computer Inc., 1992; Beaudouin-Lafon, 2000). This section describes the well-established principles of good Design on which the ABC system will be based.

- Principle 1: Recognize the Diversity
- Principle 2: Use Golden Rules of HCI Design
- Principle 3: Prevent Errors
- Principle 4: Follow the Guidelines for Data Display
- Principle 5: Follow the Guidelines for Data Entry
- Principle 6: Balance Automated and Human Control

More in depth, each principle can be proposed as follow:

Principle 1: diversity of users, tasks, and interaction styles. The main aspects to be considered here are:

- Direct manipulation (in GUI or VR)
- Form fill-in
- Command language
- Natural language

Principle 2: Use Golden Rules of HCI Design:

- Consistency (terms, icons, data / command flow)
- Universal usability (novices, intermittent users, experts)
- Informative feedback
- Dialogs with closure (beginning, end)
- Prevent errors (highlight required actions, selection rather than freestyle typing, automatic completion, well-defined messages)
- Reversal of actions (undo)
- User in control (automated adaptability can cause confusion)
- Reduce short term memory (keep displays simple)

Principle 3: Prevent Errors

- Highlight required actions
- Selection rather than freestyle typing
- Automatic completion
- Well-defined, polite messages

Principle 4: Follow the Guidelines for Data Display Consistency (terms, colors, abbreviations)

- Efficient information assimilation by the user (data outlining, lining up of decimal points, spacing)
- Minimal memory load on the user (no need to remember information from screen to screen)
- Provision of user control of data display (font size, contrast, volume, views)
- Appropriate and not over use of techniques for getting user attention
    - Intensity
    - Marking
    - Size
    - Fonts
    - Blinking
    - Color
    - Audio

Principle 5: Follow the Guidelines for Data Entry

- Consistency (similar style for similar data)
- Minimal input actions (selection rather than freestyle typing) (automatic completion)
- Minimal memory load
- Provision of user control of data entry (e.g., experts may prefer command language)

Principle 6: Balance the Automated and Human Control

- Remember principles
- Draw on experience
- Generalize from observations
- Develop new solutions

The key aspects to be considered during the creation of designs of interactive systems are:

- Access concerns removing the barriers that would otherwise exclude ABC users from using the system at all.

- Usability refers to the quality of the interaction in terms of parameters such as time taken to perform tasks, number of errors made and the time to become a competent user.
- Acceptability refers to fitness for purpose in the context of use. It also covers personal preferences that contribute to users 'taking to' an artefact, or not.
- Engagement concerns designing for great, exciting and riveting experiences.

The aspect of accessibility is meanwhile a very important one in general and crucial when it comes to designing system for all users including elderly and disabled persons.

- Access to physical spaces for people with disabilities has long been an important legal and ethical requirement now becoming increasingly so for information spaces.
- Legislation requires software to be accessible.
- UN and W3C have declarations and guidelines on ensuring that everyone can get access to information that is delivered through software technologies.
- Extraordinary users with an increasingly wide range of computer users and technology designers need to focus on the demands their designs make on people's abilities.
- The sorts of issues that face an ordinary user in an extraordinary environment (such as under stress, time pressures, etc.) are often similar to the issues that are faced by an extraordinary user (e.g. a user with disabilities) in an ordinary environment.

The exclusion of people during the design phase may happen at different levels:

- People may be excluded because they cannot understand complicated instructions or obscure commands so that they cannot form a clear mental model of the system.
- People are excluded if they cannot afford essential technology.
- Making inappropriate assumptions about how people work and organize their lives.
- Equipment is unavailable at an appropriate time and place.

Several approaches exist to enable design systems to overcome barriers of access e.g. 'design for all' or 'universal design'. The universal design is based on the assumption that varying ability is not a special condition of the few but a common characteristic of being human and we change physically and intellectually throughout our lives; if a design works well for people with disabilities, it works better for everyone; at any point in our lives, personal self-esteem, identity, and well-being are deeply affected by our ability to function in our physical surroundings with a sense of comfort, independence and control; and usability and aesthetics are mutually compatible.

The principles of Universal Design are:

- Equitable Use: The design does not disadvantage or stigmatize any group of users.
- Flexibility in Use: The design accommodates a wide range of individual preferences and abilities.
- Simple, Intuitive Use: Use of the design is easy to understand, regardless of the user's experience, knowledge, language skills, or current concentration level.
- Perceptible Information: The design communicates necessary information effectively to the user, regardless of ambient conditions or the user's sensory abilities.
- Tolerance for Error: The design minimizes hazards and the adverse consequences of accidental or unintended actions.
- Low Physical Effort: The design can be used efficiently and comfortably, and with a minimum of fatigue.
- Size and Space for Approach and Use: Appropriate size and space is provided for approach, reach, manipulation, and use, regardless of the user's body size, posture, or mobility.

Usability has always been the central pursuit of human-computer interaction (HCI). The original definition of usability is that systems should be 'easy to use, easy to learn, flexible and engender a good attitude in people'. This definition, whilst still being valid hides many important issues e.g. accessibility, sustainability. The goals of usability are now primarily seen as concerned with efficiency and effectiveness of systems.

A system designed following usability criterias would be efficient in that people will be able to do things quickly, by expending appropriate resources, effective in that it contains the appropriate functions and information content, organized in an appropriate manner, easy to learn how to do things and remember how to do them after a while, safe to operate in the variety of contexts that it will be used and have high utility in that it does the things that people want to get done.

Acceptability is about fitting technologies into people's lives e.g. some railway trains have 'quiet' carriages where it is unacceptable to use a mobile phone, cinemas remind people to turn their phones off before the film starts. An essential difference between usability and acceptability is that acceptability can only be understood in the context of use. Usability can be evaluated in a laboratory (though such evaluations will always be limited), but acceptability cannot.

The key features of Acceptability are on the different levels e.g. do the users trust it? Concerning convenience, does the design fit effortlessly into the situation? Concerning culture, social habits and usefulness, does the design considers usage context? Economically, does the designed system promise successful technology and does it fit into a successful business model?

Engagement is concerned with all the qualities of an experience that really pulls people into a sense of immersion such as one feels reading a good book. The challenge one feels when playing a good game or the fascinating unfolding of a TV drama. Engagement is concerned with all the qualities of the interactive experience that make it memorable, satisfying, enjoyable and rewarding. While usability is concerned with optimizing the interaction between people, activities and engagement occur when the elements are truly harmonized.

4.2 Identification of ABC features.

To identify the most important features that the ABC systems should provide to DCP users, an exhaustive list of ABC features has been constructed. It is based on state of the art elements. An expert group, specialized in people with communication difficulties, integrated by members of the ABC project has identified the "basic" requirements of this list. The objective of this preliminary selection was to reduce their impact over the evaluation of the other parameters.

To prioritize the complementary features of the ABC system, 20 professionals from different fields were recruited to participate in an online survey (see Appendix A). They evaluated the importance of the features not considered as "basics" (they will be mandatory in an ABC system concept). The profiles of the participants are detailed in Table 4.1 .

Table 4.1. Profile of the participants.

Profiles
1 psychologist
2 speech therapists
1 physiotherapist
2 educators
3 care givers
5 medium degree technicians
1 communication technician
4 engineers
1 teacher

4.3 Prototyping of ABC user interfaces.

This section presents the developed prototypes, based on the state of the art ideas, expert opinions and user needs. They were designed as reference tool for the validation and improvement process with end users.

The ABC system interface should provide different functionalities according to user needs (communication, emotion management, health recommendations, etc.) (Figure 4.1). A dedicated configuration interface (essentially for caregivers) should provide the necessary tools to adapt the interface to the specific user needs. However, the configuration interface could also be used by the user with the support of the caregiver using a computer.

The configuration interface will adapt the user interface and communication means to user needs and preferences. The communicator interface will be designed for DCP users; it will propose the communication items and the settings defined with the configuration interface.

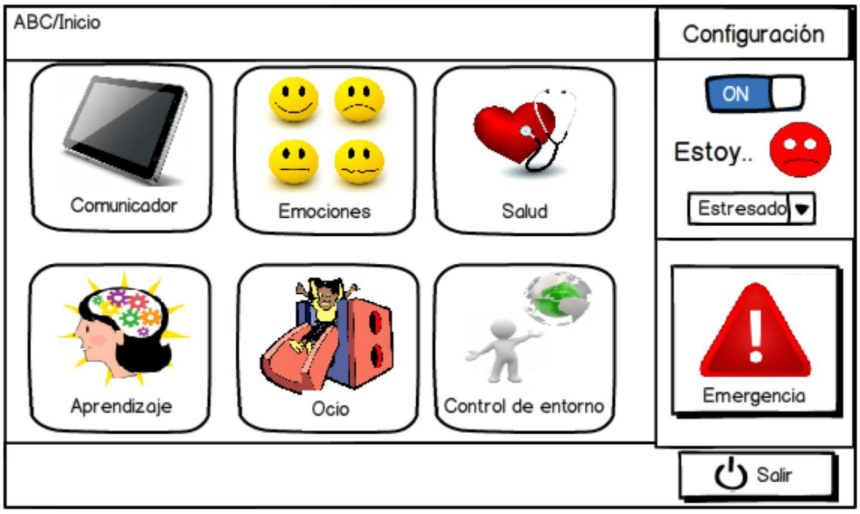


Figure 4.1. Prototype of the main interface of ABC system.

4.3.1 Prototype of configuration interface.

Following the ABC project philosophy, the system will be adaptable to the user profile. In this way, the system will have a configuration screen (in computer environment) where the caregiver will set up the communication interface, manage user profiles and synchronize the communicator device. The system will provide a rule editor allowing the caregiver to individualize the reaction of the system to detect physiological or neuronal states of the user. The editor will have at least three parameters a) the detected physiological or neuronal state b) the time c) the reaction of the system, e.g. a reminder, an SMS to the caregiver or a multimodal presentation.

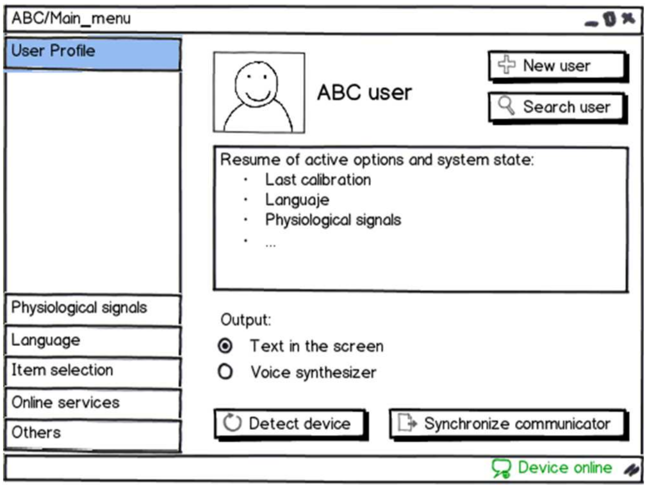


Figure 4.2. Configuration interface. User profile management.

4.3.1.1 Physiological signals.

The system will have a configuration window for the physiological signals. The signals used will be grouped into those for control and those for the affective system.

The control signals are used to select items on the screen according to user limitations: electroencephalography (EEG), electromyography (EMG) or movement sensors (IMUs). A calibration process will adjust the signal levels, references and noise control (i.e. the IMU calibration will set the initial position of the user).

Signals of the affective system (galvanic skin response, hearth rate variability) will be used to evaluate the user's emotional state and it will react according to the rules predefined by the caregiver (i.e. when the user is stressed). A configuration tool of emotional thresholds will be included. Communication of emotions will be an option that can be disabled depending on user preferences. The user will always decide if he/she wants to express his/her emotions.

Only medical staff will manage signals for the health monitor system. These signals will be switched off by default and their use will be password protected. Limits for these physiological parameters will be set in accordance with the user's health.

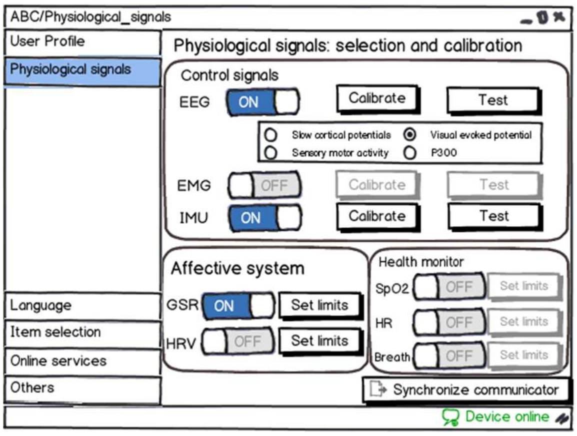


Figure 4.3. Physiological signal management: Control, affective and health signals.

4.3.1.2 Language.

An information window will provide a resume of the active language for the selected user. Available information will include aspects such as the number of active elements, name of item groups, etc. Additionally, the system will include a prediction algorithm to propose items according with their priority, frequency of use or the semantic structure.

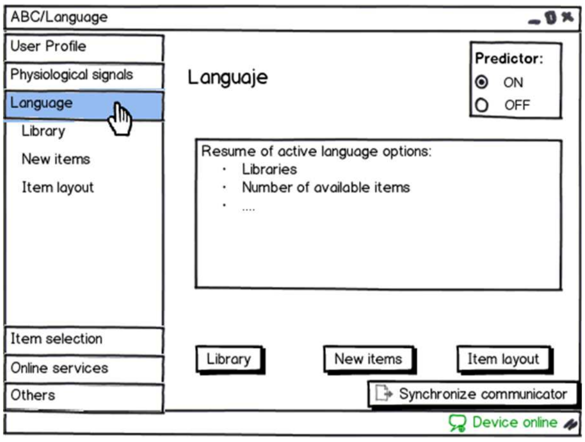


Figure 4.4. Language configuration screen.

4.3.1.3 Library.

Communication items will be managed in the Library options. The configuration program will have predefined libraries (according with the bibliography). The caregiver may create new libraries for the user by importing elements from one or several libraries.

The properties of the items that can be modified are:

- Category: This property will provide a classification for the predictor system. In this way, the communication speed will be optimized.
- Group: This property will be used in the item grids to represent several elements at a time. Thus, searches of elements in large libraries will be optimized. Thus when a critical case is reported (health or emotional alert), the system will provide items related with health or emotions (i.e. doctor, pain, help, sadness, etc.).
- Priority: This property will be useful to be fed into the rule system e.g. if there is a rule indicating that if the affective system detects a user emotional change, then if the number of elements on the screen has to be modified, the system will select the elements using the priority.

To facilitate the item search, filters by group or categories will be provided. Additionally, new groups and categories may be created.

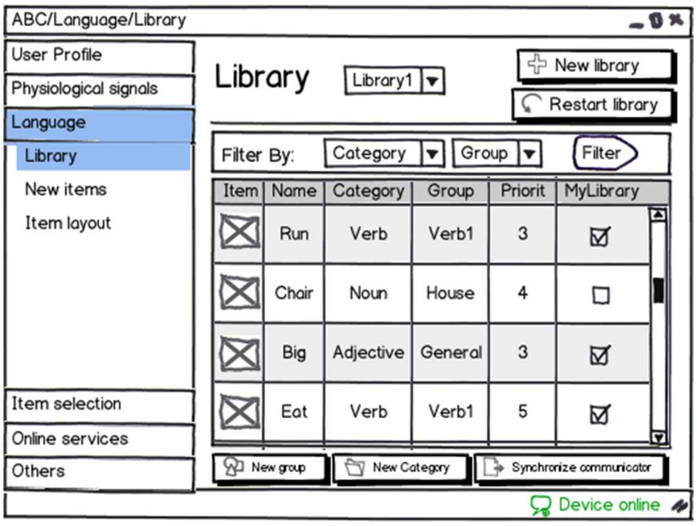


Figure 4.5. Library selection and management.

4.3.1.4 Creating new elements

For the selected library, new items can be included. They can be imported from other libraries or by using a new image. Future changes of the new items will be carried out in the library manager.

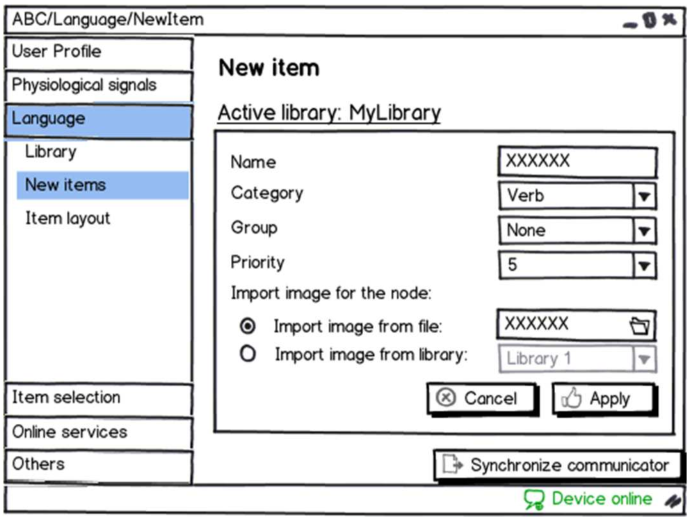


Figure 4.6. Creating new items in a library.

4.3.1.5 Item layout.

Elements on the screen can be organized using grids or scenes. Flexibility in number of items will be configurable by the caregiver. The minimum and maximum number of elements will be set to change the interface according to the predefined rules based on the user profile including the user's affective state or health monitor. Elements in the resized grids will be selected according with their priority (the item priority can be modified in the library manager). For instance, if the health monitor detects an emergency, the grid will show only 2 or 4 elements related to help.

Nodes will structure scenes. Nodes are groups of items and they can include other nodes (child nodes). Nodes will have an image where child nodes or items can be tagged.

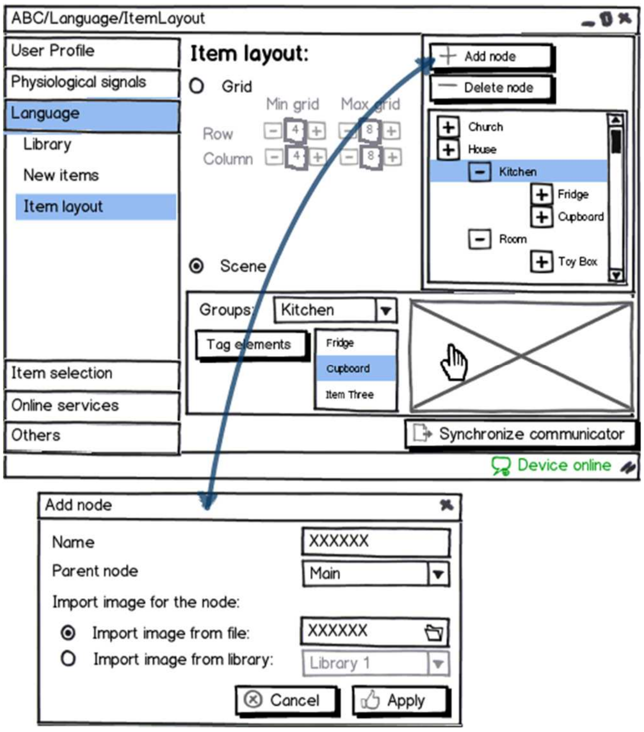


Figure 4.7. Item layout: grid or scene.

4.3.1.6 Item selection.

Item selection can be carried out by scanning or by direct selection.

Scanning selection is to be used with any physiological signal included in the system. Scanning technique, pattern and speed have to be selected depending on user abilities and available signals.

EMG signals can be used as a switch for scanning (activating a muscle) or for direct selection (with the power level of the signal).

IMU signals can be used as switches for scanning (performing a movement with a specified acceleration) or for direct selection (changing the position and orientation of the IMU sensor).

EEG control has special consideration due to the differences between the EEG methodologies. Thus, the EEG approach has to be selected and it can be used as a switch (i.e. using sensory motor activity, switching may be to think about the movement of a hand) or direct selection.

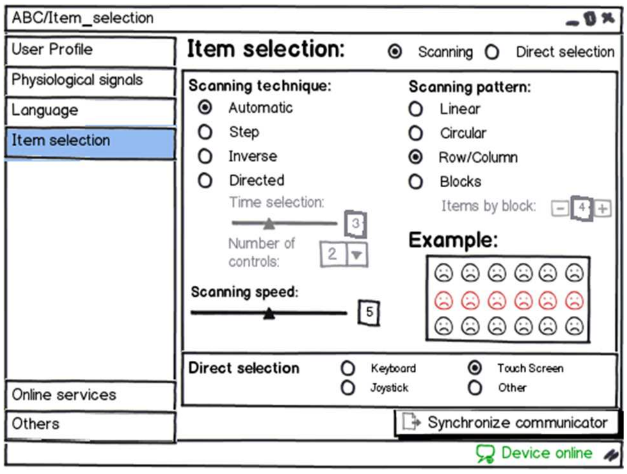


Figure 4.8. Item selection properties.

4.3.1.7 Online services.

The ABC system will provide Internet access and a link with the main social networks to allow posts in user profiles.

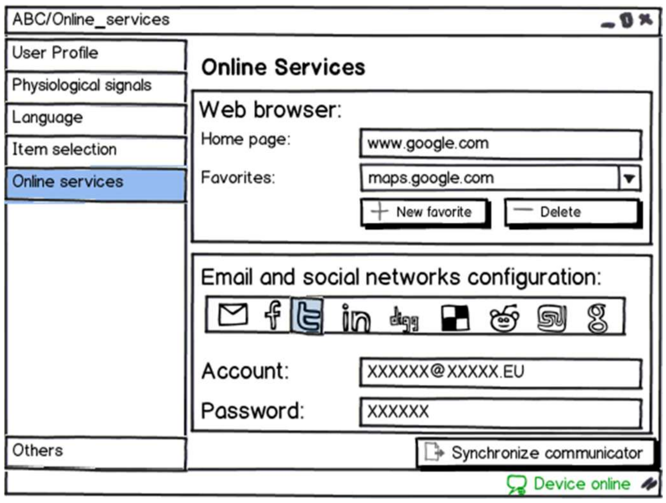


Figure 4.9. Online service configuration.

4.3.1.8 Other services.

Additional functions and services will be included in the configuration interface (music player, video player or sound recorder).

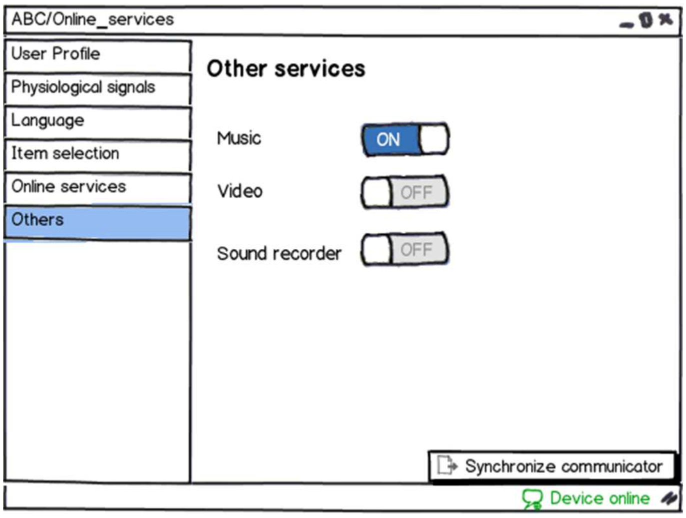


Figure 4.10. Additional services to be included in the communicator.

4.3.2 Prototype of communicator.

Configuration interface will prepare the communicator to be used by the user. The communicator will have an easy calibration tool to be activated when the user detects that the system is not calibrated (i.e. after a long period using the system, if the user is tired, if he could change the EMG levels).

Communication user interface will be adapted depending on predefined rules in the user profile by the caregiver based on parameters such as the emotional and health status of the user. According to these parameters, the number and the types of items may change. The caregiver will assign complexity levels and items for each situation.

The characteristics of the communicator will depend on the number of items to be displayed, the physiological signal used for selection, the selection strategy and the message output mechanism.

The communicator will be configured for a portable device. Figure 4.11 and Figure 4.12 shows the communicator on a portable device where some of elements have been modified according to the emotional state. The output of the system will be presented on the screen. If the output method is voice, an icon will show its activation.

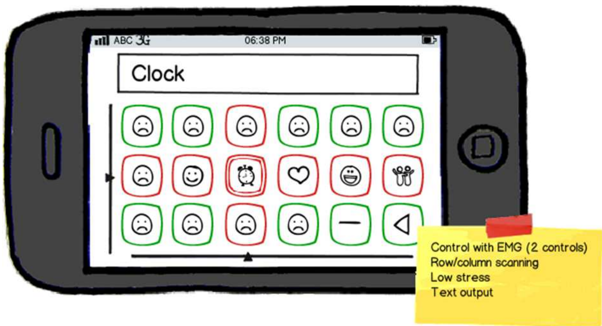


Figure 4.11. Communicator controlled by EMG with low stress.

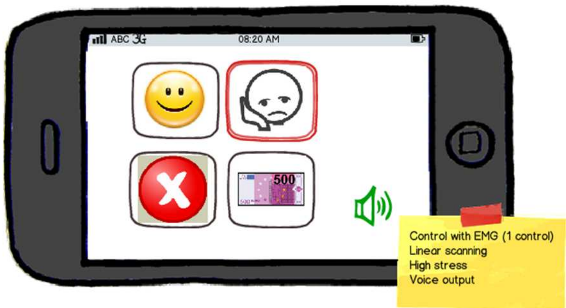


Figure 4.12. Communicator controlled by EMG with high stress.

If the communicator is controlled by IMU using direct selection, a pointer will provide feedback to the user to show the effect of his movements. Figure 4.13 shows the communicator controlled with IMU and text output.

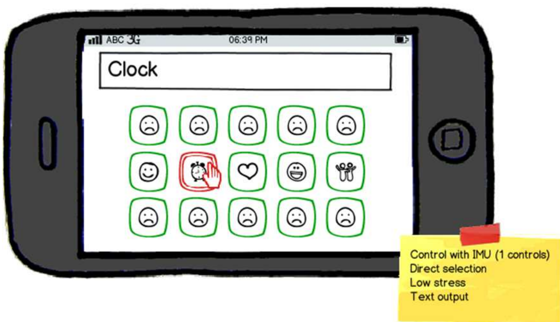


Figure 4.13. Communicator controlled with IMU.

When items are organized in a scene, the communicator will show the nodes and elements over an image. Figure 4.14 shows the communicator with a scene display with

3 elements. The selection technique is the visual evoked potential (VEP) and the element box shows several elements used to generate the VEP.

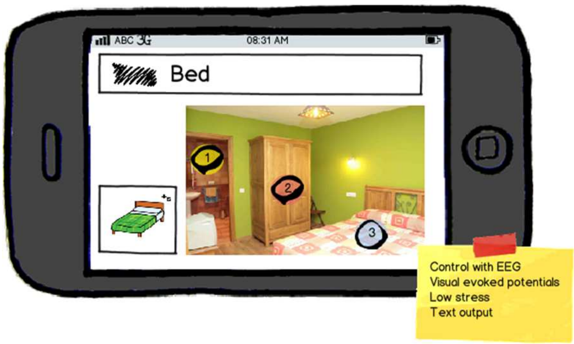


Figure 4.14. Item and group shown in a scene display.

When there is a health problem, few items related with health will be proposed to be transmited the user state (Figure 4.15). An emergency call can be included.

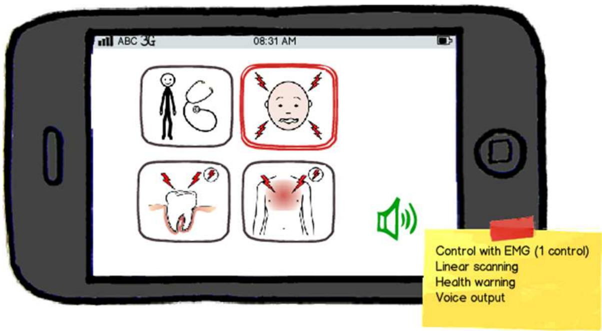


Figure 4.15. Emergency items after a health alert.

When the predictor system is activated, the communicator will present the proposed items using the prediction method (i.e. after subject selection, next items will be verbs). Figure 4.16 shows a proposed prediction after previous selection. Prediction algorithms will include the priority and use frequency of items.

Figure 4.16. Item prediction.

4.4 Analysis and evaluation of ABC user interfaces.

This section is oriented to evaluate the conceptual design of the ABC communicator with professionals and DCP users. It is a key milestone to know the opinions of the experts and users about the conceptual design of the ABC communicator, as well as to detect problems and to be able to identify potential improvements before starting interface development. Two studies have been proposed to achieve these goals:

- Assessment of the **conceptual design of the user interface** with DCP people: this evaluation was undertaken using the storytelling methodology (Quesenbery & Brooks, 2010). In this technique, the narration of a "story" is used to explain those experiences and considerations that involve the use of a product (the communicator).

  A booklet with the main screenshots of the communicator was prepared to allow users to assess the concept and add commentaries with the help of their caregivers (see an example in Appendix B). Before starting the sessions, users with the support of the caregivers use an animated power point, which describes a potential real-life scenario. After that, they evaluated and commented on each screen in the booklet, indicating the positive and negative aspects of each screenshot with the help of green and red stickers (positive and negative points).

  A discussion session with all users was carried out to obtain a general overview. The parameters of the session are described in the Table 4.2.

Table 4.2. Descriptive parameters of the sessions with users.

Technical staff	1 Moderator of the session 1 Observer
Number of sessions	2 sessions
Users profiles	Users with cerebral palsy Users of a communicator
Age	18+
Gender	3 females 7 males
Sessions duration	2 hours approximately

- Assessment of the conceptual design of the **configuration interface** with professionals: this evaluation was done using a semi interactive PDF consisting of several interfaces/screens of the communicator configuration system (The navigability of this PDF is showed in Appendix C). The process is structured in 2 steps: a) a specific task to search for information and/or features on the interface and b) free navigation. The set of professionals is described in Table 4.3.

Table 4.3. Profiles of the participating.

Profiles
1 psychologist
2 speech therapists
1 physiotherapist
1 educator
3 medium degree technicians
1 communication technician

An example of the proposed task is the following: "Imagine that a user is having problems using the predictor (it does not predict correctly what he needs) and he wants to disable it. What function of the configuration system should you select?". After the execution of the task, the professionals were asked about the ease of performing each task to assess the ease of use of the interface.

During free navigation, the different functions were explained and the professionals were asked about their satisfaction level with each interface.

Based on the results of the tests with DCP users and professionals, the validity of the first hypothesis was developped as follows:

Hypothesis 1: “Based on Dyskinetic Cerebral Palsy (DCP) user needs, it is possible to design a satisfactory concept of communication system.”

- Creation of a validated list of basic and essential features for the ABC communication system.
- Quantification of the ease-of-use of the configuration interface as evaluated by professionals.
- Quantification of the satisfaction level with the user interface as evaluated by DCP users.

4.5 Direct selection of elements with physiological control.

DCP people have difficulties manipulating direct selection pointers on a grid of concepts. This is mainly associated with the presence of spasticity.

In this way, a new control method able to reproduce the mechanical response of the muscles was needed. This new method would allow the selection of elements using small electromyographic pulses (EMG) with sensors arranged on a muscle with motor control (based on Stiffness, Inertia and Viscosity). Thus, uncontrolled movements would not significantly influence the intention to select an element on the grid of concepts.

In this section, a new method for direct selection using physiological signals is explored; it will be compared with proportional control to identify its added value and limitations. Within the framework of this thesis, this approach has been tested with EMG signals but it could be used with any other system that is able to produce controlled pulses (movements, sounds levels, etc.).

4.5.1. Physiological control with EMG.

Based on state of the art technology, the ease of instrumentation and calibration and its low level of invasiveness, it was decided to choose the EMG signals to test the directed selection system.

The BioSignalsPlux electromyography sensor has been used to register the signals for physiological control. This sensor has a gain of 1000, an input range of ±1.5 mV and a bandwidth of 25-500 Hz.

Figure 4.17. BioSignalsPlux and EMG sensor.

A priori, the sampling frequency must be at least twice the signal bandwidth, as defined by Nyquist's Theorem (Nyquist, 1928). The EMG signal has a bandwidth of 500 Hz. However, the use of EMG as a control system does not need the raw signal. Thus, the EMG envelope will be able to provide its mean value. Different studies show that 500 Hz is a good sampling frequency to obtain the envelope (Ives & Wigglesworth, 2003; Larivière, Delisle, & Plamondon, 2005), which is the maximum sampling frequency allowed by the equipment used.

The EMG signals provided by the BioSignalsPlux are preprocessed as follow:

- A "notch filter" at 50 Hz and 100 Hz to cancel the possible effect of the noise associated with the first and second order harmonics of the electric network.
- A high pass filter at 0.2 Hz to reject the baseline effect, and a band pass filter between 30 Hz and 500 Hz, which corresponds to the band of interest of the EMG.
- A full-wave rectification with a low-pass filter at 4 Hz to acquire the EMG envelope.

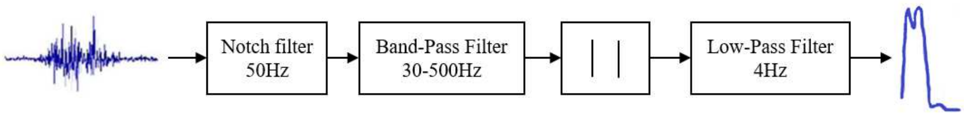


Figure 4.18. EMG preprocessing.

4.5.2. Proportional control.

The EMG signal can be used to control a pointer. The user should maintain the force of a muscle to reach an element on the grid. Two dimensions of the grid can be considered by using two independent muscles and channels of the EMG communication system.

To calibrate the system, a physiological limited input has been proposed, between the minimum (increased by 100 %) and the maximum EMG signal (reduced by 30 %). The threshold during rest was increased to reduce the impact of noise associated with movements. The threshold of the maximum level was reduced due to the difficulty of repeating the maximum value when the user is tired.

4.5.3. Physical model control.

A new control system based on EMG signals has been proposed. It is developed using 4 principles of usability focused on DCP users:

- Improvement in precision of the selection and error rate: the new method should improve performance of the communication system.
- Reduction of the impact of the continuous muscular effort to guarantee item selection and precision: the new control method must avoid a sustained effort to select an element.
- Reduction of muscle fatigue due to continuous muscular effort: the new control method should improve the usage time in comparison with the proportional control method.
- Reduction of dependency between muscular capacity (maximum level of EMG) and the number of elements of the grid: a grid with many concepts should be accessible to people with low muscle capacity.

4.5.3.1. Mechanical model of one degree of freedom

A pointer position in one direction, controlled by a force (EMG in our case), can be modeled as a continuous system with one degree of freedom. Pointer position (Pos) can be calculated with the value of the EMG and the physical model (Dyns) as is shown in Equation 4.1.

$$\text{Pos} = \text{EMG} * \text{DynS}$$

Equation 4.1

The continuous system can be expressed as a function related to Stiffness (*k*), Inertia (*I*) and Viscosity (*t*):

$$\text{DynS} = f(k, I, c)$$

Equation 4.2

Where:

Stiffness/Rigidity (*k)*: the extent to which an object resists deformation in response to an applied force. This can be expressed as the inverse of the system gain G (Equation 4.3).

Inertia (*I)*: Resistance of an object to any change in its state of motion. Where (wn) is the natural frequency and (tr) is the response time of the system.

$$Wn = 2*\pi/tr$$

Viscosity (*c*): Dissipation of energy from a vibrating structure. Where (chi) is the damping factor

$$k = 1 / G$$

Equation 4.3

$$I = k / (wn^\wedge 2)$$

Equation 4.4

$$c = 2*chi*wn*I$$

Equation 4.5

The code (Python) to model the continuous systems is shown in Figure 4.19.

```python
from numpy import *
from scipy.linalg import expm

class dynsyst():
    def __init__(self, I,c,k,ts):
        # Sistema continuo
        A = matrix([[0,0,0],[1/I,-c/I,-k/I],[0,1,0]])
        self._sist = expm(A * ts)
        self.reset()

    def pos(self, emg_val):
        self._internal[0,0] = emg_val
        self._internal = self._sist * self._internal

        return self._internal[2,0]

    def reset(self):
        self._internal = matrix([[0],[0],[0]])
```

Figure 4.19. Python code of physical model.

Different values of the damping factor (chi) were tested to produce a critically damped model of rapid response (Figure 4.20).

chi= 0.8
G = 30
tr = 3

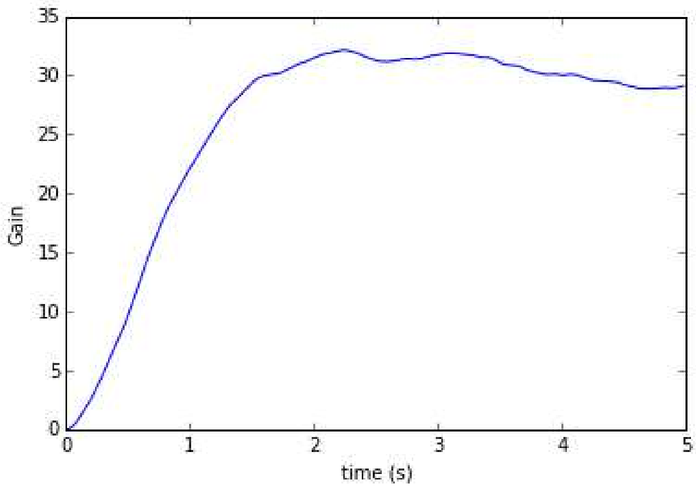


Figure 4.20. Critically damped behavior of the model.

Highest values of chi (Figure 4.21) showed overdamped behavior where the desired gain (G) was not reached within desired time (tr).

chi > 1.2
G = 30
tr = 3

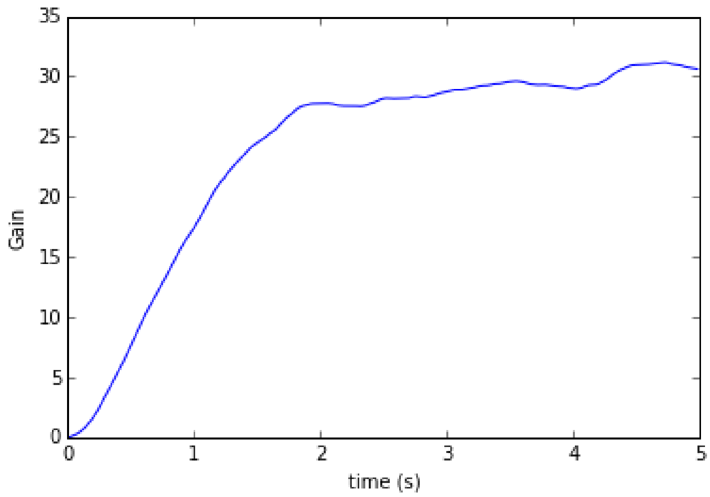


Figure 4.21. Overdamped behavior of the model.

Lowest values of chi (Figure 4.22) showed underdamped behavior where oscillatory response cannot ensure the desired gain (G) in time (tr).

Chi < 0.5
G = 30
tr = 3

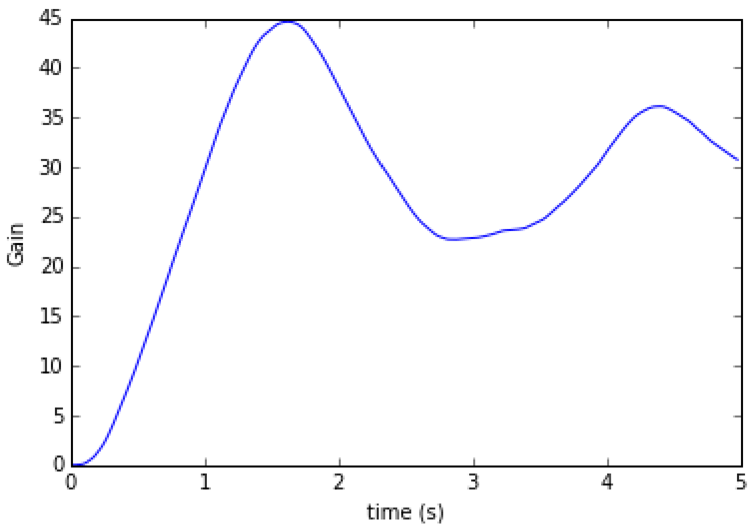


Figure 4.22. Underdamped behavior of the model.

4.5.4. Physical model validation.

The task and the operating environment should guide the selection of the most suitable physiological control system ("input device"). In the specific context of two methods of selection ("proportional control" and "physical model control") a "primitive task" has been configured to evaluate the communication efficiency and effectiveness. This test will consider the maximum number of elements in the grid and the feedback needed to ensure an accurate bit rate in the communication process.

Six healthy subjects participated in the study that consisted of ten tasks (see section 4.5.4.2). The test area was quiet and free from distractions, with optimal temperature and lighting conditions.

The surface electromyography of one muscle of the forearm (flexor carpi radialis muscle) was used as the input device. This muscle acts to flex and (radial) abduct the hand. Thus, the pointing performance in one axis was tested.

Rules governing the ethical conduct of human experimental testing were followed including the protocol of the "Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles" (Hermens & Roessingh Research and Development BV, 1999) for this muscle.

A testing interface was developed to conduct the task according to ISO 9241-9:2000. It was configured to provide user feedback (visual and auditory), to capture and store user actions and their times.

4.5.4.1. Variables and factor definition for the test

The following variables were calculated:

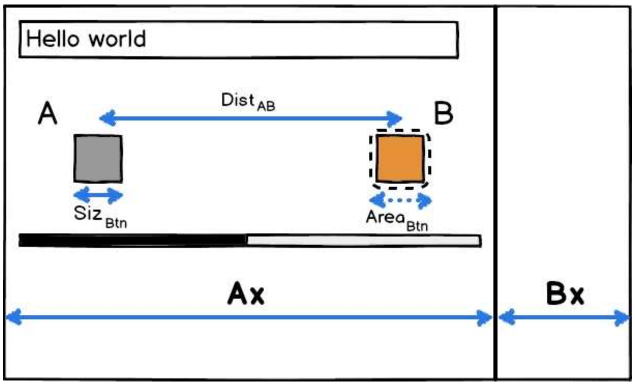


Figure 4.23. The distribution of distances on the screen.

- <u>The size of the button (w):</u>

  The area of the button ($Area_{Btn}$) is the maximal region that can use the button. Inside this area, we can define the size of the buttons (SizeBtn) to prevent direct contact between them (difficulties selecting a specific button between borders).

  $$Area_{Btn} = \frac{0{,}76\,Rx}{Ncol} \qquad SizeBtn\ (w) = Area_{Btn} * 95\ \%$$

  Equation 4.6.

  Where:

  Rx is the resolution in the x axis.
  Ncol is the number of columns of the grid

  The available area (Ax) of the communication grid will be placed on 80 % of the screen:

  $$Area_x\ (Ax) = R_x*0{,}8$$

  Equation 4.7

  Three sizes of buttons (w) were proposed:

  1) Small = grid of 20 columns
  2) Medium = grid of 14 columns
  3) Large (Big) = grid of 8 columns

- Distance (d):

The distance ($Dist_{AB}$) is the distance of movement between targets described as follow:

$$Dist_{AB}=Area_{Btn} * BtnY$$

$$Dist_{AB}=\frac{0{,}76\,Rx}{Ncol} * (BtnY)$$

Equation 4.8

Where:

BtnY is the column of the target.

Thus, three different distances were proposed:

1) Close = maximum number of columns/5
2) Halfway = maximum number of columns/2 and
3) Far = maximum number of columns-2.

- Index of difficulty (ID):

The index of difficulty is the measure, in bits, of the user precision required for each task. For selection, pointing or dragging tasks the index is described as follows:

$$ID = \log_2 \frac{d + w}{w}$$

Equation 4.9

- Time of movement (t_m):

Time needed to reach an element.

- Selection:

Direction of the movement to reach the next target: Right-Left or Left-Right.

- Control:

Two categories of control: Proportional control (filter) or physical model (model).

- Transmission speed (Vtx):

Measurement of the amount of information transferred, with respect to time.

$$Vtx = ID/t_m$$

Equation 4.10

4.5.4.2. Procedure.

The study consisted of ten tasks; five tasks with a unidirectional selection option with ElectroMyoGraphy (EMG) and proportional control (filter) and five tasks with physical model control (model).

The subjects were informed about the objectives of the project and the task that they should carry out. An informed consent form was signed by the participants (Appendix D).

The main difference between the two possible controls was the type of contraction of the flexor carpi radialis muscle needed to reach a button.

With the proportional control, the subjects were instructed to perform a continuous contraction by flexing the wrist (activating the EMG signal) to reach the buttons, combined with relaxations periods between elements. With the physical-model control, the contractions were discontinuous, simulating the hand grip (with a foam ball as is shown in Figure 4.24) several times on the way to reach every button.

Figure 4.24. Testing conditions.

After they were instructed about the testing procedure, they had time to practice it to be familiar with the exercise, the input device and visual feedback and to know the limits of their muscle contraction.

According to ISO 9241-9:2000, the task consists of pointing and selecting each button 25 times, in our study the subjects did this 48 times (to increase the influence of the fatigue), and the users also had to keep the pointer over the button for two seconds. The level bar and the buttons changing their color provide visual feedback to the user about the EMG. Each cycle started when the subject selected the button the first time. Users had a brief break between the cycles.

The subjects were set out with two surface electrodes, as we can see in the Figure 4.25, in the dominant forearm, for gathering the EMG signals of the flexor carpi radialis. These electrodes were connected to channel one of the BioSignalsPlux. The skin was prepared and the location of the electrodes were placed following the recommendations of the "Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles". The ground electrode was placed on the dorsal area of the wrist as a reference, and was connected to the channel G of the BioSignalsPlux. The BioSignalsPlux was connected at the same time to the laptop by Bluetooth.

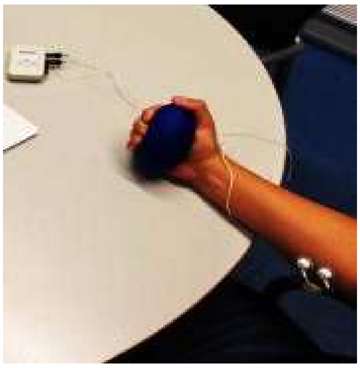


Figure 4.25. Position of the electrodes on the forearm.

The resolution of the screen was 1280 * 800 pixels. Figure 4.26 shows an example of a task.

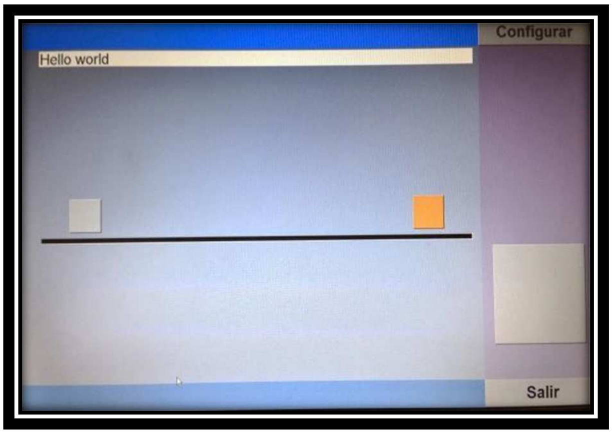


Figure 4.26. Test screen with an example of a task.

Due to the large number of combinations needed for the complete experimental design (2 factors with 3 levels and 1 with 2 levels) and with the aim of reducing experimental time, a reduced experiment design was performed. For this, a distribution of the factors among all the users was undertaken by means of an optimal division by blocks, following the algorithm of Goos and Vandebroek (Goos & Vandebroek, 2001). This ensured a balance of sampling between the different combinations of factors:

- Distance to the button: close, halfway and far.
- Size of the button: small, medium and large (big).
- Control system: filter and model.

Appendix E shows the final distribution of the factors between the users.

4.5.4.3 Data analysis.

This section is oriented to describing the analysis conducted to test the second hypothesis of the thesis.

A study of statistical inference was conducted to compare two physiological control methods and the influence of the size of the button and the distances between them.

A cause-effect model was defined for each of the variables (effects) with the following factors (causes):

- Control system used to select a button (control): proportional control (filter) and physical model control (model).
- Size of the button (SizeBtn): small, medium, large (big).
- Distance to reach a button (DistBtn): close, halfway, far.

A mixed-design analysis of variance (split-plot ANOVA) was used to test the differences between the factors under a repeated measures design:

$$Variable \sim Control + SizeBtn + DistBtn + Control{:}SizeBtn + Control{:}DistBtn + SizeBtn{:}DistBtn + Control{:}SizeBtn{:}DistBtn + (1|Usuario)$$

Equation 4.11

A Post-hoc analysis was carried out for the factors with more than 2 levels (size and distance of the buttons). In all the analyses described in this section, significant differences or relationships are considered if the "p" value is less than 0.05. These statistical analyses were carried out with the statistical software R v2.6 and the Post-hoc interactions were undertaken with the library phia (De Rosario-Martinez, 2013).

Based on the results of the inference study, the validity of the second hypothesis was analyzed as follows:

Hypothesis 2: “Our innovative approach of physiological control, based on a physical model, allows better communication performance than proportional control. This is applicable on direct selection systems over a grid of concepts”

- The independent factors with a significant influence over each variable were analyzed.

- The variation of the performance between the two control systems was compared.
- For each type of control, the influence of the button size and distance was analyzed.
- The influence of the size of the concept board (maximum distance between buttons) and the size of the buttons was analyzed.

Chapter 5
Results

The results are presented in two sections. Section 5.1 presents the results of the conceptual design of the ABC system. It starts with the initial identification of system features and finishes with the results of the user tests evaluating the proposed prototypes.

Section 5.2 presents the results of the test and the comparison between the two control systems for direct selection. These results are structured according to the analysis of the activation times and the transmission speed, both with the influence of the Size and Distance between buttons.

5.1 Conceptual design of ABC system.

5.1.1 Results of the prioritization of ABC functions.

This section presents the results of the surveys involving professionals examining the functions provided by the communication system in each module (communication, learning, affective, health, software configuration, hardware, other functions). “Basic” functions of each module have been identified and integrated into the ABC concept (Table 5.1).

Table 5.1. Basic system features.

ABC Modules	Basic features
Communication	• Allow to talk
Learning	• Improve his communication • Feedback to make easier the learning process • Levels of learning (basic, medium, advanced) • Allow different complexity levels to access the communication tools
Affective	• Identify the mood and the feelings of the user and help him/her to express them • Allow the user to decide when and how communicate his/her mood • Make easier to create new relationships beyond his family • Improve his social image and autonomy • Not modifying the natural behavior of the user
Health	• Limit the access to private data • Combine physical, mental and social health • Measure just the essential data as to not stress the user • Send alarms to medical staff and relatives without disturbing users
Software configuration	• Emotional detection • Different input interfaces (including mouse, keyboard and physiological signals) • Usability: Easy to use and learn • Intuitive navigation • Interface customization: Avatar, language, interaction way, etc. • Configuration: Easy to use and possible to change by the user • Predictive scanning • Protection against loss of information
Hardware	• Adapted to gender and age • The communicator should have recognition, access and control personalized system depending on the user (facial, look, touch, scan, head switch, head movement...) • Volume adjusting • Functional design • Like a tablet

	• Simple operation, clear instructions • Water and sun resistant • Regulation of brightness depending on the light • Customizable
Other functionalities	• Modern, aesthetic, colorful, funny • Not to evidence that it is a support product • Several color cases • Thin, lightweight, compact (fit in a backpack) • Strong and resistant • Inconspicuous • Ergonomic • Modular

The tables:

Table 5.2, Table 5.3, Table 5.4, Table 5.5,

Table 5.6, Table 5.7 and Table 5.8 show the results of the surveys. To prioritize the functions, a reduced number of elements were selected. Prioritization was done following two rules:

- The element noted as more “Essential” (dark green in the tables).
- The most significant elements through the sum of essential and very important (light green in the tables).

Table 5.2. Results of the questionnaires for the communication module.

Valore la importancia de las siguientes prestaciones para el **módulo de COMUNICACION.** Por favor, NO VALORE COMO IMPRESCINDIBLE MÁS DE 5 PRESTACIONES.

	Imprescindible	**Muy importante**	**Importante**	**Poco importante**	**Nada importante**	**Total**	**Priorizacion**
Disponibilidad de frases predeterminadas para conversación de arranque, saludos, temas, aficiones, necesidades básicas, etc.	7	9	5	1	0	22	16

	Imprescindible	Muy importante	Importante	Poco importante	Nada importante	Total	Priorizacion
Ayuda para la construcción de frases complejas a través de predictores, correctores gramaticales, diccionarios…	5	8	7	2	0	22	13
Combinación de texto y pictogramas.	7	9	4	2	0	22	16
Autocorrección en los mensajes pictográficos, no sólo en los mensajes de texto.	3	8	7	4	0	22	11
Disponibilidad de librerías de voculario extenso, símbolos, etc.	8	8	5	1	0	22	16
Sistema inteligente de reconocimiento de términos. El sistema, además de corregir, aprende nuevos términos, basándose en el uso frecuente del usuario.	7	10	4	1	0	22	17
Detección inteligente de mensajes contradictorios. A veces, el usuario no comunica lo que realmente ocurre.	6	7	5	4	0	22	13
Posibilidad de tener diferentes idiomas/lenguajes. Traductor.	2	8	3	9	0	22	10
Traducir la información a otros modos (escrito-oral-pictograma).	6	11	5	0	0	22	17
Detectar la complejidad de un texto y simplificarlo para leerlo.	1	9	7	5	0	22	10

	Imprescindible	Muy importante	Importante	Poco importante	Nada importante	Total	Priorizacion
La síntesis de voz para pictogramas (el pictograma se podría traducir en alfabetización).	14	4	3	1	0	22	18
No sintetizar la voz como una máquina, que sea natural.	6	9	7	0	0	22	15
Internet adaptado al usuario (por ejemplo, con pictogramas).	7	9	4	2	0	22	16
Comunicación a través de las redes sociales.	1	11	10	0	0	22	12
Comunicación con otros usuarios ABC.	2	10	7	3	0	22	12
Organización del comunicador por temas de conversación.	4	11	6	1	0	22	15

Table 5.3. Results of the questionnaires for the learning module.

Valore la importancia de las siguientes prestaciones para el **módulo de APRENDIZAJE**. Por favor, NO VALORE COMO IMPRESCINDIBLE MÁS DE 3 PRESTACIONES.

	Imprescindible	Muy importante	Importante	Poco importante	Nada importante	Total	Priorizacion
Tutoriales para ampliar el vocabulario (diccionario, sinónimos y antónimos...).	8	5	7	1	0	21	13
Tutoriales para favorecer el aprendizaje de la comunicación (corrección ortográfica y gramatical).	7	7	6	1	0	21	14
Tutoriales para aprender a navegar por Internet de forma autónoma.	6	8	5	2	0	21	15

	Imprescindible	Muy importante	Importante	Poco importante	Nada importante	Total	Priorizacion
Tutoriales explicativos de las funciones y programas del comunicador.	5	11	4	1	0	21	16
Conocimientos sobre cultura general (por ejemplo, a través de libros, enciclopedia, etc.)	1	5	10	4	1	21	6
Refuerzo positivo. Feedback con colores y música.	7	4	6	4	0	21	11

Table 5.4. Results of the questionnaires for the emotions module.

Valore la importancia de las siguientes prestaciones para el módulo de EMOCIONES. Por favor, NO VALORE COMO IMPRESCINDIBLE MÁS DE 5 PRESTACIONES.

	Imprescindible	Muy importante	Importante	Poco impor tante	Nada importa nte	To tal	Prioriz acion
Aviso al usuario sobre el cambio del estado emocional detectado por el cambio en las señales fisiológicas.	9	8	4	0	0	21	17
Aviso al cuidador y/o padres sobre el cambio del estado emocional detectado por el cambio en las señales fisiológicas.	7	10	4	0	0	21	17
Sugerir al usuario y/o cuidador y/o padres diferentes procedimientos de mejora del estado emocional cuando se detecte un cambio.	5	12	4	0	0	21	17
Permitir la posibilidad de crear reglas de mejora del estado de ánimo (ejemplo, si el usuario está contento y son entre las 3 y las 6 de la tarde, sugerirle la posibilidad de chatear).	1	11	7	2	0	21	12

	Imprescindible	Muy importante	Importante	Poco impor tante	Nada importa nte	To tal		Prioriz acion
Utilización de imágenes como mecanismo de mejora del estado de ánimo.	1	8	11	1	0	21		9
Utilización de música personalizada como mecanismo de mejora del estado de ánimo.	2	7	12	0	0	21		9
Utilización de código de colores como mecanismo de mejora del estado de ánimo.	1	4	11	5	0	21		5
Utilización de lectura agradable como mecanismo de mejora del estado de ánimo.	0	6	13	2	0	21		6
Personalización del software en función del estado de ánimo (por ejemplo, si el usuario está nervioso la interfaz se simplifica, se muestran menos símbolos).	11	6	3	1	0	21		17
Permitir expresar sentimientos y emociones mediante frases ya hechas.	9	11	0	1	0	21		20
Permitir expresar sentimientos y emociones mediante conceptos emocionales.	8	10	3	0	0	21		18
Permitir expresar sentimientos y emociones mediante voz natural (modulada con emociones).	9	10	1	1	0	21		19

Table 5.5. Results of the questionnaires for the health module.

Valore la importancia de las siguientes prestaciones para el módulo de SALUD. Por favor, NO VALORE COMO IMPRESCINDIBLE MÁS DE 3 PRESTACIONES.

	Imprescindible	Muy importante	Importante	Poco importante	Nada importante	Total		Priorizacion
Aviso al usuario sobre el cambio del estado de salud detectado por el cambio en las señales fisiológicas.	4	14	3	0	0	21		18

	Imprescindible	Muy importante	Importante	Poco importante	Nada importante	Total	Priorizacion
Aviso a los cuidadores y/o padres sobre el cambio del estado de salud detectado por el cambio en las señales fisiológicas.	9	12	0	0	0	21	21
Comunicarse con el personal de salud en caso de emergencia.	18	3	0	0	0	21	21
Sugerir al usuario y/o cuidador y/o padres diferentes procedimientos de mejora del estado de salud cuando se detecte un cambio.	4	9	7	1	0	21	13
Proporcionar consejos preventivos para mejorar el estado de salud.	1	7	12	1	0	21	8
Posibilidad de descarga del historial de salud.	3	6	9	3	0	21	9
Proporcionar información visual continua de algunos parámetros fisiológicos importantes para el usuario (por ejemplo, con una barra de herramientas de la salud).	2	7	8	4	0	21	9
Proporcionar información del valor de parámetros fisiológicos registrados anteriormente.	2	7	8	4	0	21	9
Juegos para el seguimiento y para la detección de estado de salud.	3	4	11	3	0	21	7

Table 5.6. Results of the questionnaires for the software characteristics.

Valore la importancia de las siguientes prestaciones para el configurador del software. Por favor, NO VALORE COMO IMPRESCINDIBLE MÁS DE 5 PRESTACIONES.

	Imprescindible	Muy importante	Importante	Poco importante	Nada importante	Total	Priorizacion
Permitir diferentes niveles de uso (básico, medio, avanzado) dependiendo de las características físicas y cognitivas del usuario.	17	4	0	0	0	21	21
Personalización total del comunicador en función del usuario.	21	0	0	0	0	21	21
Posibilidad de que el usuario pueda configurar su comunicador.	4	14	3	0	0	21	18
Botón de acceso directo al módulo de comunicación.	8	11	2	0	0	21	19
Botón de acceso directo al módulo de salud.	5	14	2	0	0	21	19
Botón de acceso directo al módulo de emociones.	7	11	3	0	0	21	18
Uso de colores y sonidos.	2	6	12	1	0	21	8
Posibilidad de disponer de pantalla táctil.	9	8	4	0	0	21	17
Necesidad de feedback contínuo.	5	11	4	1	0	21	16

	Imprescindible	Muy importante	Importante	Poco importante	Nada importante	Total	Priorizacion
Que el comunicador le de feedback en forma de conversación.	4	11	4	2	0	21	15

Table 5.7. Results of the questionnaires for the hardware characteristics.

Valore la importancia de las siguientes prestaciones para el configurador del hardware. Por favor, NO VALORE COMO IMPRESCINDIBLE MÁS DE 5 PRESTACIONES.

	Imprescindible	Muy importante	Importante	Poco importante	Nada importante	Total	Priorizacion
Sensores inalámbricos.	6	13	2	0	0	21	19
Sensores ocultos: sensores en el gorro, gafas, reloj, cinturón…	6	8	5	2	0	21	14
Sensores prefijados, sin necesidad de colocarlos.	3	12	6	0	0	21	15
Sensores colocados en la silla de ruedas.	2	12	7	0	0	21	14
Posibilidad de encendido / apagado de los sensores por los propios usuarios.	8	9	4	0	0	21	17
Detección y calibración automática.	12	7	2	0	0	21	19
Integración de teclado.	2	18	1	0	0	21	20
Integración de pulsador.	6	14	1	0	0	21	20
Comunicador portátil, similar a un tablet.	10	10	1	0	0	21	20
Comunicador incorporado en la silla de ruedas.	7	11	3	0	0	21	18

	Imprescindible	Muy importante	Importante	Poco importante	Nada importante	Total	Priorizacion
Comunicador que se pueda utilizar en diferentes ámbitos, en la playa, en el colegio, en el parque, no solo en casa.	15	4	2	0	0	21	19
Incluir características de teléfono móvil: GPS, SMS, móvil, etc.	2	15	4	0	0	21	17
Diseño personalizado adapatado al sexo y edad (por ejemplo, para niños que sea como un juguete)	3	12	4	2	0	21	15
Posibilidad de recargar inalámbricamente la batería.	1	13	7	0	0	21	14
Posibilidad de recargar la batería mediante energía solar).	0	12	7	2	0	21	12

Table 5.8. Results of the questionnaires for the other functionalities.

Valore la importancia de las siguientes prestaciones. Por favor, NO VALORE COMO IMPRESCINDIBLE MÁS DE 3 PRESTACIONES.

	Imprescindible	Muy importante	Importante	Poco importante	Nada importante	Total	Priorizacion
Gestión de la domótica del hogar.	14	6	1	0	0	21	20
Control del movimiento de la silla de ruedas.	14	4	2	1	0	21	18
Reproducción de música.	6	9	6	0	0	21	15
Visualización de películas.	3	12	6	0	0	21	15
Lectura de libros.	0	14	6	0	1	21	14
Narración automática de	4	13	4	0	0	21	17

libros (mediante la voz del comunicador).							
Juegos offline y online.	2	15	3	1	0	21	17
Compartir imágenes.	1	15	5	0	0	21	16

Table 5.9 shows a recompilation of the prioritized features of each module as made by the professionals.

Table 5.9. Prioritized features with professionals.

ABC Modules	Prioritized features
Communication	• Pictogram voice synthesizer • Intelligent system for recognizing the terms. Based on frequent use, the system corrects and learns new terms. • Translator (written-oral-pictogram)
Learning	• Tutorials for learning new vocabulary (dictionary, synonymous, antonyms...) • Tutorials of communicator functions and programs
Affective	• Software customization depending on emotions • To allow expressing feelings and emotions through natural voice • To allow expressing feelings and emotions through premade sentences
Health	• Possibility of communicating with the professionals in case of an emergency. • Notify care givers and parents of changes in the state of health as detected by changing of physiological signals • Notify the user of changes in the state of health.
Software configuration	• Total communicator customizing depending on the user • Allow different levels of use (basic, medium, advanced) depending on the physical and cognitive characteristics of the user and the experience (previous use on similar devices, tablets...) • Allow the user to configure the communicator • Direct buttons (communication module, health module, affective system module)
Hardware	• Communicator able to be used in different environments • Automatic detection and calibration • Keyboard integration • Push-button integration • Wireless sensors
Other functionalities	• Home control management

	• Wheelchair movement control

The professionals also provided a set of recommendations that were not assessed in the survey:

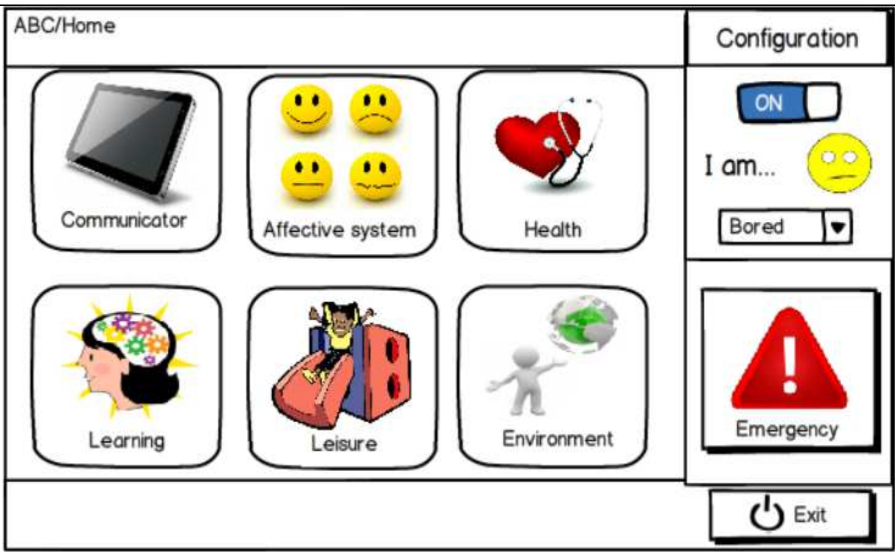
- Detect context and adapt the vocabulary to the context. For example, if the user is at school because he has a radio workshop, the communicator should identify the context and adapt the vocabulary, prioritizing the relevant issues.
- Combine text messages with pictograms to transmit them in a standardized way.
- Screen organization depending on communication needs: a) I Need information, b) I give you information, and c) I have another need.
- Reduce childish reinforcement.

5.1.2 Assessment of the user interface by DCP users.

The main problems and recommendations of each screenshot provided by DCP users are described in the next tables. The information has been classified into 4 groups: a) general features and main interface, b) communication module, c) health module and d) affective module. The number in parentheses represents the number of users that agree with that comment.

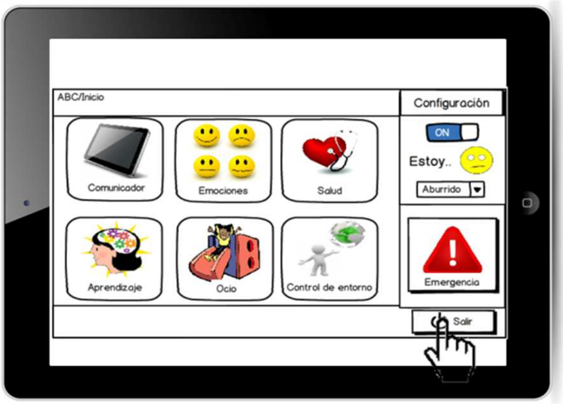
5.1.2.1 General features and main interface.

Switching on the communicator and main screen



Problems found	**Improvement recommendations**
• Users cannot switch on the communicator by themselves • No problems with the main screen	• Switching it on autonomously (4) or using a push button (2) • Adding the possibility of introducing a phone option in the communicator (4)

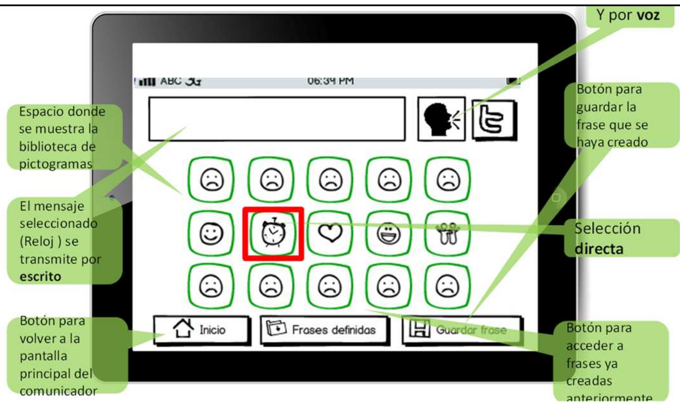
Shortcuts	
	
Problems found	**Improvement recommendations**
▪ The emergency button should not appear in all the screens because you can push it unintentionally. It should appear just in the home screen ▪ The usefulness of the emergency button is not well understood (2)	▪ Remove the Emergency button in all the screens (2) ▪ Ask for confirmation when pushing the emergency button

Switching off the communicator	
	
Problems found	**Improvement recommendations**
▪ All the users who said about the exit button prefer it only in the home screen	▪ The turned off of the device should be guide by the look

Turning off the communicator: Confirmation message	
	
Problems found	**Improvement recommendations**
▪ Users cannot understand the information because don't know how to read	• Allow transmitting the information verbally

5.1.2.2 Communication module.

Pictograms Grid



Problems found	Improvement recommendations
• Grill too big, 3x4 preferred • Buttons missing: ▪ Return to the previous screen ▪ Return to the main grid	• Add an erasing text button (3) • Allow the system to transmit the message by words. Thus, the user can correct it is wrong. • Allow the system the capacity of ranking the pictograms in order of use

Reduction of the number of elements

Problems found	Improvement recommendations
▪ A user does not think that the reduction would decrease the stress of the user, even so, he likes the idea	▪ Add some relaxing tasks to calm the user quickly (“music”, “book”, etc.) (2) ▪ Use pictogram reduction also for health problems

Sharing information on social networks

Problems found	Improvement recommendations
▪ Users need help for accessing the social networks ▪ Users prefer Facebook rather than Twitter (3) ▪ Users cannot understand the information written	▪ In the text box should appear the pictogram instead of the text.

Communication based on “real” scenes

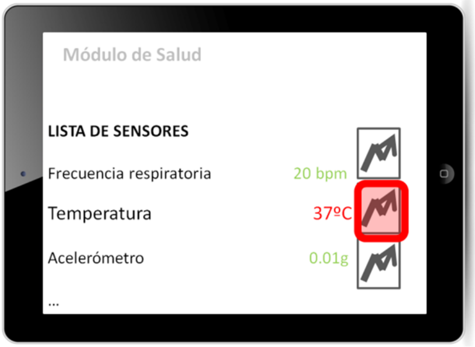
Problems found	Improvement recommendations
• Users cannot understand the information written	• Add the option of telling it verbally

<table>
<tr><th colspan="2">Predictive selection system</th></tr>
<tr><td colspan="2">
</td></tr>
<tr><th>Problems found</th><th>Improvement recommendations</th></tr>
<tr><td>The degree of its utility is inversely proportional to the hurry he has
Users cannot understand the information written</td><td>In the text box should appear the pictogram selected instead of the text.
Add option of activate/deactivate the predictive selection system</td></tr>
</table>

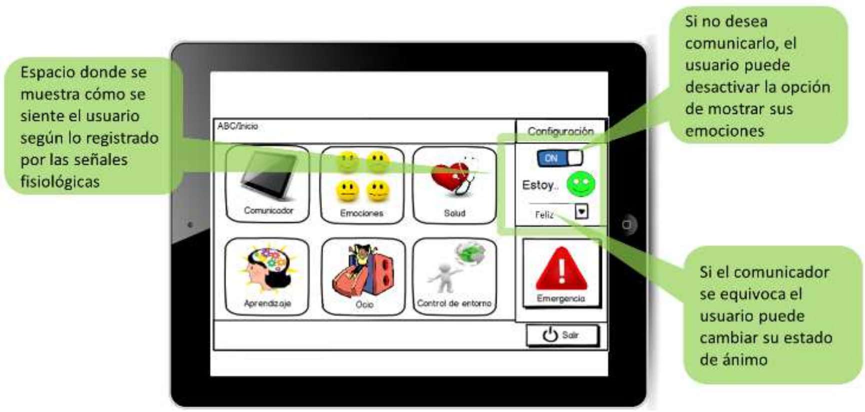
5.1.2.3 Health module.

<table>
<tr><th colspan="2">Health warning</th></tr>
<tr><td colspan="2">
</td></tr>
<tr><th>Problems found</th><th>Improvement recommendations</th></tr>
<tr><td>No problems found</td><td>Add a pictogram representing:
Decreasing of blood pressure</td></tr>
</table>

	o Back pain (2) o Knee pain

User reports	
	
Problems found	**Improvement recommendations**
▪ The understanding of the plots is difficult (3) ▪ One of the user does not think this information is relevant	▪ Show the information in a visual way. ▪ Include: o Blood Pressure o Oxygen saturation

5.1.2.4 Affective system module.

Home screen	
	
Problems found	**Improvement recommendations**

▪ Show feelings, something intimate, in the home screen (3)	• Show the emotional state in the affective system module, as a private option (2)

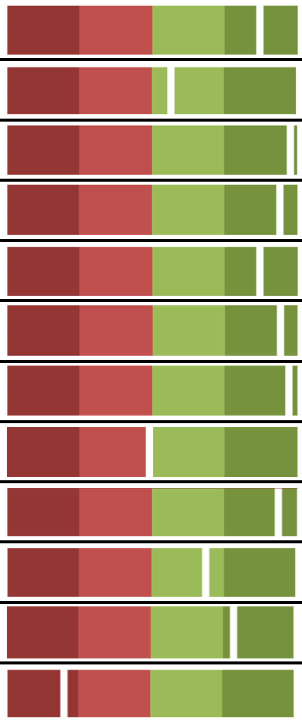
Different ways of communication of emotions: basic smileys, facial expressions and colors	
	
Problems found	**Improvement recommendations**
▪ The feeling menu is written and some users cannot read it. ▪ One of the users thinks that the facial expression is over information ▪ Some of the users do not understand well the meaning of each expression (3) ▪ It is difficult because there are too much concepts and color range (3)	• Faces and colors customizing option, because some users do not associate well the faces (3) • One of the users prefers to identify the tone of the voice with the feeling expressed • Reduce the color range (2)

5.1.2.5 Satisfaction level with the different functionalities.

Table 5.10 shows the qualitative results of the satisfaction for each function, quantified with the stickers used by the participants.

Table 5.10. Overall evaluation of functionalities with DCP users.

		Qualitative evaluation	Green stickers	Red stickers	No stickers
Basic functions	Switching on the communicator		1	9	0
	Main screen		9	1	0
	Shortcuts		8	2	0
	Switching off the communicator		8	2	0

	Switching off: Confirmation message		8	2	0
Communication	Pictogram grid		6	4	0
	Reduction of the number of elements		10	0	0
	Sharing information on social networks		9	1	0
	Communication based on "real" scenes		8	2	0
	Predictive selection system		9	1	0
Health	Health warning		10	0	0
	User reports		5	5	0
Emotions	Emotions: home screen		8	2	0
	Communication of emotions: basic smileys		5	2	3
	Communication of emotions: facial expressions		7	2	1
	Communication of emotions: colors		2	7	1

5.1.3 Assessment of the configuration interface.

This section provides the results of the test with professionals of the configuration interface. Firstly, the ease of use to access/interact with each module/feature is provided. Secondly, the satisfaction of the professional with each screenshot is also provided.

5.1.3.1 Ease of use and performance of the configuration interface.

The Table 5.11 shows the results of the ease of use (feature assessment) and the level of accomplishment of each task (task performance). The last column shows the selected screen when the professional has not finished the task.

Table 5.11. Results of the ease of use of the configuration interface.

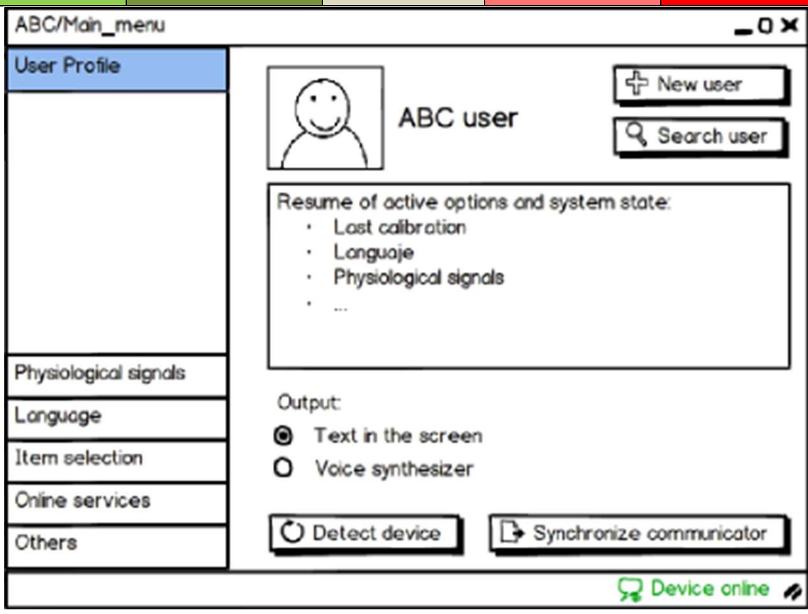
Screen	Function	Feature assessment					Task performance	
		Very easy	*Easy*	*Medium*	*Hard*	*Very hard*	*Yes*	*No*
User profile	Add a new user	8	1				9	0
	Activate voice synthesizer	4	4	1			8	1(Configure board)
Physiological signals	Tune up control signals	4	3	1			8	0
	Configure affective system signals	6	2				8	0
Language	Deactivate the predictor	3	3	1			7	0
Library	Make a filter to locate a pictogram		5				8	1(New pictogram)
New pictogram	Assign the priority to a new pictogram	3	6				8	1 (Language)
Configure board	Configure the number of pictograms per screen	3	5				7	1(pictogram selection)
Pictogram selection	Configure scanning by rows and columns	4	5				7	2(Configure board)
	Configure a selection via joystick	3	4	1			8	0
Online services	Configure internet home page	5	4				9	0
Others	Activate video option	6	3				9	0

5.1.3.2 Satisfaction questionnaire

The next tables show the level of satisfaction concerning the configuration interfaces. The main problems and recommendations are also shown.

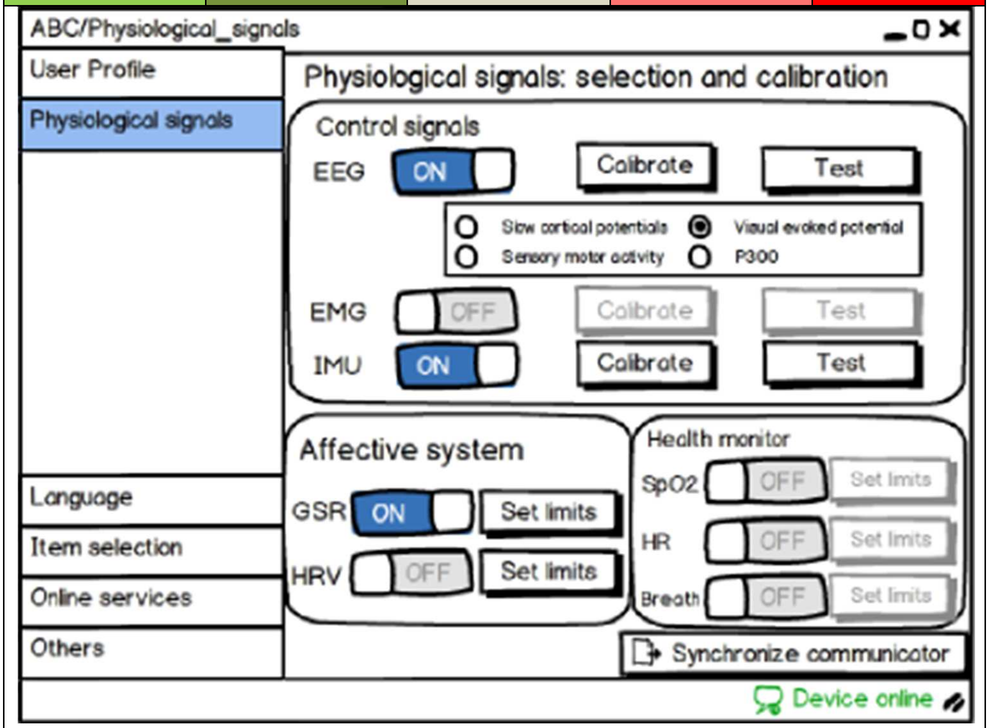
User profile

Very satisfied	Satisfied	Neutral	Unsatisfied	Very unsatisfied
1	8			



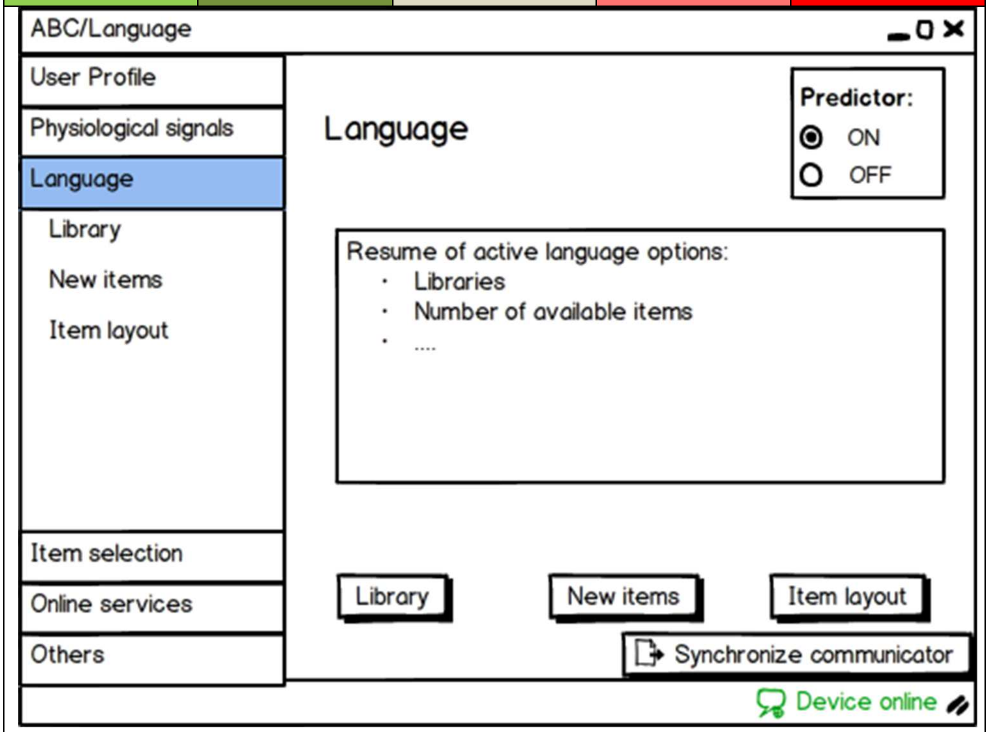
Problems found	Improvement recommendations
• No problems detected	• A menu on each option of "Output" o In "Text in the screen" give the option of configure width, spacing, color, source... o In "Voice synthesizer" give the option of configure voices, speed, tone, pause between words...

Physiological signals				
Very satisfied	Satisfied	Neutral	Unsatisfied	Very unsatisfied
3	5	1		



Problems found	**Improvement recommendations**
• Professionals considered that health is a complex issue	• Codify the signals using colors • Change the position of the health monitor to other screen

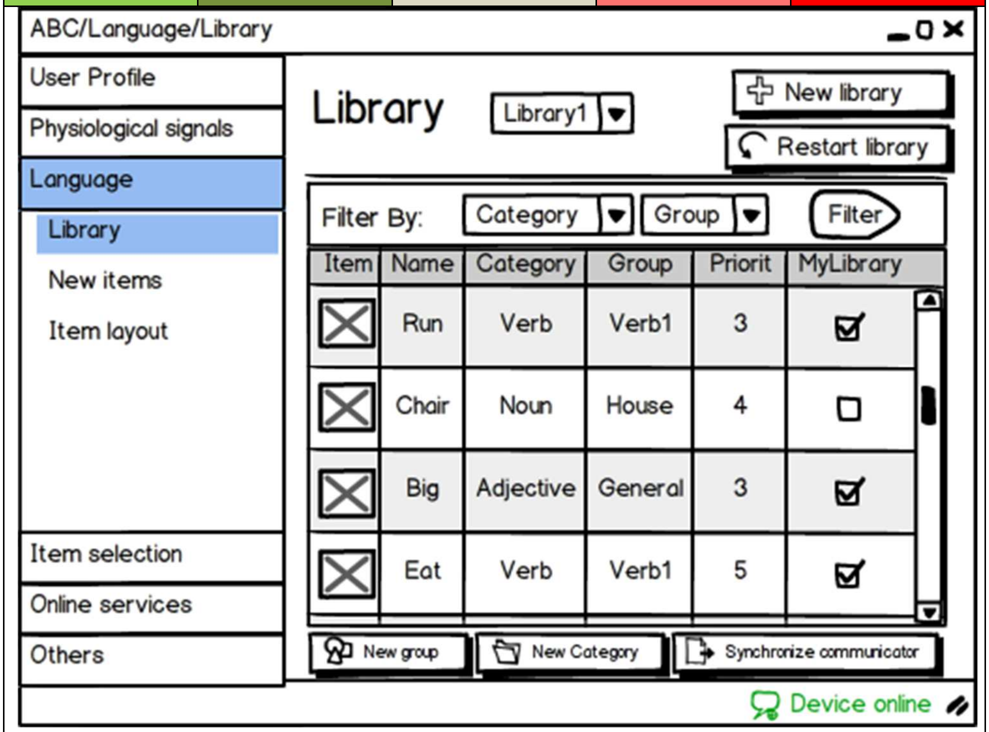
Language				
Very satisfied	Satisfied	Neutral	Unsatisfied	Very unsatisfied
2	7			



Problems found	Improvement recommendations
• The screens of "Language" and "Item selection" may cause confusion between each	• An orthography corrector o An option of changing the capital letters of some words

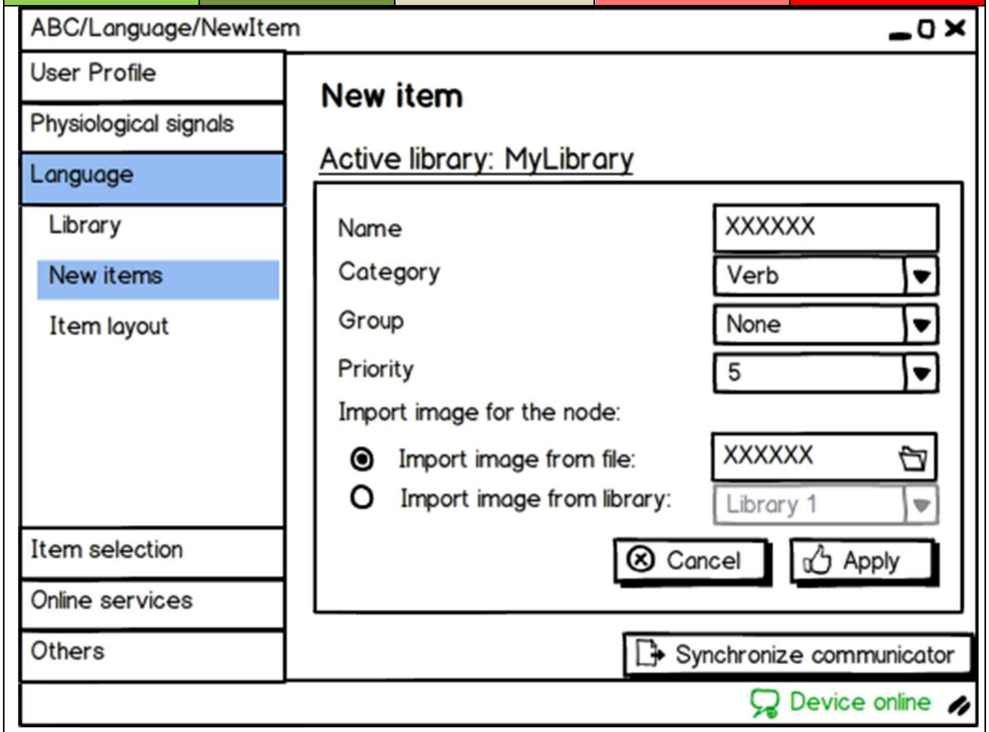
Library

Very satisfied	Satisfied	Neutral	Unsatisfied	Very unsatisfied
2	7			



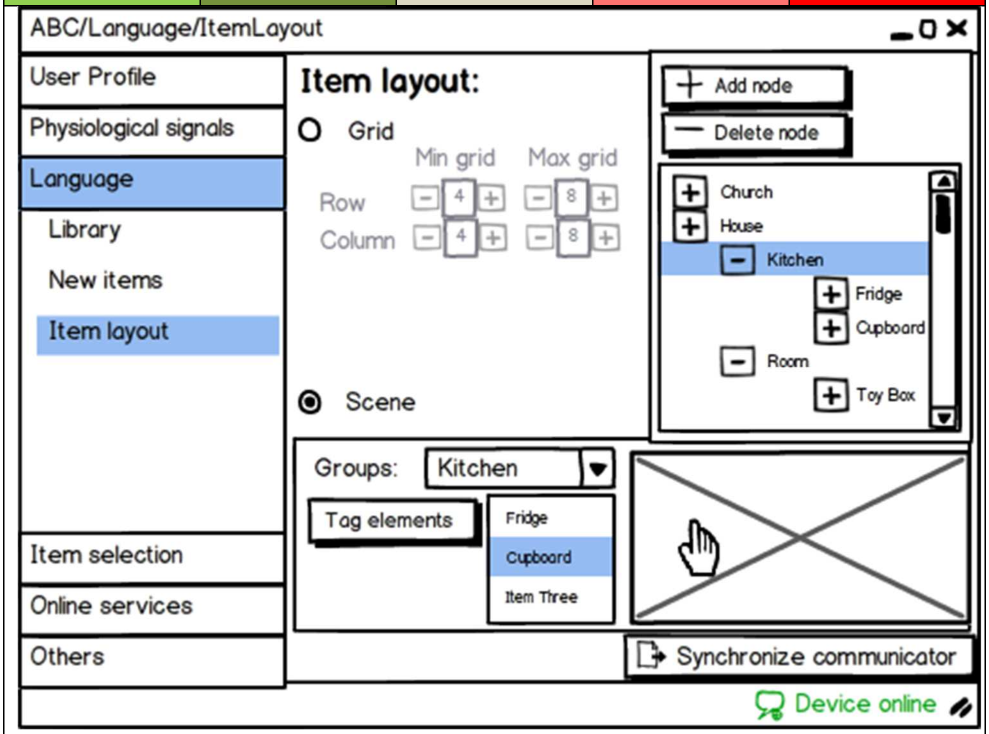
Problems found	**Improvement recommendations**
• The grammatical category is not important (2)	• Add an option for filtering by name • Add the possibility of reading by a "scanning pen"

New item				
Very satisfied	Satisfied	Neutral	Unsatisfied	Very unsatisfied
3	6			



Problems found	Improvement recommendations
• No problems detected	• Add the possibility of watching the pictogram before inserting it

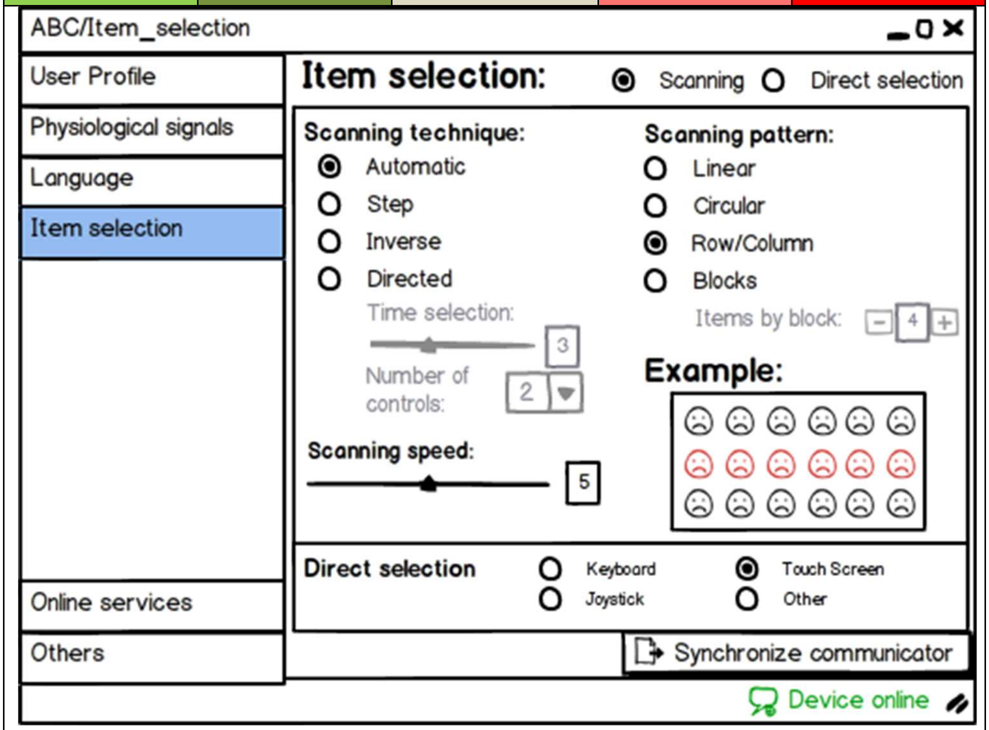
Configure board				
Very satisfied	Satisfied	Neutral	Unsatisfied	Very unsatisfied
1	7	1		



Problems found	**Improvement recommendations**
• No problems detected	• No improvements detected

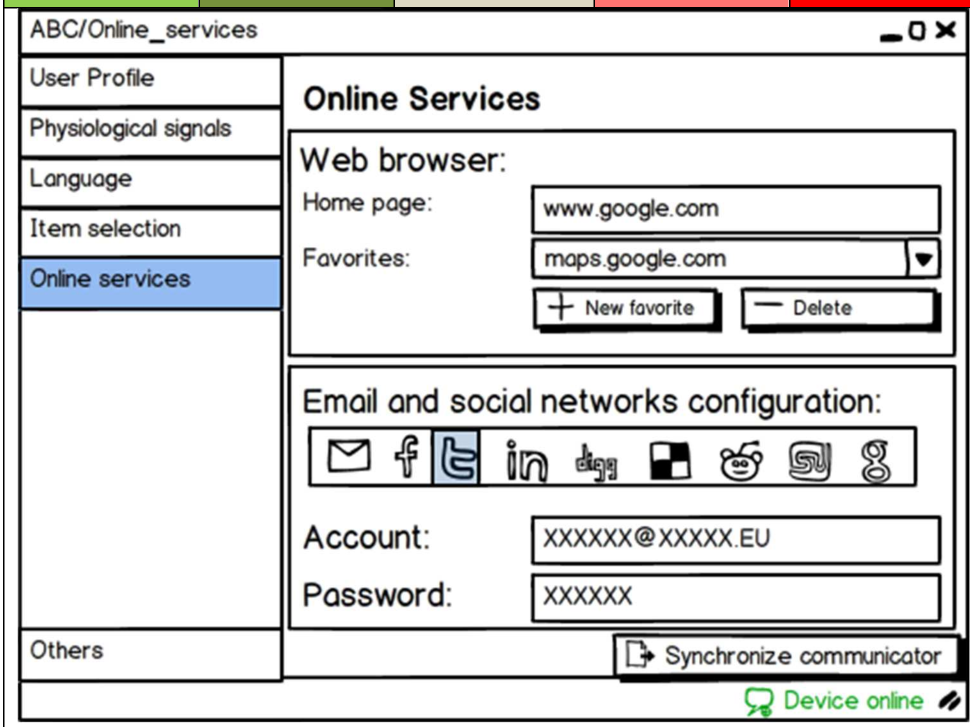
Item selection

Very satisfied	Satisfied	Neutral	Unsatisfied	Very unsatisfied
1	7	1		



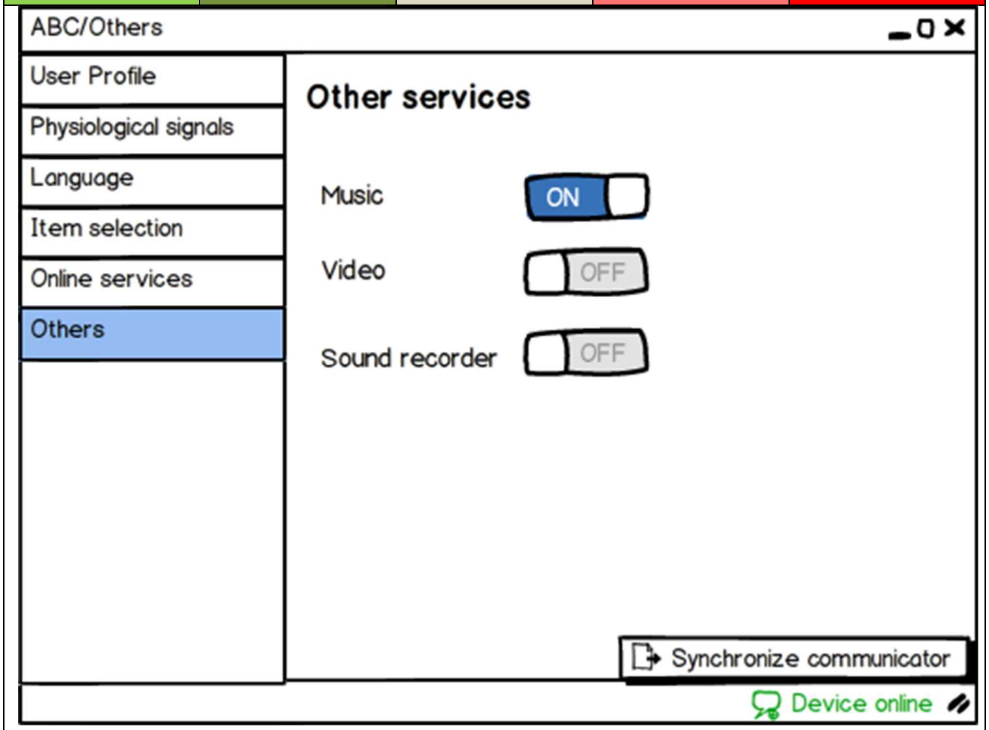
Problems found	**Improvement recommendations**
• Terms like inverse scanning, step, directed are confusing	• Add more options inside the scanning option: hold to move forward, scanning laps, hop empty cells.. • Configure highlighted times during the scanning

Online services				
Very satisfied	Satisfied	Neutral	Unsatisfied	Very unsatisfied
2	7			



Problems found	**Improvement recommendations**
• No problems detected	• Add an YouTube app in order to access directly

Others				
Very satisfied	Satisfied	Neutral	Unsatisfied	Very unsatisfied
2	7			



Problems found	**Improvement recommendations**
• No problems detected	• No improvements detected

From the point of view of the DCP users, evaluation of the different functions of the communication system shows the positive points and the elements that can be improved (only two parameters were evaluated negatively).

Additionally, evaluations with professionals showed that the proposed system is easy to use and the interfaces developed are satisfactory and adapted to DCP user needs.

These results are in line with hypothesis number 1. Different evaluations have made it possible to identify new characteristics to improve the functionality and usability of the system.

ABC communicator is perceived as an Information and Communication Technology tool that must consider the BASIC features initially proposed (communication, learning and self-regulation of emotions) and, in addition:

- Leisure through internet tools (watch movies, read, play online, listening to music, etc.).
- Environmental control to provide greater autonomy at home and at the centre.
- Information and culture: reading newspapers, thematic forums, access to cultural events, etc.
- "Advanced" Activities of daily living: access to shopping, bank operations, etc. through Internet.

Figure 5.1 shows the compiled features that should include the new communication system.

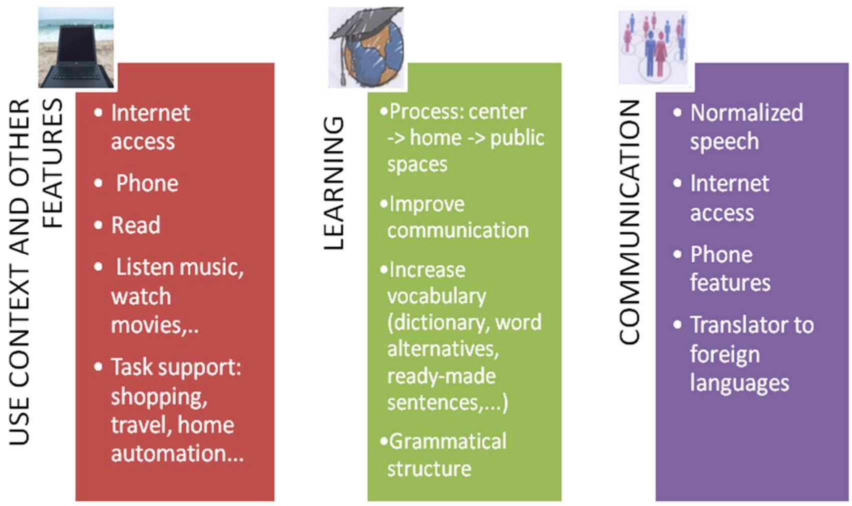


Figure 5.1. Identified features for the ABC communication system.

5.2 Results of the validation of the physiological control system.

In this section, the results of the influence of the different factors on activation time (Time) of the buttons and transmission speed (Vtx) are presented.

5.2.1. Activation times for the different control systems, sizes and distances between buttons.

Table 5.12 shows the significant factors of the ANOVA model for the activation time of the buttons (Time). The results of the post-hoc analysis for factors with 3 levels (SizeBtn and DistBtn) are shown in Table 5.12 and Table 5.13.

Table 5.12. Significant factors of the ANOVA for the activation time (Time).

(Time)	Chi-square tests	Df	Pr(>Chisq)
Control	4.139	1	<0,05
SizeBtn	190.490	2	<0,05
DistBtn	178.010	2	<0,05
Control:SizeBtn	37.459	2	<0,05
Control:DistBtn	61.879	2	<0,05
SizeBtn:DistBtn	32.130	4	<0,05
Control:SizeBtn:DistBtn	30.558	4	<0,05

Table 5.13. Test Interactions of the 3 levels of the button size (SizeBtn), for the variable Time.

	Value	Df	Chisq	Pr(>Chisq)
Big-medium	-3.2834	1	66.894	<0,05
Big-small	-6.2986	1	219.420	<0,05
Medium-small	-3.0152	1	50.146	<0,05

Table 5.14. Test interactions between levels of the distances between buttons (DistBtn), for the variable Time.

	Value	Df	Chisq	Pr(>Chisq)
Close-far	-6.2485	1	210.995	<0,05
Close-halfway	-1.5119	1	14.568	<0,05
Far-halfway	4.7365	1	123.383	< 0,05

a)

b)

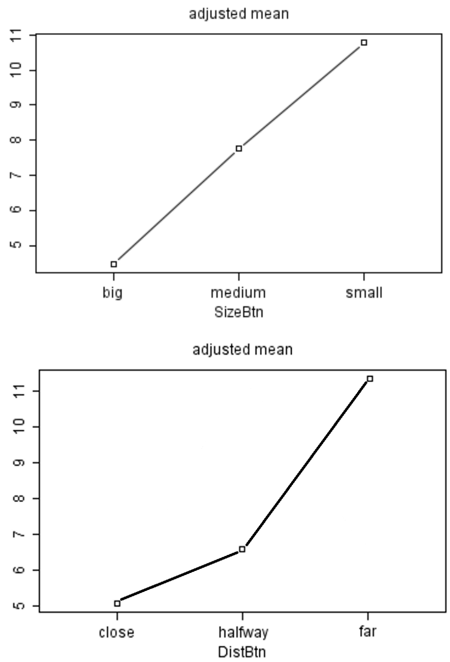


Figure 5.2. Estimated marginal means of the activation times for the different a) sizes of buttons (SizeBtn) and b) distances between buttons (DistBtn).

Figure 5.2 shows the impact of sizes and distances on the selection times (Time). The subjects need more time when the separation distance (DistBtn) is increased and when the size of the buttons (SizeBtn) is reduced.

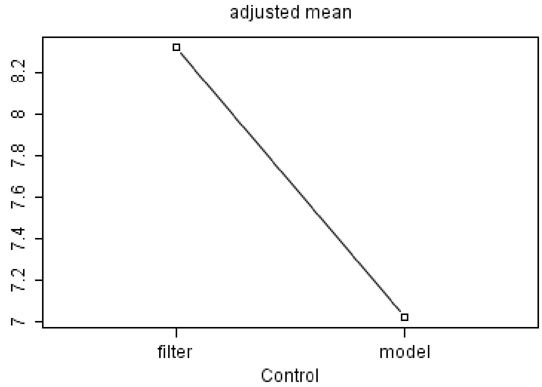


Figure 5.3. Estimated marginal means of the activation times for the different control systems.

The results of Figure 5.3 show the activation times between the different control systems. The physical model (model) is faster than the proportional control (filter).

The results of the interactions SizeBtn:Control and DistBtn:Control are shown in Figure 5.4. The impact of the control system is different depending on distances and sizes. These multiple interactions are analyzed in section 5.2.3.

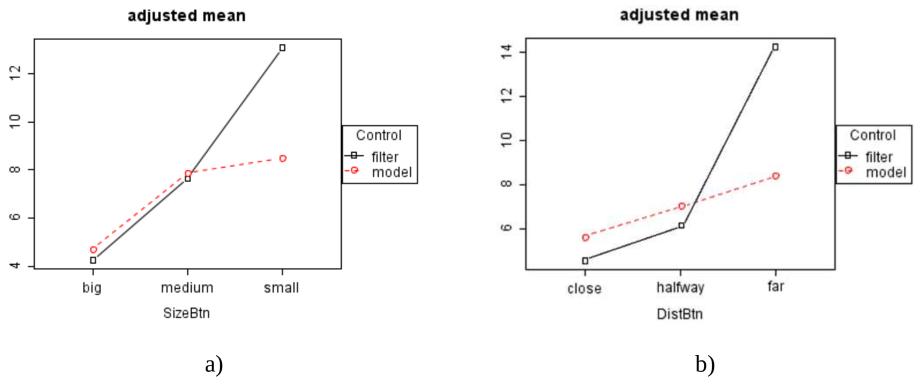


Figure 5.4. Estimated marginal means of the activation times (Time) for the interactions a) SizBtn:Control and b) DistBtn:Control.

5.2.2. Transmission speed for the different control systems, sizes and distances between buttons.

The transmission speed (Vtx) was compared to the Control system (Control), the size of the button (SizeBtn), the distance between buttons (DistBtn) and their interactions.

Table 5.15. Significant factors of the ANOVA model for the transmission speed (Vtx).

	Chi-square tests	Df	Pr(>Chisq)
Control	63.098	1	<0,05
SizeBtn	13.972	2	<0,05
DistBtn	146.937	2	<0,05
Control: SizeBtn	47.181	2	<0,05
Control: DistBtn	52.610	2	<0,05
SizeBtn: DistBtn	24.308	4	<0,05
Control: SizeBtn: DistBtn	36.811	4	<0,05

Significant differences are established for each factor and their interactions as shown in Table 5.15. Table 5.16 and Table 5.17 show the details of the test interactions of Vtx/SizeBtn and Vtx/DistBtn:

Table 5.16. Test Interactions (Vtx, SizeBtn).

	Value	Df	Chisq	Pr(>Chisq)
Big-medium	0.039890	1	2.5019	0.113706
Big-small	0.108121	1	16.3864	<0,05
Medium-small	0.068231	1	6.5090	<0,05

Table 5.17. Test Interactions (Vtx, DistBtn).

	Value	Df	Chisq	Pr(>Chisq)
Close-far	-0.201484	1	55.611	<0,05
Close-halfway	-0.286303	1	132.367	<0,05
Far-halfway	-0.084819	1	10.027	<0,05

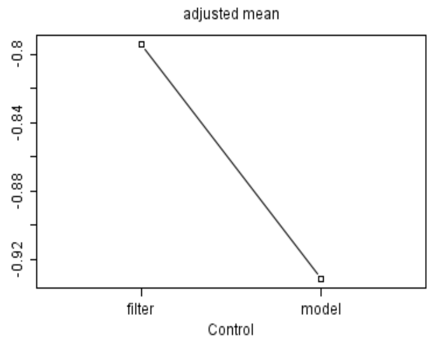
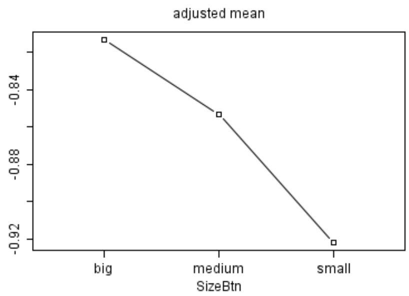


Figure 5.5. Estimated marginal means of the transmission speed for the different control systems (Vtx, control).

Figure 5.5 shows the influence of the control system on the transmission speed. The tasks with “model” were performed faster than the tasks with “filter”.

a)



b)

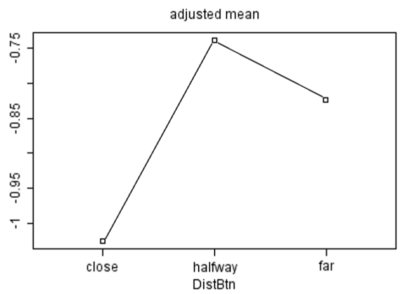
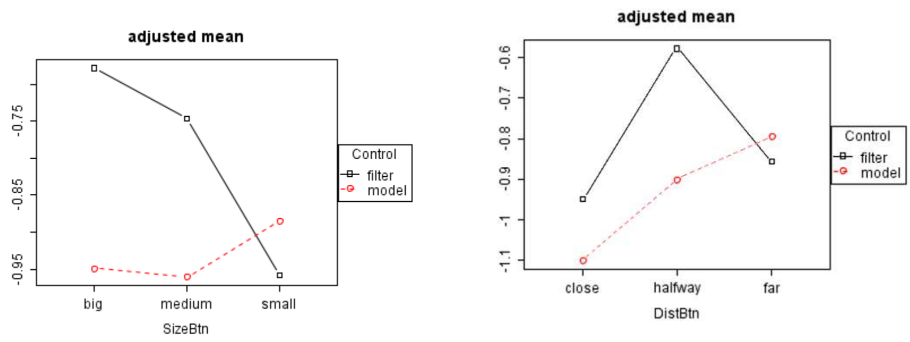


Figure 5.6. Estimated marginal means of the transmission speed for the different a) sizes of buttons (SizeBtn) and b) distances between buttons (DistBtn).

Figure 5.6 shows the comparison between sizes and distances between buttons. Users gradually increased the transmission speed (Vtx) when the size of the button was reduced.

The transmission speed is not proportional to the distance between buttons (the lowest transmission speed was achieved with the “halfway” distance). The analysis of the double interaction of the factors DistBtn:Control and SizeBtn:Control was carried out and the results are shown in Figure 5.7.



a) b)

Figure 5.7. Estimated marginal means of the transmission speed (Vtx) for the interactions a) SizBtn:Control and b) DistBtn:Control.

When the distance is “far” the size of the button determines the difficulty of the task, being more difficult with the proportional control (filter).

When the distance is “halfway” the control determines the difficulty of the task. Using physical model control (model) was easier than using proportional control (filter).

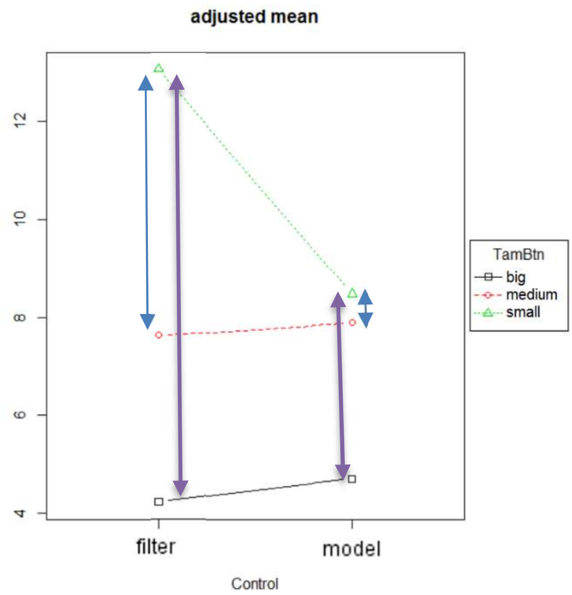
When the distance is “close” the task is influenced by the control and the size of the button. The easiest task is with the big button and the physical model control.

5.2.3. Multiple interactions of the different control systems, sizes and distances between buttons.

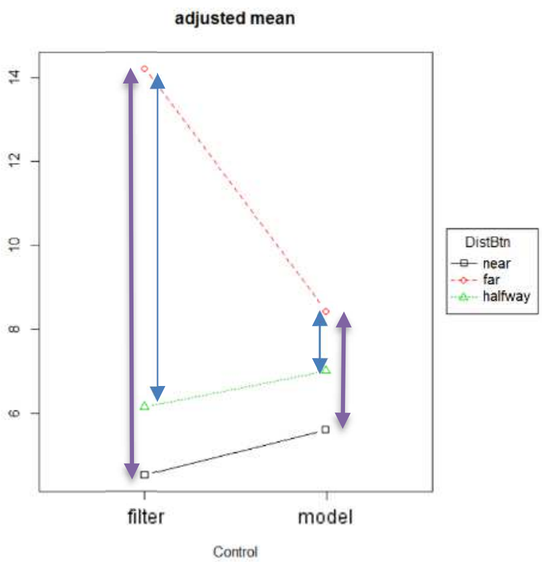
The analysis of the multiple interactions between factors (SizeBtn, DistBtn, Control) for the variables Time (Time) and Transmission speed (Vtx) shows the benefits of the control by physical model in comparison with the proportional control:

- The control by physical model reduces the difficulty of the tasks.
- The performance of the tasks with the control by physical model is less affected when the size of the button is reduced and the distance between buttons is increased.

To show this influence, Figure 5.8 presents the results of the interactions where the significant results are indicated with blue and magenta arrows. Post-hoc analysis are presented in Table 5.18 and Table 5.19.



a)



b)

Figure 5.8. Estimated marginal means of the activation times (Time) for the interactions a) TamBtn:Control b) DistBtn:Control

Table 5.18. Post-hoc analysis of the Time for the interactions between SizeBtn and Control.

	Value	Df	Chisq	Pr(>Chisq)
Big-medium:filter-model	-0.2133	1	0.0676	0.79
Big-small:filter-model	-5.0614	1	33.6414	**<0,05**
Medium-small:filter-model	-4.8481	1	31.8713	**<0,05**

Table 5.19. Post-hoc analysis of the Time for the interactions between DistBtn and Control.

	Value	Df	Chisq	Pr(>Chisq)
Close-far:filter-model	-6.8905	1	52.1488	**<0,05**
Close-halfway:filter-model	-0.2197	1	0.0658	0.7976
Far-halfway:filter-model	6.6708	1	58.7508	**<0,05**

Table 5.20. Post-hoc analysis of the triple interactions

	Value	Df	Chisq	Pr(>Chisq)
Close-far:Big-medium:filter-model	7.8988	1	15.2751	**<0,05**
Close-halfway:Big-medium:filter-model	5.5481	1	8.0839	**<0,05**
Far-halfway:Big-medium:filter-model	-2.3507	1	1.3507	0.627
Close-far:Big-small:filter-model	10.7518	1	22.4580	**<0,05**
Close-halfway:Big-small:filter-model	2.3385	1	1.3826	0.627
Far-halfway:Big-small:filter-model	-8.4133	1	14.0781	**<0,05**
Close-far:Medium-small:filter-model	2.8530	1	1.5776	0.62
Close-halfway:Medium-small:filter-model	-3.2095	1	2.5517	0.44
Far-halfway:Medium-small:filter-model	-6.0626	1	6.9017	**<0,05**

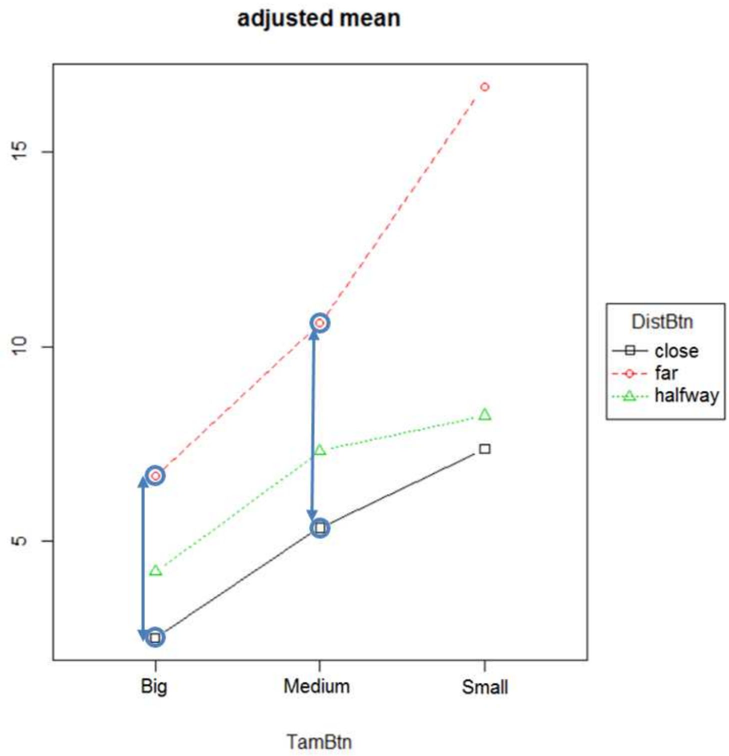


Figure 5.9. Example where a triple interaction was found.

The results of the triple interactions between factors are presented in Table 5.20. To explain these interactions, Figure 5.9 shows the interaction between the factors DistBtn and SizeBtn. The blue circles represent an example of a statistically significant difference between control systems (close-far:big-medium:filter-model). This interaction also shows that the negative impact of the size and the distance between buttons is also different between control systems (worst with the proportional control).

Chapter 6
Synthesis and Perspectives

In order to propose a synthesis of our work and to develop new perspectives, this chapter is organized into 3 sections. Section 6.1 presents a discussion about the hypotheses proposed in this thesis.

- In section 6.1.1 the discussion is focused on the results related to hypothesis 1: "Based on Dyskinetic Cerebral Palsy (DCP) user needs, it is possible to design a satisfactory concept of communication system". With the identified requirements/features of the system, the proposed improvements, and the positive evaluation of satisfaction experienced by the users, a satisfactory concept of communication system for DCP people has been designed.
- In section 6.1. 2 the discussion is focused on hypothesis 2: "Our innovative approach of physiological control, based on a physical model, allows better communication performance than proportional control. This is applicable to direct selection systems over a grid of concepts". We established that our proposed control system improves the performance of communication in comparison with a proportional control with EMG. The variations of performance associated with the size and distance between the buttons show the importance of limiting the available number of elements over a grid of concepts.

Section 6.2 presents the conclusions fulfilling the objectives and hypothesis proposed in Chapter 3.

Section 6.3 presents the valorization of the knowledge developed in this thesis carried out through scientific publications.

Finally, section 6.4 presents proposed future work leading on from this thesis.

6.1 Discussion

6.1.1 Conceptual design of the ABC System.

The participation of people with DCP and their caregivers, throughout the design of the system, and especially in the early stages, has allowed the development of a conceptual design that responds to user needs. This is evidenced in the different results of the prototype validation for both the interface of the communicator and the configuration system.

Firstly, we have a set of requirements/features classified according to level of importance: basic, essential and non-essential. The basic features should be included in the development and the essential features should be included depending on their level of prioritization, complexity and available resources.

Secondly, the results of the assessment of the configuration interface showed that it is easy to use. In fact, almost all the professionals (9/10) correctly finished all the proposed tasks and almost all of them assessed as “satisfied” or “very satisfied” all the tasks performed with the interface. In addition, the level of satisfaction with each screenshot of the interface was really high between “satisfied” and “very satisfied” for almost all the screens. Some areas for improvements were detected such as the problems in differentiating between “pictogram selection” and “board configuration” interface.

Thirdly, the results of the test with DCP users showed a high level of satisfaction with the user interface. However, some limitations were detected and DCP users provided some interesting recommendations such as to optimize speed communication, allow different use of languages and input interfaces to communicate, provide basic selection buttons (verbally express, delete, save, home button), provide warning pop ups for risky actions (low battery, close system, emotional and health problems, notifications, emergency button) and to be able to completely customize the interface.

The results of the tests showed that the conceptual design of the ABC system fits with user needs and expectations but potential improvements were also identified. These tests also allowed detecting limitations and recommendations that should be considered in future development phases of the final system.

To achieve user acceptance of a product or service, it is necessary to provide all the levels proposed by Jordan (Jordan, 2000): functionality, accessibility, usability and aesthetics (Figure 6.1).

While using the concept of universal design (Wolfgang FE & Elaine, 2001) and the recommendations on issues of user need identification we addressed the first 3 levels of the pyramid. However, the research activities of this thesis did not focus on aesthetics aspects.

As was discussed in previous research projects (Laparra Hernandez, 2015), aesthetic aspects may have some influence on other aspects, such as usability. For this reason, in future phases of development of the ABC system, aesthetics should be studied.

Source: (Laparra Hernandez, 2015)

Figure 6.1. Aspects to ensure user acceptance.

The results of the thesis have already been implemented into an Android application with a configuration interface for PC (Figure 6.2). They have been tested with DCP people in daily life activities with positive results in terms of acceptance specially related to the following aspects:

- It facilitates the communication and the self-management of health status.
- It allows configuring of the communicator with the language of each user.
- Users quickly assimilate the management of the system with the navigation tools.
- The emotions module correctly identifies the emotional state of the user.

a)

b)

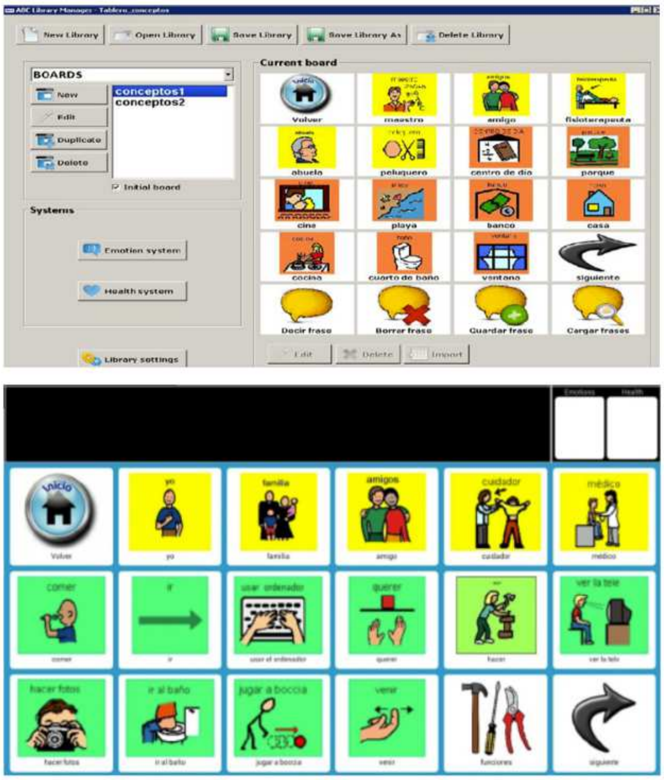


Figure 6.2. Communication system developed with the results of the thesis. a) Configuration interface, b) communicator interface.

6.1.2 Direct selection system controlled by the physical model.

The new control system proposed in this thesis has improved the performance of direct selection on concept grids in comparison with a proportional control system.

The size and distance between buttons are important factors in order to simplify the communication. With the available results, we are not able to conclude the ideal size of a grid of concepts (ideal size and distance between buttons). The results show that reducing the size of the buttons and separating them worsens overall performance. However, our proposed model reduces this impact.

In a future implementation of this new control system with DCP people, different configurations should be tested for each user:

- to determine the acceptance of the control system,
- to define the size of the grid of concepts (it can be influenced by the type of language used),

- to identify the acceptable communication performance (in comparison with other control systems),
- to avoid increasing the cognitive and emotional demands,
- to identify the muscular system used,
- and to define the parameters of the physical model (Stiffness, Inertia and Viscosity) to ensure system responsiveness.

The participants of the test with both control systems negatively evaluated the proportional control system (it produces fatigue). Thus, in future tests with DCP users, this control system should not be used for direct control.

6.2 Conclusions

The conclusions of this thesis are the following:

1. The needs and limitations of people with DCP were characterized. These were transformed into design concepts to prototype a communication system (communicator and configuration system).
2. The analysis of the prototypes with end-users and professionals allowed the functions to be prioritized leading to improvements in the system.
3. The results of tests showed that the conceptual design of the ABC system fits with user needs and potential improvements have been identified.
4. A physical model was proposed for direct control that is able to reproduce the muscle mechanics with signal pulses. This model uses Stiffness, Inertia and Viscosity to augment control and precision and to select elements on a grid of concepts.
5. The proposed physical model control system was compared with a proportional control system. It was observed that our solution reduces the difficulty of the tasks.
6. The influence of the size and the distance between buttons on task difficulty was analyzed. In general, by reducing the size of the buttons and increasing the distance between them, the tasks are more difficult.
7. The negative impact on performance associated to size and distance between buttons is less important with the physical model. It shows the potential with this system to provide larger grids of concepts for DCP users.
8. The EMG signal is a valid signal to use for the physical model control system proposed in this thesis.

6.3 Valorization/Publications

Publications are grouped into two categories according to their origin:

1. Direct results of the thesis:

   - Díaz-Pineda J, Belda-Lois J, Laparra-Hernández J, Artacho C, Palau Salvador C. Control fisiológico en sistemas de comunicación aumentativos y alternativos para persona con parálisis cerebral discinética. XXIX Simposium Nacional de la Unión Científica Internacional de Radio. URSI 2014.

2. Results obtained in other projects using the methodologies set out in this thesis:

   - Juan Vicente Dura Gil, Jaime Diaz-Pineda, Elisa Signes Perez, Helios de Rosario Martinez, Enric Medina Ripoll, Jose S. Solaz Sanahuja, Lourdes Tortosa Latonda, Ma. Jose Vivas Broseta. Integrating user feedback in the design, a new methodology. Revista de Biomecánica, 57, 75-77, December 2011.
   - Díaz J, Such MJ, Sánchez JJ, Mateo B, Laparra J. Is the user perception similar with physical and digital representation?. The Fifth International Conference on Advances in Computer-Human Interactions, ACHI, 2012. International Academy, Research and Industrial Association
   - Laparra-Hernández J, Díaz-Pineda J, Belda-Lois J, Barberà R, Poveda R, Prat-Pastor J, Sánchez-Lacuesta J, Matey F, 2012. Evaluation of the influence of user profile on the suitability of current web usability parameters using innovative methodologies. Book of Abstracts 3rd International Conference on Eye Tracking, Visual Cognition and Emotion. Universidade Lusófona de Humanidades e Tecnologias. ETVCE. Lisbon, Portugal, 2012
   - Laparra-Hernández J, Díaz-Pineda J, Belda-Lois J, Page, A, 2013. A multimodal web usability assessment based on traditional metrics, physiological response and eye-tracking analysis. CHAPTER 6 of Book "I see me, you see me: inferring cognitive and emotional processes from gazing behavior" Edited by Pedro Gamito & Pedro Rosa. Publisher: Cambridge Scholars Publishing.
   - Schmitt, Robert; Köhler, Markus; Durá, Juan V.; Diaz-Pineda, Jaime. Objectifying user attention and emotion evoked by relevant perceived product components. The 11th International Symposium of

Measurement Technology and Intelligent Instruments (ISMTII); July 2013, Aachen, Germany.

- Köhler M, Belda-Lois JM, Diaz Pineda J. Durá Juan V., Laparra-Hernández J., 2014. Messung von Emotionen und Produkt-Usability. In "Perceived Quality.: Subjektive Kundenwahrnehmungen in der Produktentwicklung nutzen" (pp. 77-98). Edited by Robert Schmitt. Symposion Publishing GmbH.
- Schmitt, R.; Köhler, M.; Durá-Gil, J.; Diaz-Pineda, J. Objectifying user attention and emotion evoked by relevant perceived product components. Journal of Sensors and Sensor Systems. 3(2):315-324. 2014.
- Garcia, L, Lespinet-Najib, V., Saioud S., Meistermann, V., Renaud, S., Diaz-Pineda Jaime, André JM. and Ron-Angevin R. Brain-Computer Interface: Usability evaluation of different P300 speller configurations. A preliminary study. IWANN 2015 - International Work Conference on Artifitial Neural Networks. June 2015.

6.4 Future work

Currently, we are exploring and analyzing several perspectives:

- To extend the study to other types of cerebral palsy.
- To include the type of language in the definition of the size of the grid of concepts with direct control systems. Our results show that having many elements increases the difficulty, but we did not consider the fact of navigating between pages to access all necessary concepts for communication.
- To implement the concept of communication systems in commercial products.
- To test the physical model control system with DCP users, improving visual feedback.
- To validate the use of another input signal to increase the range of control possibilities (depending on user profile).

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Appendix A.
Online survey with professionals

USABILIDAD DEL SISTEMA DE CONFIGURACIÓN ABC

1. INTRODUCCIÓN E INSTRUCCIONES

Buenos días/tardes. Desde el IBV estamos realizando un proyecto europeo cuyo objetivo es desarrollar un sistema de comunicación que ayude a las personas con parálisis cerebral a mejorar la comunicación con su entorno, la expresión de emociones y la gestión de salud. Este sistema (comunicador ABC) está basado en los últimos avances en procesamiento de señales neuronales, comunicación aumentada asistida por ordenador y monitorización de bioseñales. El comunicador ABC está constituido principalmente por 4 módulos independientes, el módulo de comunicación, aprendizaje, emociones y de salud.

Este sistema se está desarrollando junto con las personas con PC, sus cuidadores y personas expertas en este campo. Por lo que nos sería de gran utilidad su colaboración. Le rogaríamos que nos atendiese unos minutos contestando a este cuestionario para validar un posible sistema de configuración para el comunicador ABC.

El sistema de configuración permitirá configurar el comunicador acorde a las necesidades y preferencias de los usuarios. Está diseñado para ser usado por el familiar y/o cuidador del usuario; o por el usuario con ayuda de un familiar y/o cuidador (no está pensado para que lo maneje el usuario de manera autónoma).

Le hemos adjuntado un PDF con las diferentes interfaces/pantallas de que constaría el sistema de configuración. Este PDF es semi interactivo por lo que le permitirá navegar por las diferentes interfaces (pestañas que aparecen a la izquierda): perfil de usuario, señales fisiológicas, lenguaje (biblioteca, nuevo pictograma, organizar tablero), tipo de selección, servicios online y otros. Utilícelo para contestar a las preguntas.

Este documento consta de varias partes, por favor vaya siguiendo sus instrucciones.

Agradecemos de antemano su colaboración y le aseguramos confidencialidad absoluta en sus respuestas.

USABILIDAD DEL SISTEMA DE CONFIGURACIÓN ABC

2. NAVEGACIÓN LIBRE

En primer lugar queremos que navegue libremente durante 5 minutos por el PDF para que valore el sistema de configuración en su globalidad.

*** Indique su nivel de satisfacción global con el sistema de configuración.**

- Muy satisfecho
- Satisfecho
- Neutro
- Insatisfecho
- Muy insatisfecho

Observaciones/mejoras/opciones que cambiaría...

USABILIDAD DEL SISTEMA DE CONFIGURACIÓN ABC

3. TAREAS A REALIZAR

A continuación, le proponemos una serie de supuestos/tareas para que valore cómo de fácil sería realizarlas con este sistema de configuración. Utilice para ello el PDF interactivo. (Con el PDF no se puede acceder a todas las funciones del sistema de configuración pero imagínese cómo lo haría y que funciones activaría si pudiera).

Cronometre el tiempo que tarda en realizar todas las tareas porque al final de la realización de todas las tareas tendrá que anotarlo.

Para cada una de las tareas se hicieron las siguientes 3 preguntas:

*** ¿Ha conseguido encontrar la función?**

- Sí
- No

***¿En qué pantalla/interfaz la ha encontrado?**

- Perfil del usuario
- Señales fisiológicas
- Lenguaje
- Biblioteca
- Nuevo pictograma
- Organizar tablero
- Tipo de selección
- Servicios online
- Otros

***Indique cómo de fácil le ha resultado realizar esta tarea.**

- Muy fácil
- Fácil
- Ni fácil ni difícil
- Difícil
- Muy difícil

Las tareas fueron las siguientes:

4. TAREAS A REALIZAR

Imagínese que desea configurar el comunicador de un nuevo usuario del centro. ¿Qué función del sistema de configuración seleccionaría?

6. TAREAS A REALIZAR

Imagínese que un usuario está teniendo problemas con el uso del predictor (no predice correctamente lo que quiere decir y lo ralentiza más) y desea desactivarlo. ¿Qué función del sistema de configuración seleccionaría?

8. TAREAS A REALIZAR

Imagínese que desea configurar el acceso a internet de un comunicador para que cuando el usuario abra internet la página web de inicio sea la de AVAPACE. ¿Qué función del sistema de configuración seleccionaría?

10. TAREAS A REALIZAR

Imagínese que un usuario utiliza el sintetizador de voz para comunicar sus mensajes a los demás. ¿Cómo activaría la función del sintetizador?

12. TAREAS A REALIZAR

Imagínese que quiere localizar un pictograma de una biblioteca. Este pictograma pertenece al grupo "cocina" y a la categoría "verbo" (por ejemplo "cocinar". ¿Cómo lo localizaría?

14. TAREAS A REALIZAR

Imagínese que desea configurar el comunicador para que el usuario pueda ver vídeos. ¿Qué función del sistema de configuración seleccionaría?

16. TAREAS A REALIZAR

Imagínese que un usuario va a utilizar las señales de EEG para moverse por el comunicador y seleccionar los distintos pictogramas. ¿Cómo pondría a punto estas señales?

18. TAREAS A REALIZAR

Imagínese que ha creado un nuevo pictograma para un usuario. Este pictograma va a ser muy utilizado, importante y prioritario en su comunicación. ¿Cómo los configuraría para que así fuera?

20. TAREAS A REALIZAR

Imagínese que tiene que configurar el comunicador de un usuario para que haga un barrido por filas y columnas. ¿Como lo haría?

22. TAREAS A REALIZAR

Imagínese que un usuario va a utilizar señales GRV y HRV para que detecten sus emociones y cambios en el estado de ánimo. ¿Cómo configuraría estas señales?

24. TAREAS A REALIZAR

Imagínese que quiere configurar el comunicador de un usuario para que los pictogramas del mismo se dispongan de tal manera que, como máximo, se muestren en la pantalla 4 filas por 4 columnas de pictogramas. ¿Como lo haría?

26. TAREAS A REALIZAR

Imagínese que quiere configurar el comunicador de un usuario que va a seleccionar/ejecutar los pictogramas mediante un joystick. ¿Cómo lo configuraría?

USABILIDAD DEL SISTEMA DE CONFIGURACIÓN ABC

29. NAVEGACIÓN DIRIGIDA

A continuación va a volver a navegar por el sistema de configuración, pero le vamos a ofrecer una breve explicación de cada interfaz para poder realizar un análisis más profundo. Por tanto, vuelva a navegar por el PDF interactivo, pero ahora teniendo presente las siguientes explicaciones.

30. VALIDACIÓN INTERFAZ "PERFIL DEL USUARIO"

En esta primera interfaz se muestra el perfil de usuario. En esta pantalla se puede añadir un nuevo usuario o acceder y/o modificar la configuración de un usuario ya existente (esto permite configurar el comunicador de varios usuarios desde el mismo ordenador).

Una vez seleccionado el usuario aparece un cuadro informativo del estado del sistema y de las opciones activas: última calibración, lenguaje del usuario, señales fisiológicas activas...

En esta pantalla, también se puede seleccionar el modo en el que se quiere que el usuario comunique sus mensajes a los demás (texto, sintetizador de voz...), y por último te permite detectar dispositivos externos y sincronizar con el comunicador para implementar las modificaciones realizadas en la configuración.

*** Atendiendo a la navegación por el sistema y a la información anterior, indique su nivel de satisfacción con esta interfaz.**

- Muy satisfecho
- Satisfecho
- Neutro
- Insatisfecho
- Muy insatisfecho

Observaciones

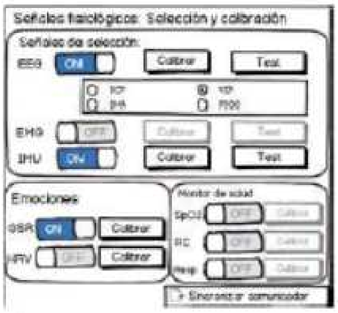
31. VALIDACIÓN INTERFAZ "SEÑALES FISIOLÓGICAS"

En esta interfaz se presentan las posibles señales fisiológicas que se podrían utilizar para el manejo del comunicador por el usuario. Estas señales se clasificarían en:

• Señales de control (EEG, EMG, IMU's): son las que utilizarían para que el usuario seleccionara los distintos pictogramas o funciones activas en la pantalla del comunicador. En esta interfaz se da la opción de seleccionar, calibrar y probar estas señales. (El proceso de calibración permitiría ajustar los niveles máximos y mínimos de estas señales para cada usuario).

• Señales emocionales (GSR, HRV): son las que se utilizarían para conocer el estado emocional del usuario y, por tanto, las que indicarían la necesidad de pasar a una comunicación más sencilla cuando el usuario está estresado. En esta interfaz se da la opción de seleccionar y calibrar estas señales. (El proceso de calibración permitiría ajustar los niveles máximos y mínimos de estas señales para cada usuario).

• Señales de salud (SpO2, HR, Breath): son las que se utilizarían para detectar el estado de salud del usuario. Sólo personal médico podrá encargarse de estas señales. Estas señales estarán desactivadas por defecto y su uso protegido con contraseña. Los límites de esta señal se fijarán conforme a la salud del usuario.



***Atendiendo a la navegación por el sistema y a la información anterior, indique su nivel de satisfacción con esta interfaz.**

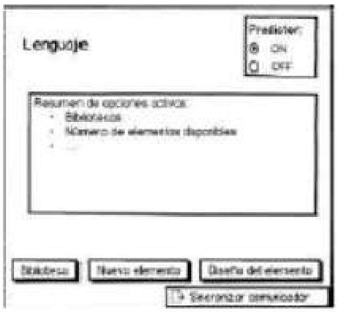
- Muy satisfecho
- Satisfecho
- Neutro
- Insatisfecho
- Muy insatisfecho

Observaciones

32. VALIDACIÓN INTERFAZ "LENGUAJE"

En esta interfaz aparece una venta informativa con las opciones de lenguaje activas para el usuario que se ha seleccionado: las bibliotecas disponibles, el número de pictogramas activos, los nombres de los grupos de pictogramas…

Existe también la posibilidad de añadir un "predictor" que proponga palabras/pictogramas al usuario a medida que éste va construyendo sus mensajes. Este sistema se basaría en: las prioridades del usuario, en su uso frecuente de determinados pictogramas o en la estructura semántica del mensaje que está escribiendo.



*** Atendiendo a la navegación por el sistema y a la información anterior, indique su nivel de satisfacción con esta interfaz.**

- Muy satisfecho
- Satisfecho
- Neutro
- Insatisfecho
- Muy insatisfecho

Observaciones

33. VALIDACIÓN INTERFAZ "BIBLIOTECA"

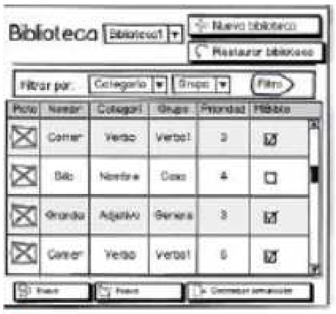
Los pictogramas disponibles se pueden visualizar desde esta interfaz. La configuración del programa tendrá por defecto varias librerías predefinidas pero el usuario y su familiar/cuidador podrá crear/personalizar nuevas, cogiendo pictogramas de otras librerías (del propio comunicador, de otros usuarios, de internet…). A cada pictograma se le pueden asignar una serie de propiedades/variables:

• Categoría: establecer si se trata de un verbo, adjetivo, nombre… Esta clasificación puede facilitar el predictor según la estructura gramatical del mensaje que se esté construyendo (P.e Si el usuarios selecciona un sujeto, después sólo le mostraría pictogramas de verbos).

• Grupo: es un término que agrupa un conjunto de pictogramas relacionados entre sí (pueden ser pictogramas de varias categorías). Por ejemplo, el grupo "cocina" agruparía términos como "sartén, cubierto, cocinar…" Esta clasificación puede aligerar la comunicación en casos críticos como sería una alerta en el estado de salud, mostrando sólo los pictogramas de los grupos relacionados con la salud.

• Prioridad: se establece según la frecuencia de uso y/o importancia que el usuario haga de cada pictograma. Esta clasificación puede ser útil en estados de estrés, cuando el comunicador a de reducir el número de pictogramas que mostrar al usuario para que escoja (mostraría sólo los de una prioridad superior).

Para localizar un pictograma también existe la opción de hacer un filtrado basándose en estas propiedades descritas.



*** Atendiendo a la navegación por el sistema y a la información anterior, indique su nivel de satisfacción con esta interfaz.**

- Muy satisfecho
- Satisfecho
- Neutro
- Insatisfecho
- Muy insatisfecho

Observaciones

34. VALIDACIÓN INTERFAZ "NUEVO PICTOGRAMA"

Dentro de una librería se pueden crear nuevos pictogramas. Se pueden importar de otras librerías o crearlos directamente. A cada pictograma que se cree se le deben asignar las categorías mencionadas anteriormente: categoría, grupo, prioridad…

*** Atendiendo a la navegación por el sistema y a la información anterior, indique su nivel de satisfacción con esta interfaz.**

- Muy satisfecho
- Satisfecho
- Neutro
- Insatisfecho
- Muy insatisfecho

Observaciones

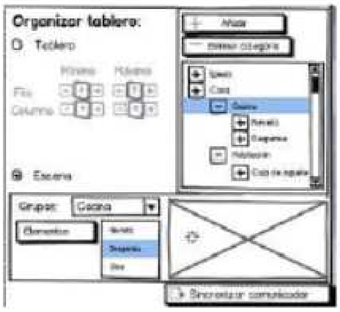
35. VALIDACIÓN INTERFAZ "ORGANIZAR TABLERO"

Esta interfaz permite configurar la organización de los pictogramas en la pantalla del comunicador. Esto se puede hacer por "rejillas" o por "escenas".

En el primero de los casos se puede establecer el número máximo y mínimo de pictogramas que se quiere que aparezcan en la pantalla del comunicador del usuario atendiendo, por ejemplo, a supuestos en los que hay variaciones en el estado emocional del usuario o el estado de salud (se podría establecer, por ejemplo que en estados de estrés no muestre al usuario más de 2 filas de pictogramas por 3 columnas).

En lo que se refiere a las escenas los pictogramas aparecerían insertos dentro de una imagen que simula un contexto real. P.e. se mostraría una imagen de una habitación en la que se podrían identificar y seleccionar varios pictogramas como la cama, el armario, la mesita...

Esta interfaz permitiría también crear subgrupos de pictogramas dentro de grupos. Sería como una especie de "mapa de árbol" dónde un pictograma incluiría dentro de sí otros relacionado, y éstos a su vez otros. P.e. el "casa" contendría dentro de sí a "cocina, habitación, comedor, baño..." y la cocina a su vez contendría "nevera, lavadora, horno...".



*** Atendiendo a la navegación por el sistema y a la información anterior, indique su nivel de satisfacción con esta interfaz.**

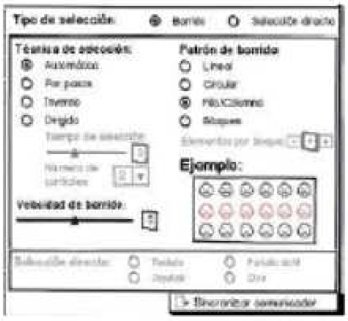
- Muy satisfecho
- Satisfecho
- Neutro
- Insatisfecho
- Muy insatisfecho

Observaciones

36. VALIDACIÓN INTERFAZ "TIPO DE SELECCIÓN"

En esta interfaz se trata de configurar el modo en el que el usuario va a seleccionar/ejecutar los diferentes pictogramas en el comunicador. Esta selección puede realizarse por barrido o por selección directa. En el caso de que la selección sea por barrido, esta interfaz permite indicar: la técnica de barrido, el patrón y la velocidad; y en caso de que sea por selección directa, el mecanismo que la controla (táctil, teclado, joystick…).

Para el funcionamiento de cualquiera de los dos sistemas de selección se han de haber configurado previamente las señales fisiológicas correspondientes (EMG, EEG, IMU's). Todas las señales se pueden utilizar para la selección por barrido y para la selección directa. En el caso del barrido, éste se detendría cuando hay un aumento en las señales; y en la selección directa estos mecanismos actuarían a modo de "ratón".



*** Atendiendo a la navegación por el sistema y a la información anterior, indique su nivel de satisfacción con esta interfaz.**

- Muy satisfecho
- Satisfecho
- Neutro
- Insatisfecho
- Muy insatisfecho

Observaciones

37. VALIDACIÓN INTERFAZ "SERVICIOS ONLINE"

El comunicador ABC dispondrá de acceso a internet, que se podrá configurar mediante esta interfaz (página predeterminada de inicio, favoritos…). Está pantalla también permitirá configurar un link de las principales redes sociales.

***Atendiendo a la navegación por el sistema y a la información anterior, indique su nivel de satisfacción con esta interfaz.**

- Muy satisfecho
- Satisfecho
- Neutro
- Insatisfecho
- Muy insatisfecho

Observaciones

38. VALIDACIÓN INTERFAZ "OTROS"

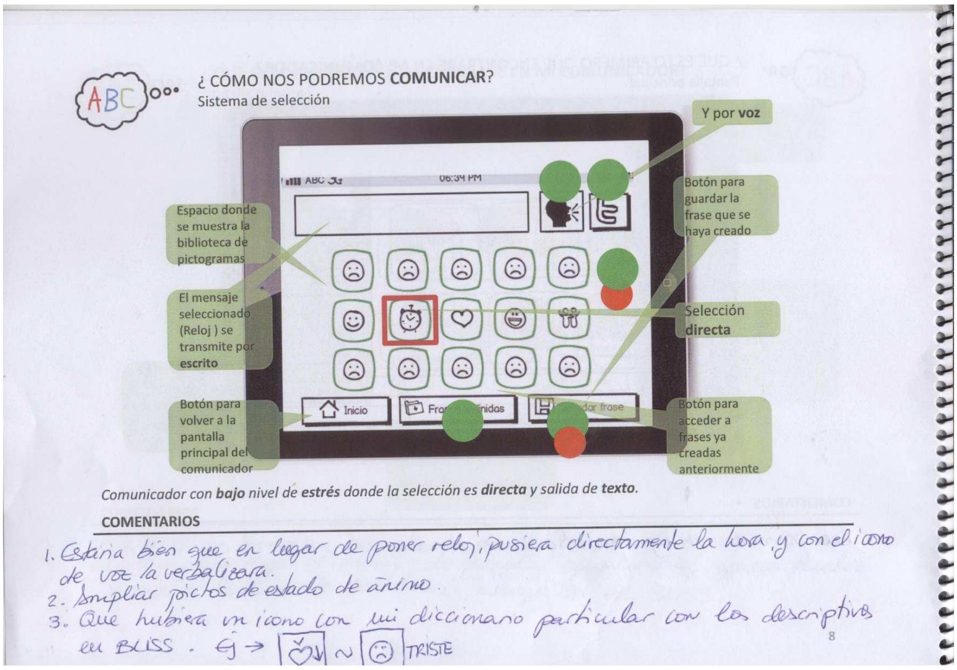
El resto de servicios y funciones del comunicador ABC como música, vídeos..., se podrán activar/desactivar en esta interfaz.

***Atendiendo a la navegación por el sistema y a la información anterior, indique su nivel de satisfacción con esta interfaz.**

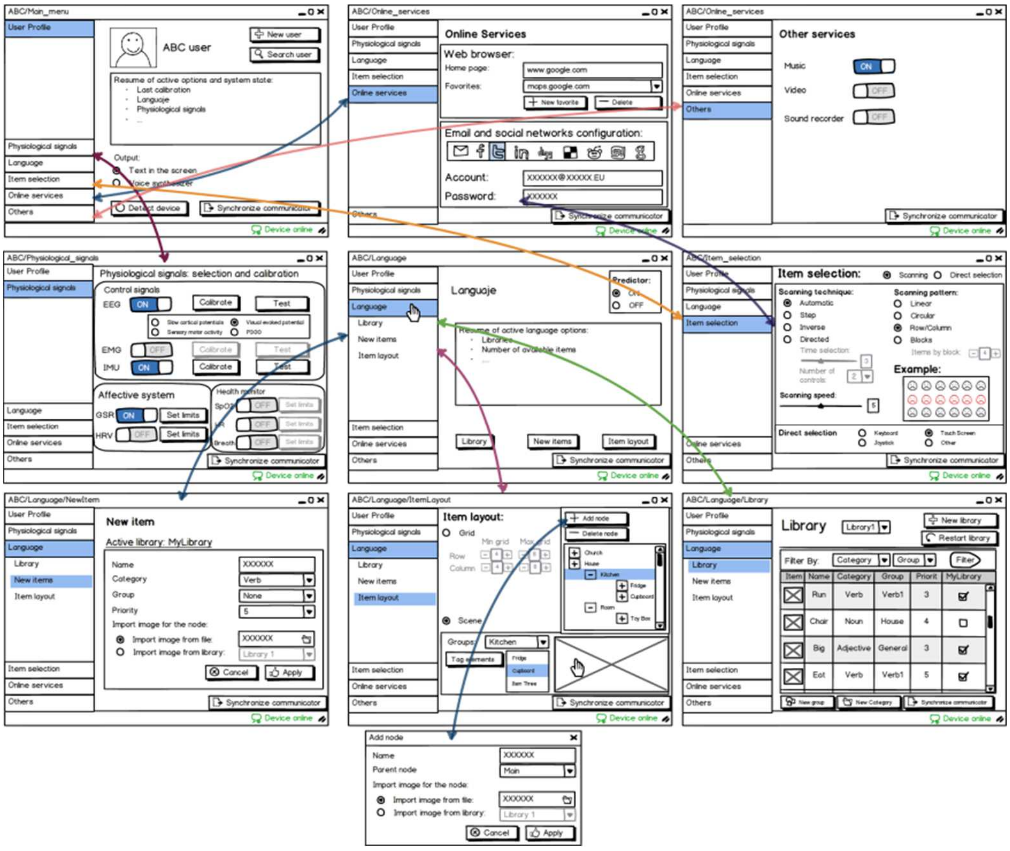
- Muy satisfecho
- Satisfecho
- Neutro
- Insatisfecho
- Muy insatisfecho

Observaciones

Appendix B.
Concept Test booklet



Appendix C.
Diagram of the Configuration Interface



Appendix D.
Informed consent

INSTITUTO DE BIOMECÁNICA DE VALENCIA

Yo, D./Dña..., con **D.N.I.**:..............................., habiendo recibido información del **proyecto ABC,** desarrollado por el Instituto de Biomecánica de Valencia, en el que voy a prestar mi colaboración, realizando actividades relativas a *"ensayos de usabilidad de un sistema de control con EMG."*; y habiendo sido suficientemente **informado/a** de las tareas a realizar, condiciones de las mismas, objetivos del proyecto y uso que se le va a dar a la información obtenida en el transcurso de la colaboración **por**.............................a quien he podido hacer preguntas sobre el mismo.

Comprendo que mi participación es voluntaria, y que puedo retirarme del estudio en cualquier momento. Por lo que doy libremente mi conformidad para:

SÍ	NO	
☐	☐	Participar en el presente estudio.
☐	☐	Registrar imágenes de mi participación en el estudio.
☐	☐	Incluir las imágenes obtenidas en publicaciones y materiales promocionales de ámbito científico.
☐	☐	Incluir los datos personales en un fichero automatizado propiedad del Instituto de Biomecánica de Valencia cuya finalidad es **la localización de personas que colaboren en la realización de estudios desarrollados por el IBV**. Los datos serán tratados conforme establece la Ley Orgánica 15/1999, de 13 de diciembre, de Protección de Datos de Carácter Personal.

Fdo: …………………………………………...   Fdo:……………………………………………

El participante, tutor o representante legal   La persona que ha informado

Valencia, a ...., de .... de 2014

Podrá consultar, modificar o cancelar sus datos poniéndose en contacto con el Servicio de Valoración de la Información de los Usuarios a través de los modos de contacto indicados en el pie de página.

Appendix E.

Experimental design: distribution of the diferent sizes and distances of the buttons between control systems.

User	Test	Ncolum	Col objective	Control	SizeBtn	DistBtn
1	U1T1	14	7	filter	medium	halfway
1	U1T2	8	4	filter	big	halfway
1	U1T3	20	18	filter	small	far
1	U1T4	14	12	filter	medium	far
1	U1T5	8	6	filter	big	far
1	U1T6	20	4	model	small	close
1	U1T7	14	3	model	medium	close
1	U1T8	8	2	model	big	close
1	U1T9	20	10	model	small	halfway
1	U1T10	14	7	model	medium	halfway
2	U2T1	8	2	model	big	close
2	U2T2	14	7	model	medium	halfway
2	U2T3	8	4	model	big	halfway
2	U2T4	20	18	model	small	far
2	U2T5	14	12	model	medium	far
2	U2T6	20	4	filter	small	close
2	U2T7	8	2	filter	big	close
2	U2T8	20	10	filter	small	halfway
2	U2T9	8	4	filter	big	halfway

2	U2T10	14	12	filter	medium	far
3	U3T1	8	2	filter	big	close
3	U3T2	20	10	filter	small	halfway
3	U3T3	14	7	filter	medium	halfway
3	U3T4	14	7	filter	medium	halfway
3	U3T5	20	18	filter	small	far
3	U3T6	20	4	model	small	close
3	U3T7	8	2	model	big	close
3	U3T8	20	10	model	small	halfway
3	U3T9	14	12	model	medium	far
3	U3T10	8	6	model	big	far
4	U4T1	14	7	model	medium	halfway
4	U4T2	8	4	model	big	halfway
4	U4T3	20	18	model	small	far
4	U4T4	14	12	model	medium	far
4	U4T5	8	6	model	big	far
4	U4T6	20	4	filter	small	close
4	U4T7	14	3	filter	medium	close
4	U4T8	14	3	filter	medium	close
4	U4T9	20	10	filter	small	halfway
4	U4T10	8	6	filter	big	far
5	U5T1	20	4	filter	small	close
5	U5T2	14	3	filter	medium	close
5	U5T3	8	2	filter	big	close
5	U5T4	8	4	filter	big	halfway
5	U5T5	8	6	filter	big	far
5	U5T6	14	3	model	medium	close
5	U5T7	20	10	model	small	halfway
5	U5T8	14	7	model	medium	halfway
5	U5T9	20	18	model	small	far

5	U5T10	8	6	model	big	far
6	U6T1	20	4	model	small	close
6	U6T2	14	3	model	medium	close
6	U6T3	8	2	model	big	close
6	U6T4	8	4	model	big	halfway
6	U6T5	14	12	model	medium	far
6	U6T6	14	3	filter	medium	close
6	U6T7	20	10	filter	small	halfway
6	U6T8	8	4	filter	big	halfway
6	U6T9	20	18	filter	small	far
6	U6T10	14	12	filter	medium	far