Improving the Social Inclusion of Mobility Impaired Users

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ABSTRACT
In this paper we present a study with a group of mobility impaired individuals (paraplegic and quadriplegic). The goal of the study was to unveil usability issues with current user interfaces and to derive design recommendations towards the development of future mobility impaired-oriented user interfaces that facilitate an integrated access to several communication and social media services in a unified user experience. We focused our analysis on hardware interfaces, considering modalities beyond the more traditional keyboard and mouse, like touch or speech interaction, and on specific computer-mediated communication software interfaces for services such as email, agenda, audio and video conferencing, and social media services. Our study revealed that multimodal interfaces, in particular those that include the speech modality, may help overcome observed interaction difficulties both on the mobile and desktop platforms.

Categories and Subject Descriptors
H5.m [**Information interfaces and presentation**]: Miscellaneous. K.4.2 **[Computers and Society]**: Social Issues – *assistive technologies for persons with disabilities*.

General Terms
Human Factors, Measurement.

Keywords
Social inclusion, mobility impairment, multimodal interfaces, user study.

1. INTRODUCTION
Over the past decades, computer-mediated communication has evolved from email and rudimentary text-based services, such as Bulletin Board Systems (BBSs) and Internet Relay Chat (IRC), to audio-video conferencing and more recently, to a vast range of social media services that comprise today's Social Web.

The use of social media services has grown over the past decade from thousands to several million users, with some of the most popular services like Facebook, currently having over 400 million active users [1]. The communications revolution, coupled with this social interaction revolution has made it virtually possible to reach anyone, anywhere, anytime, with great ease, through the more conventional means like email or instant messaging (IM), and increasingly through audio and video conferencing and social media services. Such evolution has led to increased interaction among people, potentially contributing to individuals' sense of social inclusion. Among those who might benefit greatly from the range of services available in the Social Web, are individuals with mobility impairments. Real-world physical obstacles can severely limit their ability to interact with other people and, consequently, affect their integration in society, leading to forced social isolation. Computer-mediated communication, offers great opportunities to fight these problems. However, there are still usability issues that need to be addressed in order to make communication on the Social Web truly accessible to all.

This paper presents the results of a user study conducted to uncover the difficulties mobility impaired individuals face while dealing with Information and Communication Technologies (ICTs), using traditional interaction modalities like keyboard and mouse, as well as other modalities, such as touch and speech-based interaction, on desktop computers, as well as on standard mobile phones and smartphones. The methods used in our study included open and semi-open questionnaires, interviews and naturalistic observation [2], while the users performed a set of pre-defined tasks, using several services and hardware devices. We considered several types of computer-mediated communication services, namely, email, audio and video conferencing and social media services. The results of our study indicate that multimodal interfaces and in particular, the speech modality, may improve interaction for mobility impaired individuals, avoiding problems such as having to type key combinations in the keyboard, which limits their ability to write more than a few words a minute, hitting small buttons on mobile user interfaces, plugging and unplugging external USB devices, among others.

The remainder of this paper is organized as follows. Section 2 presents some background and related work in the area of inclusive technologies for mobility impaired users. Section 3 describes the user study, presenting details about the participants, the usability tasks that were performed and the analysis methods. Section 4 presents and discusses the study results and Section 5 follows with design recommendations. Finally, Section 6 presents the conclusions

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and directions for further research on the social inclusion of mobility impaired users.

2. BACKGROUND

Mobility impaired individuals have disabilities that affect, to a greater or lesser extent, their ability to move, manipulate objects or in any other way, interact with the physical world. These limitations usually result from genetic issues, accidents or excessive muscle strain. These impairments can also severely limit individuals' interaction with the digital world, due to their inability to control standard computer input peripherals, such as keyboards, mice and tactile devices. These interaction limitations, coupled with mobility difficulties in real-world environments, can severely limit these individuals' independence as well as leading to social isolation, which may originate a depressive state [3, 4].

Several electronic inclusion initiatives have been launched by the European Union (E.U.), especially since the year 2000, focusing on aspects such as universal broadband access, accessibility enhancements, Ambient Assisted Living initiatives, thus enabling a better quality of life for these individuals [5, 6].

The emergence of the Social Web brought about new ways of communication, increasingly online and social. Blogs allow common users to share their thoughts with the world, and social media services make it possible for users not only to connect with new people online, but also to maintain existing real-world relationships, thus allowing a new level of online interaction [7]. With rich social media services, like Twitter or Facebook, new forms of computer-mediated communication have merged. Social interactions occur in response to user-generated content, such as giving comments, ratings, following users based on their posted videos or images, as happens today with YouTube and Flickr, respectively. There is thus a great opportunity to avoid social isolation of mobility impaired individuals, by connecting them to the Social Web. However, it is necessary to design appropriate user interfaces that address interaction issues and offer custom solutions that minimize entry barriers for these individuals [8].

Over the past 30 years, user interfaces have evolved far beyond typical keyboard and mouse, to more natural to means of interaction, with current devices allowing touch and speech interaction, as well as some support for gesture [9, 10]. Although speech interfaces are relatively seamless to use, some issues make them inappropriate to be used in noisy environments, such as input misinterpretation due to lack of robustness in the underlying speech recognition technology. This is more evident in public in open public environments. Other issues, such as accessing private data (i.e.: authentication [11], personal data insertion, etc.), must be taken into consideration. Speech use for long periods of time can also cause fatigue.

Touch interfaces allow users to interact with devices by means of a bi-dimensional touch screen. Recent advances in this type of interfaces have made it possible to interact in more natural ways, through the use of bi-dimensional gestures on the screen, as well as multi-touch gestures, emulating in some cases common human gestures [9, 10]. Since these interfaces require some hand coordination skills, some caution must be taken when attempting to use them for mobility impaired users.

With three-dimensional (3D) gesture-based interfaces, a user can interact with a computer by making free gestures using, for example, video-based approaches [12], inertial units [13], or a mixture of video-based, infra-red based depth sensing for full-body 3D gesture recognition, along with acoustic source localization and ambient noise suppression, for robust speech recognition, as provided by the Kinect system [24]. However, these systems also have some challenges that may limit their adoption: image processing and computer vision techniques, in purely video-based systems, can in some scenarios create incorrect interpretations [14]. Due to the amount of required physical activity, user stress and physical limitations are also other issues that must be taken into account when using this type of interfaces [15].

One attempt to make interfaces accessible to impaired users relies on gaze detection. This type of interface works by identifying where the user is looking at, either through computer vision, captured by a webcam, where the image is scanned to track the eye position, or through infrared cameras equipped with infrared emitters, that track special markers placed, for example, on glasses or on a hat [16-19]. The latter option is considered a better choice, since many image processing problems can be avoided, such as unfavourable lighting conditions, although it is more costly. Issues, such as equipment placement by users with mobility or dexterity limitations can, however, make it more difficult to use this kind of interface.

One way to overcome some of the problems described above, as well as reducing the impact of some of the limitations disabled people face, is using multimodal Human-Computer Interaction (HCI) [20, 21]. This approach allows users to interact through one or more HCI modalities, according to the users' interaction environment, their personal preferences or even disabilities. Thus, with multimodal user interfaces, should users be unable to speak, they could instead use a gesture interface or, in situations where they could not properly coordinate their arms or hands, a speech interface could be used instead. The advantage of multimodal interfaces is not only the ability to enrich the usability experience by allowing multiple means of interaction, but also the ability to use them in a seamless way, without explicitly requiring users to specify upfront the type of interface to use.

3. USER STUDY

This section presents details about our user study design and methods. The study was conducted in two sessions. The first session consisted on a preliminary interview with the study participants, which aimed at gathering information about ICT usage patterns by mobility impaired individuals. In the second session, participants were asked to complete a set of tasks focusing on the usage of e-mail, audio and video conferencing, and social media services. The tasks were followed by a questionnaire.

3.1 Participants of the User Study

Eleven participants with mobility impairments took part in the user study divided in two sessions. All participants excepting P4 participated in session 2, and only five participants (P1 to P5) participated in session 1. Since session 1 was conducted to gather initial information, which would be analysed more in-depth in future work, five participants were deemed sufficient.

All participants were recruited from a panel of associate members of Associação Salvador [22], a non-for-profit social solidarity organization dedicated to support the interests and rights of people with reduced mobility, which is partnering this research. Detailed information about the study participants is provided in Table 1. Their profiles in terms of gender, age, profession and computer skills were diverse.

3.2 Session 1: Preliminary Interview

This initial phase of the study aimed at gathering mobility impaired users' needs, desires and limitations regarding current interfaces. In this session we conducted a structured interview with participants P1 to P5, asking them a number of questions about their difficulties and limitations on using standard computers and mobile phones. They were also asked about their usage habits and improvement perspectives on using hardware and software interfaces.

Table 1 – Information about the study participants, consisting of individuals with paraplegia and quadriplegia.

Participant	Gender	Age	Profession	Disability
Control	Male	22	Student	None
P1	Female	26	Life Sciences Technician	Paraplegia
P2	Male	43	Informatics Technician	Quadriplegia
P3	Male	47	Book Keeper	Paraplegia
P4	Female	26	Unemployed (Social Psychologist)	Paraplegia
P5	Male	28	General Manager	Quadriplegia
P6	Male	37	Unemployed	Quadriplegia
P7	Male	26	Informatics Technician	Paraplegia
P8	Female	54	Technical Assistant	Paraplegic
P9	Male	41	Informatics Engineer	Quadriplegia
P10	Male	19	Student	Paraplegia
P11	Male	40	Enologist	Quadriplegia

3.3 Session 2: User Tasks

In order to uncover the limitations that mobility impaired users face with user interfaces, we designed a set of tasks for participants to perform. In this session all participants (see Table 1) participated, with the exception of P4. Session 2 was divided in two parts: (1) experimenting of communication services and (2) HCI modalities and associated hardware. The first part consisted on a set of tasks related with communication services. In each task, participants were free to use an application of their choice, for interacting with email, agenda, social media, etc. The particular choice of application was irrelevant in this study, as the objective was to observe the difficulties users have with applications they normally use. Therefore, participants had the opportunity to choose familiar applications, thus contributing to the reduction of the learning curve effect. Task completion times were registered, as well as difficulties that participants had with each task. All tasks were conducted in controlled environments and were carried out in random order (the counterbalancing principle of usability evaluation [2]). On the second part of this study session, participants carried out another set of tasks with hardware devices to experiment with several HCI modalities.

3.3.1 Experimenting HCI of Communication Services

An analysis was conducted to evaluate the easiness/difficulty of computer usage, regarding communication and entertainment management services. The former is related with email, agenda, audio/video conference, and social media services. The latter is related with audiovisual information management, in this case, the use of a Media Center. Participants were invited to do some simple tasks with the applications described below.

In the *email task*, participants were asked to write a short email message, in which they had to use key combinations for uppercase letters and symbols. Finally they had to attach a file and send the email to a given address. Participants used an email account of their choice from Gmail, Windows Live Mail, Microsoft Office Outlook and Hotmail.

In the *agenda task*, participants had to create a new appointment according to our instructions and then delete it. Again, participants were free to choose an agenda from Gmail Calendar, Windows Live Mail, Microsoft Office Outlook and Hotmail Calendar.

In the *conference task*, participants were asked first to start an audio-only call and then a video call, with a contact. Two applications were available: Skype and Windows Live Messenger.

In the *media center task*, participants were invited to try for the first time Windows Media Center (as most of them never have used a media center before), and were asked to view a slideshow and a video.

Finally, in the *social media task*, participants were asked to perform a set of activities specific to a *social media service* of their choice, from the following list: Twitter, Facebook, YouTube, Flickr, Last.fm, LinkedIn and Digg. From this list, only Twitter, Facebook, YouTube and Last.fm were chosen by the participants. The tasks conducted focused in the areas of message viewing and publishing, as well as content retrieval and publishing, namely, photos and videos.

Participants were asked to express aloud their decisions, opinions and difficulties while performing the study tasks. A Control participant, an undergraduate student without any kind of mobility-impairment, was asked to perform the same set of tasks with all available services, prior to the user study session with the mobility impaired participant group. This Control participant was used for calibrating the user study.

3.3.2 Hardware and HCI Modalities

Another objective of our study was to observe and perceive how mobility-impaired users interact and what limitations they face, with current hardware interfaces, namely peripherals of desktop computers and mobile devices, as well as with alternative modalities of interaction such as touch and speech.

Regarding the use of traditional keyboard and mouse/touchpad interfaces, participants were observed while performing the set of communication services' tasks. We also conducted another set of tasks in order to observe the use of other HCI modalities. To evaluate the touch modality, participants were asked to use a stylus on a laptop to simulate some multi-touch gestures, such as rotating, scaling and dragging an image on a laptop surface. Regarding the speech interaction, participants were asked to use an European Portuguese ASR (Automatic Speech Recognition) application, that was running in a laptop.

In order to explore smartphones' capabilities, we designed a task where participants were asked to try 2D gestures on the touch screen and 3D gestures with one of such devices (Samsung Omnia), which inherently uses the smartphone's accelerometer.

3.4 Analysis Methods

All sessions were recorded in video and audio formats. The analysis consisted on retrieving both qualitative and quantitative results. Qualitative results rely on observations and participants opinions during each task. For quantitative results, we considered the following: (1) time to complete a task (in minutes), from the time each participant was instructed to do a task, until the task was completed; (2) Number of aids – number of times participants asked for an aid or were helped. This data shouldn't be strictly interpreted, and is considered as mere guidelines towards future evaluation. For qualitative results we considered: (1) Result – level of task completion; (2) Observations – our interpretation of the participant's actions, considering interaction with hardware and software; (3) Participant's opinion – some opinions given by participants while performing the tasks.

4. USER STUDY FINDINGS

4.1 Results from the Preliminary Interview

All interviewees from the first session of the study, consisting in four paraplegics and one quadriplegic, reported having different levels of limitations concerning computers and mobile phone use. To increase keyboard usability, some of them adopted the use of a pen as a typing assistance. Participant P5, due to the extent of his limitations, had to resort to a gaze-based interface [19]. The participant noted that without this interface he would be unable to use a computer. However, due to specific adjustments needed to properly use the device, including camera adjustments, marker and eye glass placement and registration, he still isn't completely independent to setup the computer gaze-based interface whenever he needs to. Regarding mobile phone usage, the majority of the participants have pointed out small keys, as one of their main difficulties while using these devices. Regardless of these limitations, they all consider that using computers is extremely important, either for work, entertainment or both purposes (see Figure 1). These individuals also reported daily computer usage, of more than five hours a day (Figure 2). Mobile phone usage is, however, somewhat more limited, and varies according to their personal and professional needs (Figure 3).

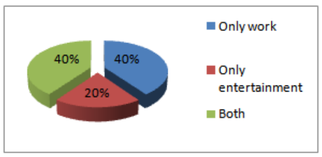

Figure 1 – Computer tasks executed by the participants.

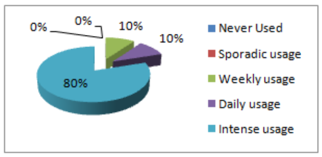

Figure 2 – Participant computer usage.

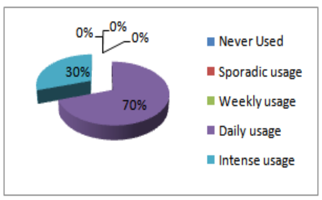

Figure 3 – Participant mobile phone usage.

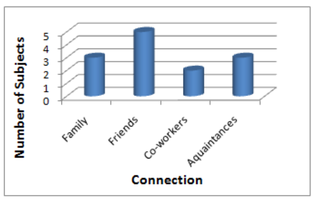

Figure 4 – Participant relevant connections.

Taking into account that mobility impaired users have to stay at home more than they ideally would like, one of the major advantages of computers linked to the Internet, is communication provisioning. The interviews' results show that these individuals believe that ICTs could help them keep in touch, mainly with family and friends, but also with co-workers and acquaintances (Figure 4). They already use social media services, mainly Facebook, forums, instant messaging (IM) and email (especially Hotmail, Gmail and Outlook), as we can see in Figure 5 and Figure 6. Participants view these services as tools to increase their online presence and communicate with other people. However, they feel that some of these tools are still too complex to use. Regarding audio and video conferencing, their usage is sporadic.

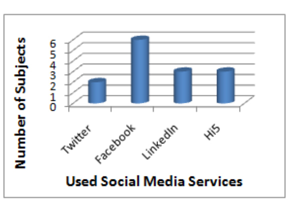

Figure 5 – Known SMS sites.

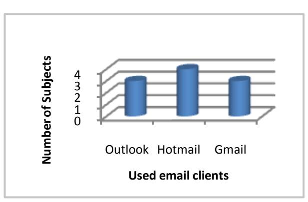

Figure 6 – Email clients usage.

All participants believe that keeping an electronic agenda is extremely important for their professional activities. Participant P5 stated that he uses Outlook, while other participants use either Gmail, integrated with Google Calendar. P5 also mentioned that one restriction he constantly experiences in his Outlook agenda configuration is the lack of synchronization between devices, such as his home and office computers.

Media management is generally done offline, with resource to physical storage media such as flash cards or hard drives. Most of the participants, however, stated that it would be interesting to try something new, such as a media centre or an online social media solution.

Overall, the participants believe that, in order to improve their interaction with digital devices, the availability of a speech input modality could greatly increase their usability experience. They also considered an access to computer-mediated communication services in a ubiquitous way, that is, through a mobile device, through a computer and, in the living room, through the television, could be beneficial. Quadriplegic participants also expressed their strong desire to use more powerful mobile-based applications as a way to increase their mobility, such as in scenarios where a traditional computer, be it mobile or desktop, wouldn't be feasible, such as while moving or in a car, due to the inherent need of specially adapted interaction modalities like eye-gaze.

4.2 Analysis of HCI of Communication Services

4.2.1 Email Task

Since email is probably the most widely used communication tool, all participants demonstrated at least some knowledge on using an email service, and all mentioned that the email interfaces are generally simple to use. However, they also pointed out that there were some problems with the email interfaces, as some of them could be too complex. For example, participant P6 had some difficulties in finding the attach icon in Gmail and even in reading what was on screen (due to his physical limitations, P6 was at some distance from the screen and he had to approach to it to read, which was a complicated maneuver).

In terms of hardware interfaces for interacting with email, some problems were observed, mainly with quadriplegic participants. As presented in Figure 7, the time to complete the email task was strongly affected by writing speed. We noticed that normally quadriplegic participants use a single finger at a time or, at most, two fingers to write. They all considered their writing speed to be slow and, using speech for email dictation and control could be very useful. For example, participant P2 said: "I think using speech could increase writing speed and avoid spelling errors".

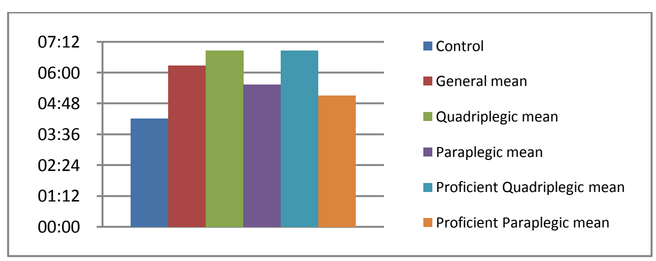

Figure 7 – Email task average completion time.

Another observed problem deals with key combinations, as participant P6 pointed out: "I have to use a bent wire to insert @ symbol (…) if I could insert a symbol by touching it or saying its name, it would be nice". Participants P1, P2 and P9 also had difficulties with key combinations. Sometimes keys like Alt or Ctrl are placed differently in the keyboard, depending in its type. Participant P11 said that he normally uses the Sticky Keys functionality to overcome this problem. All quadriplegic participants considered that a toolbar with symbols (with large enough icons) selected by touch or speech interfaces, would be very useful.

Comparing the average execution time of the Control participant and the study participants, we can see that differences are quite large (about 2 minutes and 3 seconds). Considering problems that quadriplegic users experienced, which we have reported above, we divided the task time analysis into two separate groups of participants (quadriplegic and paraplegic) and we calculated the average time separately for each group – the observed mean differences were relatively small, 1 minute and 8 seconds. Considering that participants P3 and P8 use email sporadically, and that they took long time to complete the task for not being proficient email users, we excluded them to calculate the average task completion time for proficient quadriplegic (i.e. all quadriplegic participants) and proficient paraplegic (i.e. all paraplegic excluding P3 and P8). Now, mean differences are larger, with quadriplegics taking, on average, 1 minute and 44 seconds more than paraplegics to complete the task.

4.2.2 *Audio and Video Conference Task*

Regarding this task, we noticed that most of the participants did not accomplish what was asked in the task script. When asked to first start an audio-only conference call, most participants started a video-conference instead. In most of the situations Skype was the preferred choice, as Windows Live Messenger was not working properly. We noticed that using Skype could be less error-prone for conference functionality, than using Live Messenger, as buttons for starting an audio conference and a video conference are well separated and are far more visible in the interface.

Quadriplegic participants referred that speech and even touch could improve conference applications' usability. In terms of speech they referred that invoking user interface commands by voice would be "nice to have" (e.g. saying a contact's name or "start call"). Touch was considered helpful for contacts' selection.

All quadriplegic participants mentioned that audio and video conference are preferable to instant messaging, since they have constrains with keyboard writing. Given that dealing with a conferencing application requires minor or no keyboard input, it is no surprise that the task execution results (see Figure 8) show practically no differences between the quadriplegic and paraplegic groups, and even between these groups and the Control participant. We point out again that most participants did not accomplish this task successfully, i.e. they only completed half of it (the video conference part), and so we have to consider that differences between mobility impaired and Control participants are actually larger.

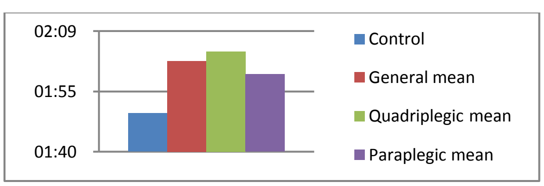

Figure 8 – Conference task average completion time.

4.2.3 *Agenda Task*

The use of an electronic agenda brought no major problems to the participants. Since this service can be essentially managed with the mouse, none of the participants had considerable problems in using this traditional interface. Participants that never used an agenda before felt some minor usability problems, but only at the start of the task. As we can see from Figure 9, there are practically no differences between paraplegics and quadriplegics. The small observed differences are essentially due to the lack of experience in using an agenda application.

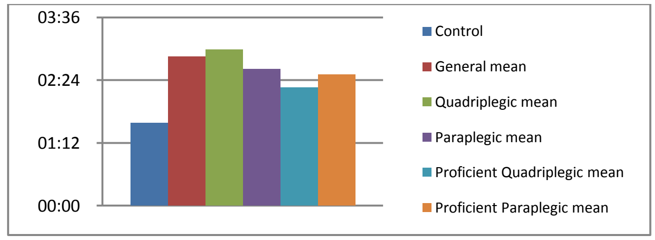

Figure 9 – Agenda task average completion time.

Considering participants P9 and P11 as proficient quadriplegics, as they reported using an agenda on a daily basis, and participants P7 and P10 as proficient paraplegic, for the same reason, the observed difference between proficient quadriplegic and paraplegic is smaller, but still paraplegic took longer to complete a task. This can be explained because P10 used a device (smartphone) that he had never used before, and so he took longer than others. Considering that impairments of proficient quadriplegic considered in this case, are not so advanced as other cases, completion times regarding mouse usage were not affected. Although we consider that quadriplegics still have limitations on using pointing devices (see 4.3.3), depending on their limitation level.

4.2.4 *Media Center Task*

Regarding the media center's interface, participants had some difficulties in ending slideshows and video playbacks, as they could not find a way to do so. Most of them even closed the media center, by pressing the media center's exit button by mistake (X on right-top of the screen). In terms of the interactive experience itself, no major problems were observed.

Quadriplegics considered that using speech to control the media center control would be "nice to have". For example, subject P11 said that for controlling slideshow commands via speech, like "pause", "next" or "previous" could be an interesting feature. Gestures could also improve usability: as an example, pressing the right part of the screen could mean "next photo", while pressing left part, "previous photo".

In order to use the media center, participants used touchpads, mice and keyboards. Comparing the task execution times of the quadriplegic and paraplegic participants we observe that the differences between these two groups are fairly small (Figure 10). Even so, quadriplegics take a little longer when using interfaces like touchpads and mice. An interesting finding is that paraplegics took even less than the Control participant, which suggests that they have practically no problems in using this type of traditional hardware interface.

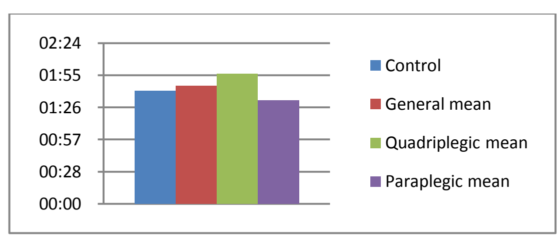

Figure 10 – Media Center task average completion time.

4.2.5 *Social Media Services Task*

Overall participants were familiar with social media services, either for using them or for having heard about them in traditional media. The majority knew and had previously used the more popular services, like Facebook, Twitter and YouTube, an aspect that, in some situations, influenced the participants' choice of service to carry out the task. As mentioned in section 3.3.1, the task was adapted to the service that was chosen.

Figure 11 shows a minor difference between quadriplegic and paraplegic individuals in completing the message posting tasks (on Twitter and Facebook). However, quadriplegic results aren't as consistent as paraplegic ones. This issue is due to some of the quadriplegic individuals being less proficient in social media services use. In all cases, however, participants were considerably slower in completing the task than the Control user.

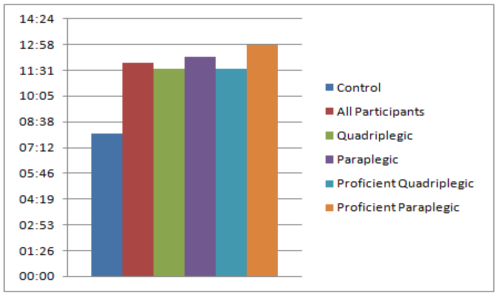

Figure 11 – Twitter and Facebook tasks average completion time.

Similarly to what was observed in the email task, participants had many difficulties with long text input, especially when using key combinations and special characters and with interaction with the Graphical User Interface (GUI) itself, feeling that it was too confusing due to an overwhelming amount of information displayed on each page.

Regarding YouTube use (Figure 13), quadriplegic participants felt considerably more difficulties when compared to paraplegic. As with the previous scenario, participants found it hard to use some of YouTube's profile configuration page and nested features like the user menu on the main page, also due to an overwhelming amount of information on some pages.

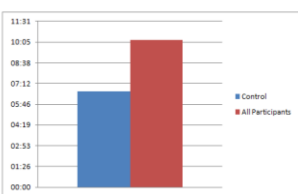

Figure 12 – Last.fm task average completion time.

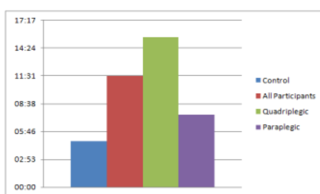

Figure 13 – YouTube task average completion time.

Although taking some time to adapt to a new service user interface, participant P1, who chose the Last.fm service, found no significant issues with the task (Figure 12). The participant felt that more contextual help on the interface, especially in Last.fm's desktop scrobbler, would have helped to minimize the learning curve.

Overall, participants felt that speech interaction would help them interacting with social media services, especially when long text insertions and navigation in complex scenarios is required. These participants would thus like to use speech both in dictation and in command and control modes.

When asked about what tasks participants felt would be more valuable in their daily social interaction, they stated that their ideal social media application should provide message-based communi-cation, contact management, offline and online photo and video management, allowing interaction with these media.

Participants also added that in general their ideal application should allow interaction through different HCI modalities, namely speech, 2D touch and conventional interfaces like keyboard and mouse, with the user being able to choose his/her preferred modalities.

Due to the difficulties expressed while interacting with some complex GUIs, participants noted that their ideal application should be simple to use, without any technical jargon and with a low volume of information condensed into any single location. Participants added that contextual information, in both visual and audible formats, should be available.

Due to their physical limitations, participants also noted that they would like to use a GUI with a sort of a color scheme that would make it easy to read the GUI's contents at some distance, with large icons and text that wouldn't require too much precision during interaction.

4.3 Analysis of Hardware and HCI Modalities

4.3.1 Speech

Since all participants had no speech production problems, they all managed to use the speech interface without problems. Participants were told to say some words and phrases to a laptop computer, in which an experimental European Portuguese ASR application was running. Although with some recognition problems and out-of-vocabulary words, due to the nature of the command and control application (that uses context-free grammars to drive the recognition process) and participants' accent, in some cases, participants considered speech as a good alternative, mainly for large text input, i.e. for using speech in dictation mode.

4.3.2 Touch (Stylus and Multi-touch)

Paraplegics managed to use a stylus without problems, but they considered that it is not yet a good alternative for writing. Some quadriplegics considered that using a stylus device is extremely difficult (see Figure 14), as the produced pressure must be more than using a pen on a paper, which is obviously a barrier to these users. Other participants considered the stylus device as a good alternative for keyboard writing, using handwriting capabilities.

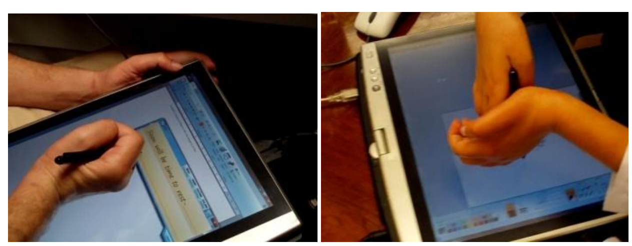

Figure 14 - Quadriplegic participants using stylus on laptop

Multi-touch gestures were generally considered "impossible to do" by quadriplegics. On the other hand, paraplegics considered the opposite. When considering gestures, quadriplegics said that only single gestures, such as dragging or simple touch, were doable.

4.3.3 Keyboard and Mouse/Touchpad

Regarding traditional hardware interfaces like keyboard and mouse, we noticed some disparities, mainly with quadriplegics. Some managed to use keyboard with just one finger at a time, as others used keyboard with two fingers at the same time. One participant used keyboard in an interesting manner: he used pencils to write (Figure 15). Quadriplegics had problems on using key combinations, for example for specials characters insertion.

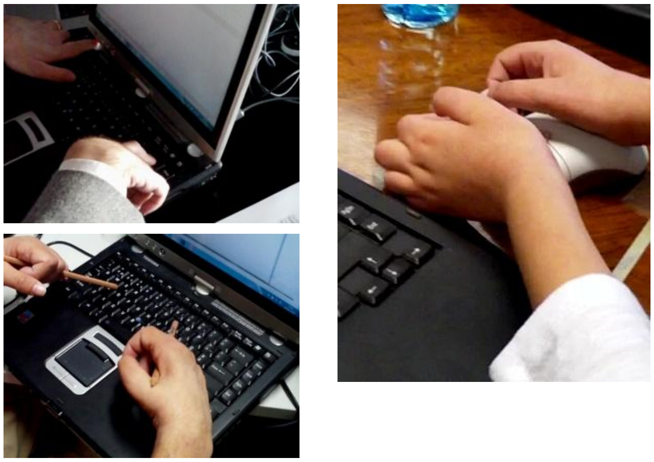

Figure 15 - Quadriplegic participants using mouse and keyboard

Some participants mentioned that different keyboard formats could bring additional key combination difficulties, and participant P6 referred that he had to use a bent wire. As we have seen in section 3.2.1, writing speed is still an issue, and so quadriplegics took longer to write a text using a keyboard than paraplegics.

Regarding mouse/touchpad usage, most quadriplegics managed to use the mouse with both hands as depicted in Figure 15. One quadriplegic used mouse with only one hand (but on the left side, as he normally uses the back of his hand). Other participants used touchpad instead and considered it to be easier than the mouse. Paraplegics managed to use keyboard, mouse/touchpad without problems.

4.3.4 Smartphone (2D touch and 3D gestures)

Smartphone's touch capability (referred to as 2D touch in the surface of the phone´s screen), was considered "easy" by paraplegics. Quadriplegics on the other hand, had some difficulties in doing dragging gestures and in selecting correct icons as they were considered to be too small.

Some quadriplegics could not hold a smartphone due to their condition (see Figure 16), and so normal 3D gestures were impossible to do by some quadriplegics. Other quadriplegics and all paraplegics managed to accomplish a simple 3D gesture task, consisting in shaking the smartphone device.

We note that quadriplegics that could not hold the smartphone, normally use their mobile phone attached to their wheelchair, and so for them this task was executed on that condition.

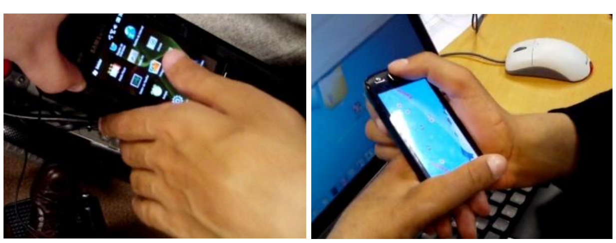

Figure 16 - Quadriplegic participants using smartphone device

5. HCI DESIGN RECOMMENDATIONS

Based on the user study findings, we were able to derive several recommendations for the design of user interfaces geared towards mobility impaired users:

General HCI recommendations:

- Graphic icons should be large enough to be correctly used by both target groups, with special care for quadriplegics and additionally, shouldn't require precise movements and actions.
- The interface should be readable at some distance and must have not only large icons, but also large and clear text, that allows operation from fixed locations at some distance from the user, such as quadriplegics' wheel chair arms.
- GUIs must have simple text and a carefully chosen color scheme.
- Multi-touch interaction should be carefully implemented so as to not become a usability barrier for quadriplegic users who aren't able to perform these gestures with ease.

Specific Mobile HCI recommendations:

- 3D gesture interaction should be carefully implemented so as to not become a usability barrier for quadriplegic users who aren't able to perform these gestures with ease or at all.
- Mobile interfaces must be designed to allow easy usage while the device is fixed to a wheelchair's armrest
- Mobile UIs should offer a feature set as close as possible to a desktop UI, to increase user's mobility, maintaining interfaces as simple as possible in order to increase usability

Specific Desktop HCI recommendations:

- 2D gesture interaction must be carefully implemented, taking the same precautions mentioned for mobile GUIs.
- Touch interaction must be discouraged should the screen be placed vertically, to avoid the *Gorilla Arm* effect [15], as well as reducing the effect that the users' limitations have on this particular type of interaction, as was noted by the participants during task execution.
- As most quadriplegic individuals felt many difficulties using key combinations, they should be avoided. Should key combinations be needed, a special character sidebar should be available with large items, selectable by speech, touch or by picking with a regular mouse cursor.

Recommendations for HCI of Communication Services:

- Email interfaces should be similar to existent ones, but simpler with just essential features (subject, text, attach option and recipients).
- Conference interfaces must be simple with audio call and video call buttons separated and understandable - developers and testers must consider that audio and video conference are more easy and convenient to use than instant messaging.
- Social media services UIs must be simple enough to use and not resort to service specific jargon
- Social media services UIs should be carefully designed to have a low volume of information on each page/window to reduce the user's learning curve.

Recommendations for multimodal HCI support:

- Interaction modalities should not be exclusive, but instead concurrent, so as to allow individuals to interact with their preferred means of interaction [23].
- Speech should be present in dictation mode to allow for easier input of large texts, thus reducing user stress.
- Keyboard and mouse should always be present, allowing the execution of the same tasks as alternative modalities such as speech or gestures.

6. CONCLUSIONS AND FUTURE WORK

In this paper we analyzed mobility impaired-users interaction with communication services from mobile device and desktop perspectives, with the intent of gathering these individuals' needs and difficulties. We thus conducted a user study with a group of eleven participants, five quadriplegics and six paraplegics, following a counterbalancing task execution methodology. We used data gathering methodologies such as questionnaires and interviews. For each task we collected time based metrics and performed qualitative observations.

We have seen that not all mobility impaired individuals face the same limitations. Paraplegics have practically no limitations on using multimodal HCI, both on desktop and mobile. On the other hand, quadriplegics have shown some limitations, not only with traditional HCI, but also with new ways of interaction such as with multi-touch. And so, providing alternatives in order to overcome these limitations, through redundant and concurrent HCI modalities, could improve the user interaction experience.

Speech was highly regarded by all participants in the user study, as a modality that should be ubiquitous across all communication services analyzed (email, agenda, conference, media center, social services) and all devices used in the interaction experience (mobile phones or desktop).

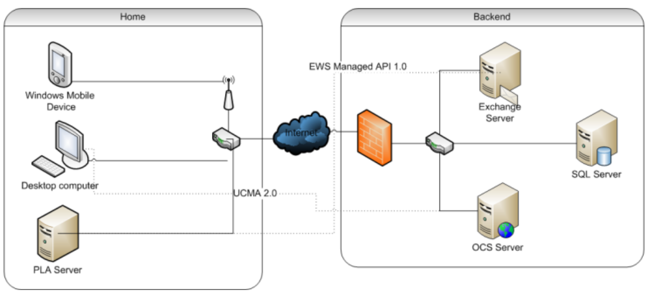

Figure 17 – Proposed physical architecture

Future work will focus on the development of a prototype multi-platform application that integrates multiple services, following the architecture proposed in Figure 17. Such application will allow mobility-impaired users to interact with communication and social media services through a simple multimodal interface that will combine conventional and non-conventional means of interaction, such as keyboard and mouse, 2D touch and multi-touch, 3D gesture and speech interaction. Further work on this subject will also extend the proposed topics by conducting user studies, including usability evaluation, with an extended set of participants to gather more in-depth information.

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