INVESTIGACIÓN E INNOVACIÓN EN INGENIERÍAS

Innovative hybrid virtual keyboard: A symbolic approach to enhance communication for individuals with severe neuro-muscular pathologies

Innovador teclado virtual híbrido: un enfoque simbólico para mejorar la comunicación en individuos con patologías neuromusculares severas

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Abstract

Objective: The objective of the study is to enhance communication efficiency for individuals with advanced neuromuscular pathologies, specifically by increasing the number of letters written per second through a hybrid Augmentative and Alternative Communication (AAC) software. **Methods:** The methodology involves the development of a hybrid AAC software that can be activated through acoustic events, physical events, or coded selection. Additionally, this system was implemented in an Android app, and a study of the target group was conducted to assess its usability and accessibility. **Results:** The results indicate that the proposed keyboard overcomes many limitations of traditional AAC systems, providing greater usability and efficiency in communication for individuals with neuromuscular diseases. **Conclusions:** In conclusion, the study demonstrates that the proposed keyboard offers an alternative solution to enhance communication for individuals with neuromuscular pathologies, enabling them to access educational and employment inclusion by using any type of computer.

Keywords: augmentative and alternative communication; usability; human-computer interaction; neuromuscular diseases; disability, educational technology.

Resumen

Objetivo. El objetivo del estudio es mejorar la eficiencia de la comunicación para individuos con patologías neuromusculares avanzadas, específicamente aumentando el número de letras escritas por segundo a través de un software híbrido de Comunicación Aumentativa y Alternativa (AAC). **Métodos:** La metodología utilizada implica el desarrollo de un software híbrido AAC que puede activarse a través de eventos acústicos, físicos o selección codificada. Además, se implementó este sistema en una aplicación de Android y se realizó un estudio del grupo objetivo para evaluar su usabilidad y accesibilidad. **Resultados:** Los resultados indican que el teclado propuesto supera muchas de las limitaciones de los sistemas AAC tradicionales, proporcionando mayor usabilidad y eficiencia en la comunicación para personas con enfermedades neuromusculares. **Conclusiones:** En conclusión, el estudio demuestra que el teclado propuesto ofrece una solución alternativa para mejorar la comunicación de personas con patologías neuromusculares, lo que les permite acceder a la inclusión educativa y laboral mediante el uso de cualquier tipo de computador.

Palabras clave: comunicación aumentativa y alternativa; usabilidad; interacción persona-ordenador; enfermedades neuromusculares; discapacidad, tecnología educativa.

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Introduction

The classic communication model comprises three components: the sender, the message, and the receiver [1]. The sender sends a message, which the receiver receives [2]. However, some individuals with diseases or traumas may be unable to send messages to the receiver, preventing effective communication. This can result in dependency and isolation, and the inability to make decisions that affect one's life [3]. Assistive Technology (AT) systems are designed to enable users with disabilities to achieve their highest level of functioning in specific life roles [4, 5, 6]. Among the different ATs, the Alternative and Augmentative Communication (AAC) system intervenes directly in language and communication issues. It refers to any device, including software, technology, equipment, or instruments, that replaces or partially replaces the ability to communicate. It also includes forms of expression other than spoken language that aim to increase the level of expression and/or compensate for communication difficulties [7, 8]. The goal of AAC is to enhance personal autonomy and quality of life [4].

Neuromuscular diseases encompass around 150 chronic neurological disorders that result in significant disability and loss of personal autonomy. The loss of muscle strength is a primary feature of these diseases [9]. Neuromotor diseases, such as amyotrophic lateral sclerosis, muscular dystonia, Friedreich's ataxia, or bone marrow injuries, can alter an individual's ability to interact with their environment [7, 10]. These diseases tend to worsen over time, and there are currently no effective treatments or cures [8, 11]. Due to their intrinsic function, AAC systems must be usable for the population with neuromuscular diseases. Usability is an essential attribute of AAC systems and refers to the degree to which a product or system can be used by specific users to achieve specific objectives with effectiveness, efficiency, and satisfaction in a specific context of use [12]. Efficiency is an attribute of usability and is defined as the resources expended in relation to the precision and integrity with which users achieve their objectives. In this research, efficiency refers to time [13].

The classical QWERTY keyboard concept has been a hindrance to people with neuromuscular diseases in terms of efficiency, and a paradigm shift is necessary [14]. Several studies have provided insights into design considerations, such as the importance of adequate design of the Visual Scene Displays (VSDs) for effective and efficient communication [11]. VSDs are images that represent events or situations, which can be particularly efficient for diseases that affect cognitive or motor skills [15]. However, there is a high rate of non-use and abandonment of AACs, especially in people with severe diseases [12]. Good design and flexibility are essential in AAC systems, as emphasized in a study of children with severe speech and physical disabilities [13]. The primary reason for abandonment of AACs is due to design flaws and traditional techniques that make their long-term use impossible [16].

The main contribution of this article is the design of a new keyboard implemented in Android systems that improves efficiency for people with neuromuscular diseases. Our design incorporates a system of signs that, when interpreted, generates a letter and includes a simple sound as a human-computer interaction method to help people with partial or total immobility. We also redefined the way to write the actual alphabet using a symbol system, which allows 64 different characters to be assigned with just three symbol combinations, reducing the time required to perform the same task with a classic keyboard. We also performed an analysis of relative frequencies in the Spanish language to establish the best efficiency for this type of software device [16].

The rest of this work is structured as follows. Section 2 presents a background of previous work reported in the literature. Section 3 describes the materials and methods used. Section 4 externalizes the results and discussion of the usability evaluation. Sections 5 and 6 show the conclusions and the bibliography, respectively.

Background

Initially, the first virtual AAC keyboards were created to help individuals with neuromuscular disorders communicate by entering text. These virtual keyboards display a keyboard layout (usually the conventional QWERTY) on the computer screen through software. However, some researchers such as [2, 4, 17] have suggested that virtual keyboards have lower typing performance than physical keyboards, even when users are not disabled. The primary reasons for this include the small size of virtual keys, the lack of tactile feedback, and the occlusion of virtual keys with fingers [18].

Users with disabilities experience even lower efficiency due to their limited ability to interact with the keyboard [4], which can affect their participation and limit their activities. Disabilities can range from simple motor limitations, such as loss of arm movement, to more severe limitations that only allow eye movements. Additionally, cognitive impairment has been shown to be associated with a more rapid progression of the disease and a shorter life expectancy [18]. To ensure that users can communicate through virtual keyboards, various interaction strategies such as acoustic or tactile events are used [20].

However, research by [21] suggests that these interaction techniques can further limit the user's typing performance. On a physical keyboard, experienced typists can produce more than thirty words per minute [22, 23, 24]. Even with techniques such as keyboard layouts, letter sequences, and complex text prediction techniques, typing efficiency on a virtual keyboard remains low, usually producing four to seven words per minute for individuals with Motor Neuron Disease (MND) [21].

Despite the availability of several solutions, the problem of low typing efficiency of virtual keyboards used by people with disabilities remains unsolved [25]. Efficiency is measured by the number of actions that can be performed in a unit of time [26], making it a crucial factor in this type of device.

Virtual AAC keyboards were initially designed to facilitate text input for people with neuromuscular disorders [27]. They display a keyboard layout, usually the conventional QWERTY, on the computer screen and support communication for those who have difficulties using physical keyboards [28].

However, according to researchers such as [2, 4, 17] virtual keyboards demonstrate lower typing performance than physical keyboards, even for non-disabled users. The main reasons are the small size of virtual keys, the lack of tactile feedback, and the occlusion of virtual keys with the fingers.

For users with disabilities, virtual keyboards are even less efficient due to their limited participation and ability to interact with the keyboard [4]. There are various disabilities, ranging from simple motor limitations to severe ones that only allow eye movements. Moreover, cognitive impairment has been shown to be associated with a more rapid progression of the disease and a shorter life expectancy [19]. To ensure communication through virtual keyboards, different interaction strategies such as acoustic or tactile events are used. However, as reported by [21, 29], such interaction techniques limit typing performance. While experienced typists can produce over thirty words per minute on a physical keyboard [22, 23, 24], a person with MND typically produces only four to seven words per minute using virtual keyboards [21, 30].

The problem of low typing efficiency with virtual keyboards remains unsolved [25], despite many solutions available. In this type of device, efficiency is measured by the number of actions that can be performed in a unit of time [26].

As reported by [31], with virtual keyboards in the English alphabet, a person can write 520 characters per minute with the scanning access technique. However, in our keyboard, we achieved a performance of 820 characters, showing an increase in efficiency compared to the literature. Furthermore, we incorporated predefined words into the remaining spaces on the keyboard. Our review, conducted in the Spanish language, also yielded the best results.

In recent years, different methods of capturing events that allow interaction between the user and the system have been researched [32, 33, 34, 35, 36]. The brain-computer interface method stands out for its wide adaptability to people with MND since it allows information to be obtained directly from the brain [37]. However, its high cost makes it incompatible with low-income users. Eye scanning is another method that tracks the eye through sensors or cameras to select a target on the screen. However, in advanced stages of MND, people lose control of their eye muscles, making this method impossible [38, 39]. Despite these limitations, research on graphical interfaces that improve the usability of the system has been overlooked [40]. Therefore, reducing time could significantly enhance the software's usability and improve the quality of life of people with neuromuscular disorders.

Different types of language representations are used in AAC. Spelling is a technique that involves joining individual letters to form words [41, 42]. While it is an effective technique since there are twenty-six letters in the English alphabet and twenty-seven letters in Spanish, it requires user skill and is inefficient for conversational communication [43]. Single meaning pictures are another technique that uses an image for each word. However, this approach is not practical because a three-year-old child can handle an average of one hundred words [28].

Semantic compaction, also known as Minspeak, is an icon or image-based technique used in AAC that is similar to the productivity improvement approach in ACC [44]. This technique uses images because they are more impactful and can convey more information than letters alone [45]. The goal is to combine a sequence of icons to form a word or phrase. Minspeak is typically presented in pairs of images, where the first image provides a theme or context and the second image gives a specific idea. You can refer to Figure 1 for a visual representation of this technique.

Figure 1. Minspeak: images of house and bed can mean room

Source: Authors' own creation

Materials and methods

To develop the new AAC virtual keyboard, several steps were followed [27, 46]. These are:

(i) Evaluating device access parameters: Before starting the development of the keyboard, different access parameters for the device were evaluated. These parameters included scanning rate, touch accuracy, and device processing speed. The goal of this step was to ensure that the device had the necessary specifications to support the AAC keyboard.

(ii) Definition of the target audience: The target audience for the AAC virtual keyboard was defined. This included people with neuromuscular disorders and other disabilities that affect their ability to communicate through traditional means. The goal was to ensure that the design of the keyboard was tailored to the needs of this specific group of users.

(iii) Development of the virtual hybrid keyboard: The virtual hybrid keyboard was developed based on the input from the previous steps. The keyboard design combined elements of both virtual and physical keyboards to improve typing efficiency. The design incorporated a larger key size, haptic feedback, and word prediction features to improve typing speed and accuracy.

(iv) Development of a prototype for Android: Finally, a prototype of the AAC virtual keyboard was developed for the Android operating system. The prototype was tested and evaluated to ensure that it met the requirements of the target audience and had the necessary features to support efficient communication.

Overall, these steps were taken to ensure that the new AAC virtual keyboard was optimized for the needs of the target audience and had the necessary features to support efficient communication.

Evaluating devices access parameters

The hybrid selection method used in our research is a combination of indirect and coded selection. The virtual keyboard we developed presents the user with a grid of icons, which can be scanned using a switch. Once the user selects a category of icons, they can then select specific icons within that category by inputting a corresponding code. This method allows for a large number of symbols to be accessed using only a few keys or switches, making it a practical and efficient solution for users with MND. However, it is important to note that the choice of access method should always be tailored to the specific needs and abilities of the user, and may require individualized assessment and training.

Definition of the target audience

The keyboard was designed for individuals with severe neuromuscular diseases, such as amyotrophic lateral sclerosis, which is a neurodegenerative disease characterized by progressive damage to motor neurons (twenty-seven), or muscular dystrophy, a group of hereditary diseases that produce weakness, muscle atrophy, and gait disturbance as the disease progresses due to structural alterations of muscle proteins that lead to cell death (twenty-eight). These diseases share a common characteristic: both are progressive and result in the loss of communication in advanced stages (twenty-nine).

The developed keyboard provides support for people with MND who have sufficient fine motor skills to use their fingers to directly point to the symbol, or who can simply hit a material external to the screen, or make some short dry sound.

Development of the virtual hybrid keyboard

The virtual keyboard proposed in this article, which is an AAC system, was developed to cater to users with severe neuromuscular diseases, such as amyotrophic lateral sclerosis and muscular dystrophy. These diseases are characterized by progressive damage to motor neurons, muscle weakness, atrophy, gait disturbance, and loss of communication in advanced stages. The developed virtual keyboard supports people with MND, and users with correct fine motor skills can use it with their fingers to directly point to the symbol, hit some material, or make some short dry sound, even external to the screen.

To achieve a significant improvement in efficiency, the virtual keyboard uses two access methods, indirect and coded selection, and is defined as a hybrid virtual keyboard. In determining the relative frequency of the letters, the language used was Spanish, as users in Medellín, Colombia carried out the tests. However, calculating the frequency of letters in a language is difficult and subject to interpretation. The context is significant, and the presence of non-alphabetic characters such as punctuation marks, figures, parentheses, and common mathematical symbols may or may not be considered.

Table 1. Relative frequency of letters in the Spanish language

Letter	Frequency %	Letter	Frequency %
E	16.78	C	2.92
A	11.96	P	2.76
O	8.69	M	2.12
L	8.37	Y	1.54
S	7.88	Q	1.53
N	7.01	B	0.92
D	6.87	H	0.89
R	4.94	The rest of the letters have frequencies lower than 0.5% and they called "infrequent"	
U	4.80		
I	4.15		
T	3.31		

Source: Authors

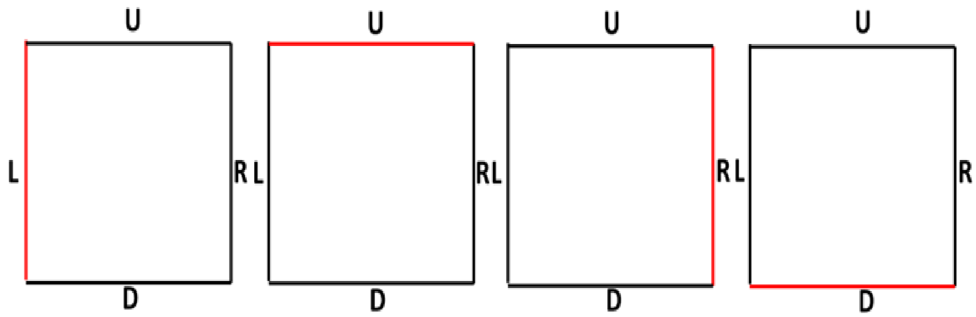
According to a study, vowels occupy about 47% of the text, and the letters “e” and “a” stand out above the others, together occupying 25% of the message. High-frequency letters account for 68% of the total, with the most frequent consonants being “l”, “s”, “n”, and “d” (about 30%). The six least frequent letters are “v”, «ñ», “j”, “z”, “x” and “k” (just over 1%), and the most frequent words such as “de”, “la”, “el” and “en” will occupy 30% of the text. Table 1 shows the relative frequency of the letters in the Spanish language.

Based on the frequencies in Table 1, inference rules were defined on the keyboard in assigning codes. The codes that are quicker to communicate are assigned to the most frequent characters, while punctuation marks are ignored to emphasize consonants and reduce the time it takes to achieve a character.

Development of a prototype for Android

The interface shown in Figure 2 is based on Android, which is a free platform for applications with a wide range of resources and innovations, including sensors, location, and services. The greatest potential of the Android application environment is that it leverages the Java programming language. While the Android SDK does not offer everything available in its standard Java Runtime Environment (JRE), it does support a significant fraction of it.

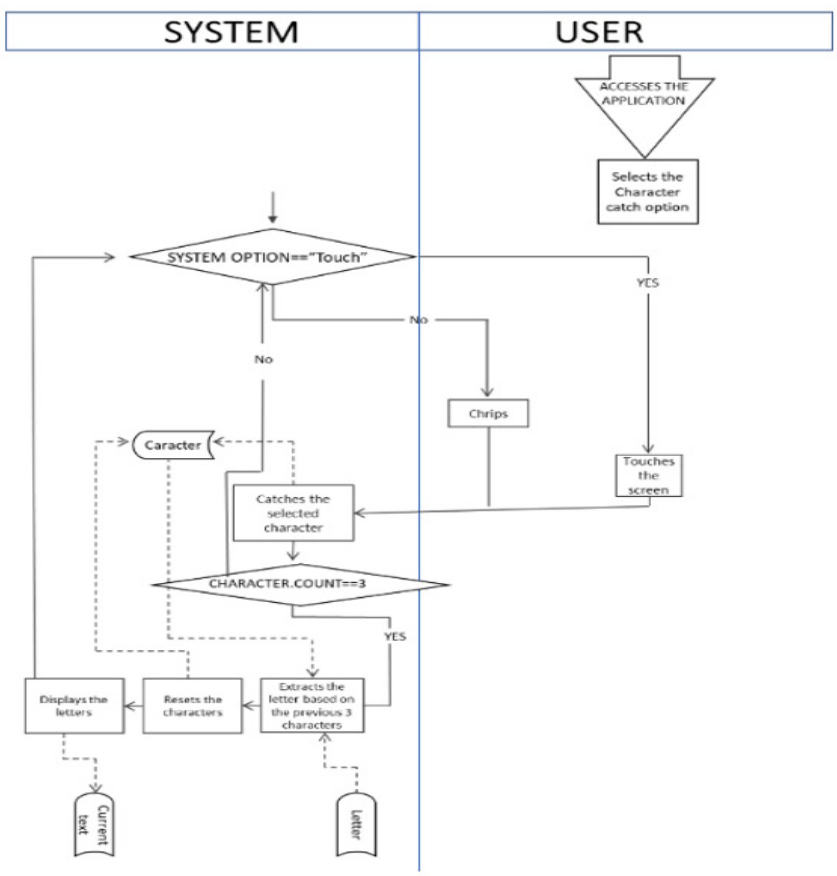
Figure 2. Steps for developing an AAC virtual keyboard



Source: Authors

Each character is represented by a unique combination of three positions in a four-sided box. If the user does not generate a selection event (hit, sound, tap) when the system points to a side, the system iterates until there is an event or the tour ends. For example, if the user wants to write the character "A," the first iteration will take two seconds due to the combination of the "A" ("U", "L", "L") that starts in "L" and then continues in "U." At this point, the user will have to carry out an event to select the side. Subsequently, the user must perform two events at the beginning of the interaction to form the letter "A" (see Figure 3).

Figure 3. System process model



Source: Authors

The keyboard has a dictionary in the Android database defined by the analysis of relative frequencies of the letters. To improve efficiency, the most frequently used character was assigned the least input time in the system. In this case, the space character is the most frequently used, followed by "A" and then by "E" (see Table 2 for the disposition of all characters). The last column of Table 2 shows the input time required to enter a letter if the user selects one second in the time between iterations.

Table 2. Assignment of character positions in the system

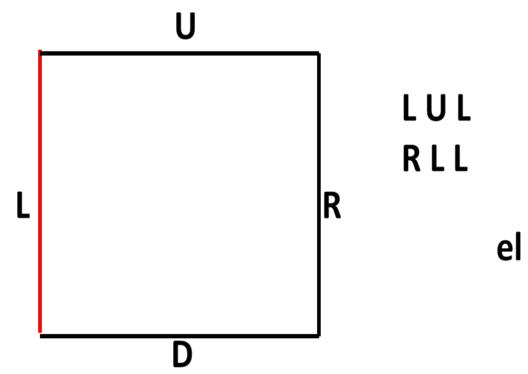
Character	Slide 1	Slide 2	Slide 3	Time (sec)
Space	L	L	L	3
A	U	L	L	4
E	L	U	L	4
O	L	L	U	4
S	U	U	L	5
R	L	U	U	5
N	U	L	U	5
L	R	L	L	5
I	L	L	R	5
D	L	R	L	5
U	L	R	U	6
T	U	L	R	6
C	R	L	U	6
M	L	U	R	6
B	R	U	L	6
P	L	L	D	6
Q	D	L	L	6
V	L	D	L	6
G	U	U	U	6
H	D	U	L	7
Y	U	L	D	7
F	L	U	D	7
J	R	R	L	7
Z	L	R	R	7
Ñ	R	L	R	7
K	D	L	U	7
W	L	D	U	7
X	R	U	D	8

Source: Authors

The system offers the option to choose one of two selection methods: screen touches, which involves a touch event on the mobile device screen, and sound, which involves a sound event generated by the user through a body sound or by generating a blow in some material that is captured by the microphone of the mobile device. If the user can press the screen, then the selected method is "touches on the screen," or if the pathology is severe, they will choose the sound method.

After choosing the selection method, the user can select the time required in each interaction of the box, such as 0.5, 1, 2, and 4 seconds (see Figure 4).

Figure 4. Example of typing the syllable "el"



Source: Authors

In this case, it would take the user nine seconds to select the lines that make up the different characters (see Table 2).

Results and discussion of the usability evaluation

Usability testing is a quality assurance service that involves inviting a sample of end users to test the system and provide valuable feedback on its ease of use and efficiency [47, 48]. This is very important because users can identify issues that are not visible to the developer.

Twenty people with neuromuscular diseases (ten with amyotrophic lateral sclerosis, seven men and three women), six with muscular dystrophy (one woman and five men) and four with spinal muscular atrophy (four men) participated in our research. The aver-age age was twenty-seven. All participants have stiff limbs, have spastic movements, use a wheelchair to get around, and do not have significant cognitive impairments.

They are taught how the system works by writing five words and are given a physical copy of the combinations (Table 2). Some participants presented difficulty synchronizing between the event and the desired character, in these cases it was decided to extend the time from two to four seconds in the auto sweep transition depending on how pronounced the desynchronization was. The results are shown in Tables 3, 4 and 5.

Table 3. Typing times of three words (sec), users from 1 to 7

	Users						
	1 ALS M	2 ALS M (2 sec)	3 ALS M	4 ALS M (4 sec)	5 ALS M	6 ALS M	7 ALS M
First attempt	120	323	196	488	136	206	135
Second attempt	95	254	174	542	148	198	145
Third attempt	85	194	166	466	118	173	115
SUS	47.5	52.5	45	60	57.5	55	50

Source: Authors

Table 4. Typing times of three words (sec), users from 8 to 14

	Users						
	8 ALS W	9 ALS W (2 sec)	10 ALS W	11 DM M (4 sec)	12 DM M	13 DM M	14 DM M
First attempt	186	284	155	522	125	198	112
Second attempt	168	315	134	538	137	172	104
Third attempt	144	257	125	505	114	164	110
SUS	45	65	62.5	62.5	60	55	65

Source: Authors

Table 5. Typing times of three words (sec), users from 15 to 20

	Users						
	15 DM M (2 sec)	16 DM W	17 SMA M	18 SMA M (2 sec)	19 SMA M	20 SMA M (4 sec)	Total usability
First attempt	186	284	155	522	125	198	56.125
Second attempt	168	315	134	538	137	172	
Third attempt	144	257	125	505	114	164	
SUS	45	65	62.5	62.5	60	55	

Source: Authors

Two attempts to use the keyboard were captured and they were asked to write three words: “hello”, “shoe” and “clothes” (in Spanish), where the optimal time is 70 seconds with one second of transition in the automatic sweep. In addition, typing errors do not reset time. It is evident that as the attempts progress, the time of the three words, the writing time is reduced in most cases.

To evaluate the usability of the developed system we use the standard method called System Usability Scale (SUS) [49]. The SUS was made up of simple and straightforward questions about the usability of the system that help identify problems while users make use of it. The questions are (Table 6):

Table 6. Questions using the SUS method

Number	Questions
1	I think that I would like to use this system frequently
2	I found the system unnecessarily complex.
3	I thought the system was easy to use
4	I think that I would need the support of a technical person to be able to use this system
5	I found the various functions in this system were well integrated
6	I thought there was too much inconsistency in this system
7	I would imagine that most people would learn to use this system very quickly
8	I found the system very cumbersome to use
9	I felt very confident using the system
10	I needed to learn a lot of things before I could get going with this system

Source: Authors

As reported by [49, 50], in their study, they performed a factorial analysis and found two factors: Usable (eight items) and Learnable (two items, 7 and 10). In our evaluation, it is evident that both elements of the learnable factor affect the result too much. This should be improved in the future if the system is to have optimal usability.

Conclusions

In the world, many people suffer from chronic neuromuscular diseases that generate motor disability and that diminish their ability to communicate orally or in writing by digital means.

A hybrid virtual keyboard AAC was developed to improve its capacity, which differs from others with similar purposes, in that, it breaks the paradigm of using a twenty-seven letter QWERTY type keyboard and, instead, uses a new series of symbols, that allows greater efficiency when entering text (820 words per minute compared to forty-seven re-ported in the literature) since it is not needed to scan up to twenty-seven elements per letter, but a maximum of four. When assigning symbols to letters, efficiency was prioritized for those with the highest frequency of use in the Spanish language.

In order to support people with a high spectrum of motor limitations, it was implemented in an Android application, in which the user can choose to give signals of choice, through external sounds (hitting any material, guttural sound, etc.) or taps any-where on the screen (not necessarily on the symbol). The user can also adjust the sweep speed. It does not require any additional device, but simply a cell phone, tablet or computer, which makes it affordable to most.

The data obtained in the usability study indicate that our AAC has good usability. However, as a scientific community we cannot forget the limitations of AAC systems, as evidence shows that users abandon these systems after a period of use. In the system developed in our research, a learning problem of the character formation structures is evident, which slows down the composition of the words while the users form the idea of the operation.

Contrasting the times obtained with others reported in the literature, it is found that a keyboard that uses bio-signals takes an average of twenty minutes to write twenty-five letters. In addition, on a keyboard that uses acoustic events through an interface similar to that of an old cell phone, writing twenty-five letters takes 8:48 in the best of cases. In our specific case, a similar test was performed by typing three words made up of sixteen letters, obtaining the result reported in table three where the task of writing three words was performed in best case in eighty-five seconds, obtaining an increase of 902% with respect to the first keyboard and 396% with the second. Likewise, the usability test yielded interesting results that can be improved if the cognitive aspect of learning the different combinations is taken into account.

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