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AACVOX: mobile application for augmentative alternative communication to help people with speech disorder and motor impairment

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Abstract **Introduction:** Communication is a fundamental element for the development of human beings, promoting their coexistence in society. However, changes in muscle tone, associated with cerebral palsy (CP), among other conditions, cause phono-articulatory dysfunctions hindering speech capabilities. Although there are resources for augmentative and alternative communication (AAC), most of them do not completely satisfy the needs of individuals with motor impairment. Therefore, this study proposes a tool based on mobile technology for AAC, which can be adapted to the characteristics of the motor limitations of CP users. **Methods:** Mobile system development was conducted employing user-centered design and development methods. Functions were developed allowing the communication of phrases through pictographic resources and a mechanism of speech synthesis, that can be customized according to specific communication needs. To validate this system, 20 CP volunteers with speech difficulties and motor impairment were recruited from two institutions in the State of São Paulo, Brazil. They operated the system following a pre-defined test protocol, and they answered a system usability scale (SUS) questionnaire, to rate the ease of learning, memorization, efficiency, occurrence of runtime errors, and the level of user satisfaction. **Results:** The results showed a score of 85.85 ± 2.28 above the average SUS scale, for each one of the quality components assessed by the volunteers. **Conclusion:** The developed software is user-friendly, representing a new option for AAC, and is customized according to the communication needs of people with speech disorder and motor impairment.

Keywords Mobile devices, Augmentative and alternative communication, Cerebral palsy, Motor impairment.

Introduction

Communication is an essential element contributing to human development, promoting coexistence and inclusiveness in society (Nunes, 2002). Through communication it is possible to express thoughts, desires, and emotions. Humans began to explore communication skills since the early ages. Throughout life, this skill is developed allowing an individual to grow and be accepted in society (Bordenave, 2002).

Severe speech or language problems impair societal interactions and could lead to social isolation (Schirmer, 2009). Nowadays, unfavorable communication skills affect a significant number of people. Countries like Canada, the United Kingdom, Australia, and the United States estimate that approximately 1.3% of their populations have speech and language problems that significantly affect their communication skills. One of the primary factors contributing to communication problems currently is cerebral palsy (CP) (Hornero et al., 2015).

Cerebral palsy is a disorder that affects the central nervous system, that could occur before, during, or after birth, and in the bulk of cases, in the first three months of life (Bax et al., 2005). It results in impairment of brain development, of a non-progressive but permanent nature, and interferes with the normal motor development of a child (Bax et al., 2005). In 60% of cases changes also occur in regions of the brain responsible for motor language functions, making it impossible for the individual to either articulate speech or speak correctly (Bax et al., 2006). In the bulk of cases CP does not affect the areas of the brain responsible for thinking and memory, and individuals with CP typically have intelligence within normal ranges (Santos, 2014). However, severe speech or language problems caused by CP are often perceived, incorrectly, as a mental disability because of prejudice or ignorance (Schirmer, 2009).

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Solving the problems encountered by people with speech disorders in daily activities has driven the development of a number of techniques and strategies to aid the speech of individuals with CP to compensate for their disabilities (American..., 2002). The first resources for augmentative and alternative communication (AAC) were developed in the 1970s in Toronto, Canada (Cook and Polgar, 2014). Since then, parents and special education teachers have been encouraged to use sign language and symbols to communicate with people with speech disorders (Light and McNaughton, 2012). The picture exchange communication system (PECS) was developed in the 1980s as a multi-phase AAC intervention to assist individuals with speech disorders (Wilkinson and Hennig, 2007). Despite the benefits of PECS, there were still significant limitations (Cook and Polgar, 2014). In an attempt to use technology to improve communication interventions, the first use of AAC technologies came in the form of AAC devices with pre-loaded software used solely for communication purposes (Wilkinson and Hennig, 2007). These devices allow a person to use digitized and/or synthetic speech to communicate and make the communication process more approach to ordinary speech (Light and McNaughton, 2012). Despite the technological advancement of AACs, speech-generating devices (also known as voice output communication aids) are extremely expensive, difficult to program or personalize, and not sufficiently flexible to accommodate the needs of users (Shane et al., 2011). With the aim of making optimal use of AAC devices, while producing a more affordable tool, AAC applications (app) were created. (Manrique et al., 2016). This is a significant milestone for AAC app growth, that also extended to the academic and scientific communities (Light and McNaughton, 2012).

Palmeiras et al. (2013), developed apps to facilitate communication between staff and patients in an intensive care unit. The app allowed communication by displaying messages on an interface. Reyes et al. (2014), developed an app with an interface comprising pictographic figures organized into groups and subgroups for structuring sentences for communication, which could be verbalized on the mobile device through the audio playback feature. Mendes and Correia (2013) developed an app with the interface based on the communication folder model. Ghatkamble et al. (2014) developed an AAC app for the sporting environment. Basile et al. (2014), developed apps for Android platform mobile devices that allowed the user to communicate in different environments through the audio playback feature using 372 everyday phrases.

Despite the increasing number of scientific studies regarding AAC app development, few studies focused on usability (Quintela et al., 2013). As a result, the anticipated benefits may not be realized for numerous individuals, not because they cannot benefit from AAC, but rather because the AAC apps are either difficult or impossible to use by individuals with motor impairments (Scardovelli and Frère, 2015). Therefore, it is essential that developers use new technology to create apps that are more accessible to the impaired in order to minimize their limitations, contributing to their independence, quality of life, and participation in society (Loja et al., 2015). With this in mind, this study aims to develop an AAC tool that adapts to the specific motor difficulty characteristics of individual CP users. Therefore, we developed an app for mobile devices with a customizable interface in order to facilitate its use by people with different levels of motor deficiencies, and validated the app through a usability test involving people with CP.

Methods

The AACVOX app was developed considering a software development process organized in four steps: software requirements, analysis, implementation, and testing.

Software requirements

The software requirement is the first step in software development, and deals with a description of the functionalities of the target system. The AACVOX app functionalities were defined through a scientific literature search, and through information collected from people with CP and their parents. Based on the analysis of this information, functional requirements (FR) and non-functional requirements (NFR) were defined:

- FR1 - The system must allow the user to communicate by using the audio sentence playback feature of the system;
- FR2 - The user can modify the existing communication features in the system by editing sentences and subtitles;
- FR3 - The system features offered for communication can be extended by using the camera feature of the device to add new pictographic features;
- FR4 - The user can configure the system communication options so the user can retain the options they use in daily communication;
- FR5 - The user can communicate any sentence or word through a system function that converts the typed text into audio;
- FR6 - The system must have a function that allows for interface configuration;
- FR7 - The system will have the “scan selection” function. This function will display on the screen one communication icon at a time, in a sequential manner, so that the user who has more serious motor impairment may select the desired option;

- NFR1 - The audio playback features offered by the system should be organized into categories to streamline the communication process;
- NFR2 - The sentences offered for system communication should be identified with an illustrative image to facilitate the use of the system by an illiterate person;
- NFR3 - The system must be able to be used on tablets.

Analysis

In the analysis and design stage, the system modeling was based on the requirements listed above. The modeling was developed by constructing a use case diagram, as shown in Figure 1, in which user the interaction with the system functionalities are shown.

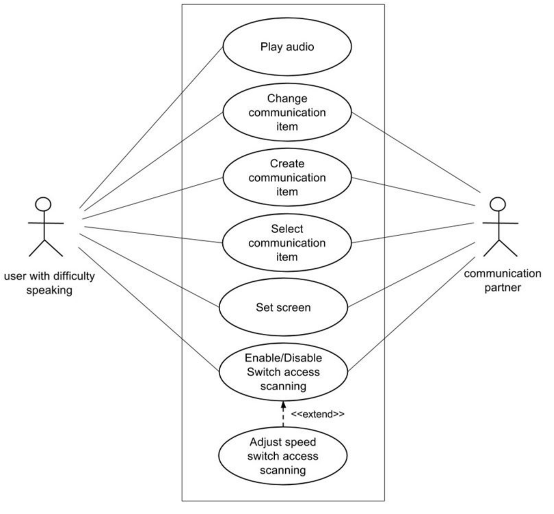

Figure 1. Use case diagram of the AACVOX app.

The system is designed so that the user with a speech disorder can use all of the functionalities of the system. However, if the user requires help, the system configuration functions can be changed by the communication partner (caregiver, a family member, or a friend) (Figure 1).

Implementation

The AACVOX app was implemented using the integrated development environment for Android Studio 1.3.1, with the Java programming language and the Extensible Markup Language. To develop this application for tablets running Android 4.1 or higher, the application programming interface of the Java Development Kit and the Android software development kit were installed.

The AACVOX development stages followed the interactive and incremental model. The SQlite database was used for data storage.

The audio sentences for communication via the app were built through the implementation of a function that uses a voice synthesis engine that converts the text characters into audio. The development of this function allows the user to build new audio features and modify the audio files that already exist.

To communicate a sentence with the app, the user must select two screen options: "Category Choice", and "Activity Choice". Initially, the user selects what he wants to communicate on the "Category Choice" screen (Figure 2A), and then the options of sentences are presented for communication on the "Activity Choice" screen (Figure 2B).

In addition to the 168 images for audio playback, AACVOX allows the user to customize the application options with the following functions (Figure 3):

- Select which items should remain on the screen ("Select icon" key);

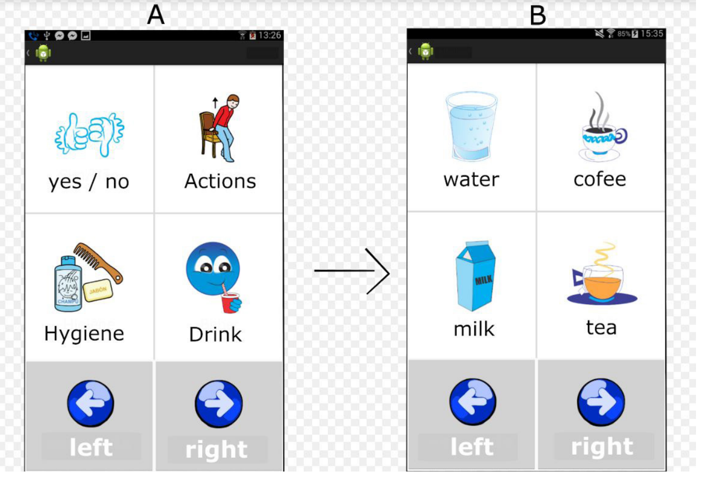

Figure 2. Screenshots of the AACVOX app: (A) Category Choice Screen; (B) Activity Choice Screen.

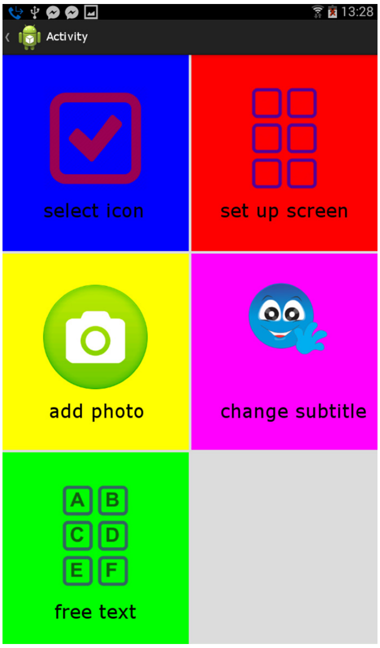

Figure 3. Screenshot of the AACVOX app: Configuration Screen.

- Configure the screen by selecting the layout type ("Set up screen" key);
- Add a new item of communication through the use of a photo ("Add photo" key);
- Change the audio sentences and the subtitle of communication items ("Change subtitle" key);
- Perform communication through typing sentences ("Free text" key).

In order to construct the application interfaces, a total of 168 pictographic symbols were used, of which 40 were created in the Corel Draw X7 image edition tool, and 128 were extracted from the ARASAAC (Aragonese..., 2018) portal. This portal provides graphic resources for AAC, and is the property of the Aragonese Center of Technologies for Education (CATEDU). It is licensed under the Creative Commons and was created by Sergio Palao. The graphic resources of the ARASAAC portal are free to use, provided the source is cited.

The AACVOX app was developed for mobile devices (smartphones and tablets), but is easier to use on tablets by individuals with CP as the screens are larger and allows the display to larger icons, that facilitates its selections by these individuals.

Software testing

Software testing was conducted to correct faults and ensure the correct functioning of the app (Pressman, 2005). The tests included the white box test used to correct faults in programming the source code, and the black box test where a virtual machine was used to simulate constant use of the application on a mobile device to identify errors.

Volunteers

Twenty volunteers that suffered from CP and speech difficulties, but did not have severe visual disabilities and/or cognitive deficiencies, participated in this study. The volunteers comprised 11 males and nine females, with ages ranging from 15–55 y. The volunteers were all wheelchair-bound, and were all boccia players. They had different degrees of motor disability and were recruited from two institutions in the Alto Tiete, Sesi and Parasports Municipal Center "Professor Cid Torquato", that are located in the cities of Suzano and Mogi das Cruzes, in the state of São Paulo, respectively.

The CP International Sports and Recreation Association (CPISRA) classified the volunteers as motor functionality level 1 (quadriplegic and tetraplegic-severe involvement, spasticity grade 4 to 3+) and level 2 (quadriplegic and tetraplegic-severe to moderate involvement).

The procedures involving human beings was performed considering the principles established in 1964 in the Declaration of Helsinki, as well as approved by the Ethics Committee involving human beings from the Mogi das Cruzes University (CAAE: 49324115.0.0000.5497) Opinion nr. 1.289.941. All volunteers enrolled in the survey gave their informed consent to perform the test procedures.

Test protocol

The tests were conducted in a noise-free controlled environment. The volunteers used the developed app on a mobile device (a 7-in tablet). A tablet holder was used to attach the mobile device to the wheelchairs. The volunteers were afforded a familiarization period with the AACVOX and its functionalities before the tests commenced. Each volunteer received an individual briefing on the AACVOX functions for a period of approximately 3 min, and was then given an additional period of 7 min free use for familiarization. The volunteers were then tasked to use the AACVOX as follows:

- Task 1 - Select a layout type: after being shown the screen layouts, the user selects a layout that is best suited to his/her level of motor impairment. The app has three layouts and the "scan selection" option;
- Task 2 - Perform the communication: the volunteer communicates the sentence "I want to drink water" by using the communication functions of the "Category Choice" and "Activity Choice" screens;
- Task 3 - Select items: the volunteer selects 3 items that will make up the communication main screen;

- Task 4 - Add a new communication item: the volunteer adds the communication item by means of photo image capture resources;
- Task 5 - Change subtitles and audio of communication items: the volunteer changes subtitles and audio of the communication items;
- Task 6 - Type the text for communication: the volunteer communicates the word "Hi", by using the function that converts normal language text into speech

After performing the tasks, the CP volunteers completed the SUS questionnaire to rate the usability of AACVOX application.

Because of the difficulty in obtaining information from people with communication impairments, the questionnaire for scientific research (Q4SR) for mobile devices was used. This app was developed to assist with the collection of information from volunteers with CP in a practical and safe manner.

Figure 4 shows the Q4SR app questionnaire screen with the SUS questionnaire used. When presenting each question, the application reproduced the audio of each question. For each alternative, a visual resource (emoticon) was adapted to help in the understanding of the answer options.

According to Tenório et al. (2011), through the score obtained from this questionnaire it is possible to recognize components of software quality as indicated by Nielsen (2012): 1. Satisfaction: how pleasant is the use of the interface; 2. Minimization of errors: the ability of the system to recover after the occurrence of errors; 3. Ease of storage: the user can easily re-establish competence when he returns to the interface after a period; 4. Efficiency: the speed with which the user is able to fulfill a task after he has learned the interface concept; and 5. Ease of learning: how easy it is for the user to perform simple tasks by using the interface for the first time.

The SUS questionnaire comprised 10 statements, and the user was requested to answer on a scale from 1 to 5: 1 (strongly disagree); 2 (disagree); 3 (neutral); 4 (agree); and 5 (strongly agree). The affirmative and negative answers are subjected to different validation calculations. To calculate the score, one needs to add the contributions of each item with values from 0 to 4. For each of the odd numbered questions, subtract 1 from the score. For each of the even numbered questions, subtract their value from 5, and then multiply this by 2.5. According to the literature the results of the SUS score, on a scale from 0-100, provide the rated usability evaluation of each volunteer.

Results

The graph in Figure 5 illustrates the results of the answers obtained from the five odd-numbered questions in the SUS questionnaire.

By analyzing the results obtained, we observed that more than 50% of volunteers agreed strongly with the affirmative questions that positively rate the usability of the AACVOX app.

For the question "I would imagine that most people would learn to use this system very quickly", 75% of the volunteers strongly agreed with this statement, while with regard to the question "I felt very confident using the system" there were no neutral or negative evaluations.

The graph in Figure 6 illustrates the results of the answers obtained from the 5 negative questions in the SUS questionnaire, regarding the evaluation of the usability of AACVOX app.

By observing the red and orange colors in graph 2, we observed that the bulk of the volunteers partially

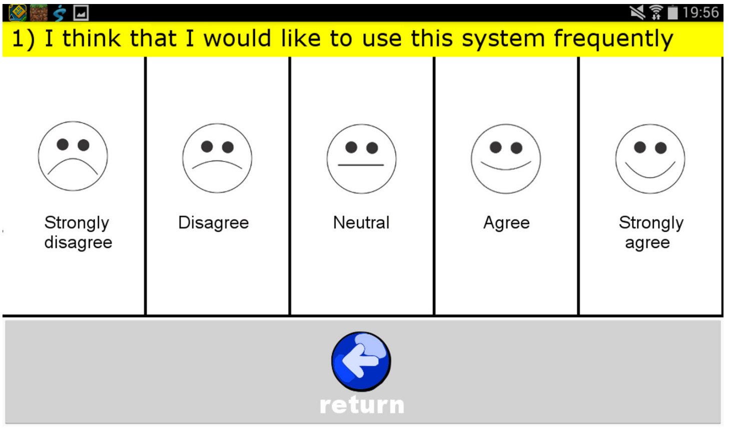

Figure 4. Screenshot of the Q4SR app.

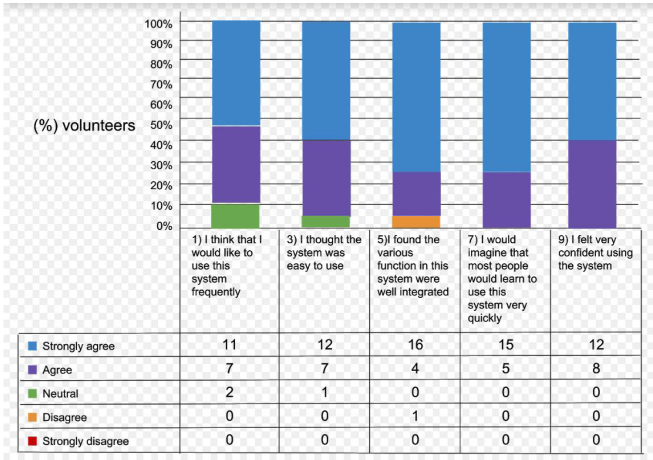

Figure 5. Evaluation of the usability of AACVOX app (SUS questionnaire - odd-numbered questions).

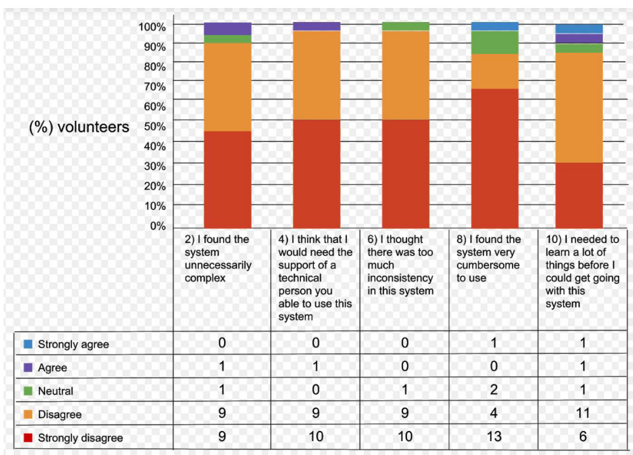

Figure 6. Evaluation of the usability of AACVOX app (SUS questionnaire - even questions).

or completely disagreed with the negative questions. Therefore, it is surmised that the AACVOX app obtained a favorable evaluation regarding its usability, including in these items.

The question that is less favorable in relation to the assessment of the usability of this application refers to the statement “I had to learn a lot of things before I could continue to use this application”. Only six of the 20 volunteers totally disagreed with this statement (graph 2). This is possibly a result of the fact that the application has a number of functions that require a longer period of time to become familiar with.

Figure 7 shows the general score obtained from each volunteer in the SUS questionnaire, relating to the usability evaluation of the AACVOX.

The sample was divided into 2 groups (GA and GB), with GA comprising volunteers V1-V10 (aged 15-29 y) and GB by volunteers V11-V20 (aged 30-57 y). After calculating the average scores in each group, GA had an average score of 84.5, and GB 88.75. In other words, the difference between the two average values is small (4.70), suggesting that AACVOX is easy to use by people in different age groups.

According to Tenório et al. (2011), it is possible to determine the software quality components reported by Nielsen (2012) through the result of the SUS questionnaire scoring averages: learning facility (questions 3, 4, 7, 10); efficiency (questions 5, 6 and 8); storage facility (question 2); error minimization (question 6); and satisfaction (questions 1, 4, 9). The AACVOX app has the following mean scores on the SUS scale relative to the software components:

- Ease of Learning: 85.94;
- Efficiency: 87.52;

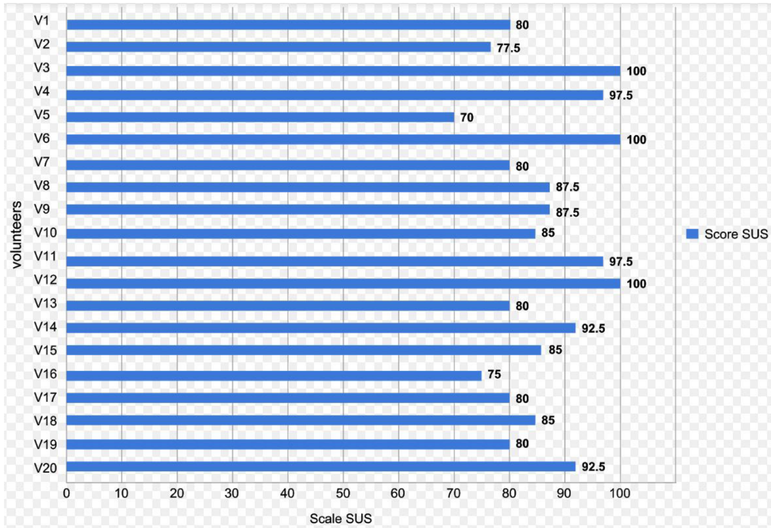

Figure 7. Result of volunteers assessment about AACVOX app usability.

Table 1. Comparison of characteristics of AAC apps.

APP	Speech synthesis	Pictographic communication resources	Screen setting	Switch access scanning	Vocabulary selection	Change resources	Add new resources
AACVOX	✓	✓	✓	✓	✓	✓	✓
CA Mobile	✗	✓	✗	✗	✗	✗	✗
Mea VOX	✓	✓	✓	✗	✗	✓	✓
TryTALK	✓	✓	✓	✗	✗	✓	✓
Falante	✗	✓	✗	✗	✗	✓	✗
Multilingui	✓	✓	✓	✗	✗	✓	✓
Vox4All	✗	✓	✗	✗	✗	✗	✗
MAAC	✓	✗	✓	✓	✗	✓	✓
TumpAAC	✗	✗	✗	✗	✓	✗	✓

- Easy to store: 82.5;
- Security: 85;
- Satisfaction: 88.3.

Calculating an overall average of the scores obtained for each software quality component (Table 1), one obtains 85.85 ± 2.28. This result is greater than the average score reported by Bangor et al. (2008) and indicates a positive evaluation regarding the ease of use of the AACVOX app.

Discussion

According to Schirmer (2009) the AAC environment has produced a number of different systems with the aim of making people with communication disorders more independent and competent in their communicative skills. With this in mind and considering the growth in the use of mobile technologies, in this study we propose a new tool for AAC, known as AACVOX, that is compatible with mobile devices such as smartphones and tablets.

McNaughton and Light (2013) reported that mobile devices are cheaper and more socially acceptable than traditional electronic AAC features. An additional advantage according to Light and McNaughton (2012), is that mobile devices have now become more readily accessible resources, specifically for people who were unaware of the AAC environment. According to International Data Corporation (International..., 2015) research, in the second quarter of 2015 mobile devices, such as smartphones with the Android operating system, accounted for 82.8% of the total international mobile device sales. Therefore, the platform chosen for the AACVOX is accessible to the majority of the population that uses mobile devices (target group of the study).

Reyes et al. (2014) points out that despite the growing number of AAC apps on the market, the bulk of them still fail to address specific weaknesses. The AACVOX, on the other hand, is an app that was developed to adapt to the limitations of the motor skill difficulties of CP users, by focusing on the needs of the user. The AACVOX features an interface with large touch areas (more accessibility) and a user-adjustable interface (configurable).

The functions developed in the AACVOX app allow the user to program common phrases so that a simple access can transmit the desired message (as shown in Figure 3 through the "Category Choice" and "Configuration Activity screens"). This is a important feature because, according to studies by Quintela et al. (2013), 72% of individuals with severe communication problems prefer AAC systems with pre-defined messages, and that allow changes in order to adapt them to their day-to-day communication needs.

The sentences for communication are organized into categories and identified pictographically. These features can be magnified in a practical manner through the camera function that is used to create new images. These images, once created, are audio-related and then integrated into the AACVOX interface, extending its reach. Other researchers have developed systems that allow reconfiguration and expansion of the interface. Vicente et al. (2013) expanded the pictographic function for communication in their study. However, in order to do this, the user is required to connect the mobile device to a desktop computer and use specific software that allows manipulating pictographic features for AAC software. In the application developed by Suchato et al. (2011), the addition of new features to the AAC can only be accomplished with internet access.

Palmeiras et al. (2013) developed the CA Mobile app for AAC that allows communication through the display of user-written messages on the device screen. Our application (AACVOX) was developed with speech output technologies to meet the daily communication needs of users. Schlosser and Koul (2015) reported that this technology makes the communication process more personal and natural, as it is a closer approach to ordinary speech.

Numerous authors have developed apps for AAC that allow communication through the recorded audio playback feature (Basile et al., 2014; Huertas and Nohama, 2014; Mendes and Correia, 2013). However, in this study a voice synthesizer resource was developed. This technology allows the user to build their own repertoire of sentences for communication according to their day-to-day needs. Caron et al. (2016) argued that the same is not true for systems with recorded audio capabilities, as sentences for communication are usually preprogrammed by manufacturers, parents, or professionals outside the daily communication interactions. In this manner, the user could find it difficult to express their actual communication needs.

According to Cook and Polgar (2014), the primary objective of AACs is to promote efficient communication that favors the interaction of individuals with speech difficulties in society. For example, Ghatkamble et al. (2014) developed the TryTalk app, whose communication repertoire is limited to the sporting environment. By contrast, the AACVOX app offers a repertoire of communication with phrases related to everyday issues in order to broaden opportunities for interaction in society. It is expected that this AAC application will prove easy to use and offer practical communication by users in order to improve their autonomy and independence.

Considering the AACVOX development process, a methodology was adopted that uses best practices in software engineering (Pressman, 2005). Functions were defined through a user-centered design approach. Lubas et al. (2014) reported that this form of development could be an important mechanism for success in using AAC apps as the interfaces must meet the special needs of users.

On the other hand, Abras et al. (2004) reported that, although there have been a number of studies aimed at including people with speech difficulties, evaluative practices using usability tests are still uncommon in software developed for AAC. In this study, the SUS questionnaire was used, that allowed us to obtain an evaluation by the volunteers on the ease of use of the AACVOX. Bangor et al. (2008), emphasized that this questionnaire is a practical and safe tool for obtaining reliable results on software usability.

The SUS questionnaire was applied through the Q4SR app developed in this study. This app was designed to assist in carrying out the usability test in order to meet the needs of volunteers with motor disabilities. According to studies by Richter et al. (2008), 62.1% of physically disabled users feel more comfortable using a tablet in a search than using paper and pen. This result is plausible as motor deficiency makes it difficult to use these materials.

The results of the AACVOX usability test showed a positive evaluation from volunteers regarding the ease of use, with an overall mean score of 85.85 ± 2.28 (on a scale from 0–100) on the SUS scale. In the studies of Reyes et al. (2014), the evaluation of the TumpAAC application obtained a general mean score of 76 on the SUS scale, that was 9.85 points less than the AACVOX score. This could have been related to the sample size and to the volunteers who tested both applications. The fact is that AACVOX has a greater number of features that influence overall usability. It is worth mentioning that, according to 33% of the volunteers surveyed in the Mendes and Correa study (2012), usability is one of the factors that most influences the purchase of an AAC application. Table 1 summarizes the primary features implemented in AACVOX compared to other similar applications developed for AAC.

The primary scientific contribution of this study and its relevance to the current state-of-the-art is the development of the AACVOX, software developed for mobile devices with a user-friendly and customizable interface to facilitate its use by people with different levels of motor disabilities.

This software is designed to provide greater accessibility than other software developed for AAC and it includes a number of functions that have been partially implemented in similar software. It requires less effort from the user as the interface buttons are larger, and, with only three steps, the user can communicate.

An important limitation of our study is related to the customization of the AACVOX interface, which is most easily performed with the assistance of individuals without movement limitation, mainly in the case of severe motor impairment.

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