Accessible Touch – Improving Touch Screen Usability

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ABSTRACT
Touch screen-based mobile phones are the new generation of phones which brought with them several improvements in terms of interfaces, adaptability, usability and beauty. On the other side, the use of large touch screens made buttons no longer necessary, bringing new barriers to usability. But even with the breakthrough in the touch screen market, some people still have problems regarding mobile phones. Motor impaired people always had problems to interact with most devices. This is especially true for these new technologies. Taking into account their limitations and capabilities, as well as their needs, it is of most importance to find good ways of interaction with touch screen devices. In this document we present different approaches to overcome limitations or problems in touch screen interaction, understanding how tetraplegic people can interact with these devices on an easy and comfortable way. The results will help developing suitable interfaces capable of dealing with these problems, increasing usability in mobile devices as well as some self independence in their use.

Author Keywords
Mobile accessibility, tetraplegia, motor impaired, touch screens, gestures, assistive technologies, user interface, domotic control.

INTRODUCTION
Nowadays, the phone is the main partner of the individual, being used for the most varied purposes. From a simple phone call, to sending a text message, passing through consulting the calendar, playing games and accessing the e-mail, among others. With the introduction of touch-screen mobiles phones in the market, we have witnessed a leap in innovation with the interaction between those devices and the human being. The use of buttons is no longer in vogue. Rather, fingers or stylus are used to interact with the screen. But this innovation comes with a price. The fact that buttons no longer exist, brings new barriers to usability, in the way interaction with the device happens. Thus, we need to better understand interaction requirements so we can design better interfaces. Our work describes exactly that, how can we improve the use and access to these touch screen devices by people with motor impairments such as tetraplegics. To accomplish that, we evaluate different interaction techniques, screen positions and target sizes, to guarantee successful measures while create suitable interfaces to those users.

Looking at the touch-screen phones’ characteristics, we highlight a skill most relevant to the interaction: motor dexterity. Due to the fact that we no longer have buttons, the entire screen surface should be used to allow interaction. It is therefore understandable that the size associated with each button is small and the user requires some precision to interact with them. These limitations, in terms of usability, are the main focus to start a study related to, in some way, reduce the difficulty inherent in these devices.

Another very important factor, regarding the usability of these devices is their use by people with motor impairments. If, for the common user, these barriers are found, as described above, the interaction with touch-screen devices for disabled users becomes more complicated. In the era we live in, with constant technological developments, it is very important that everyone has equal access to all types of innovation and opportunity to enjoy the same technology, even if sometimes certain physical limitations are imposed.

Regarding motor impaired people, specifically tetraplegic, they are more limited when it comes to tact, sensitivity and the control and accuracy with a device. Another aspect of great importance is the difficulty of access to devices, as they are limited in their physical space, usually a bed or chair. It is therefore essential to check which techniques are the best and see different solutions, getting feedback from users, facilitating their accessibility to devices.

The purpose of this work is to study different approaches of interaction with a mobile touch screen. Finding how can tetraplegic people benefit when using these devices is a contribution on improving their lives. The use of these devices will then help them in many other situations, as we are going to demonstrate, through the use of an interface to control house appliances. Therefore, the main and more motivating goal is to effectively obtain results in understanding touch screen interaction. With good results on that study, we can then build more suitable interfaces in those devices that certainly will help tetraplegic users improve their limitations, making them more self-dependent.

RELATED WORK
A motivation behind this work is the use of mobile phones to interact with other devices more difficult to control by these users. People with motor impairments, however, often
find these devices difficult to use [7]. But, in the overall, they are a great help, if used in the right way, to the right purpose.

There are many ways to interact with the mobile device. One study [11] shows the good results regarding the use of the preferred hand to interact with the mobile phone. In this same study is concluded the importance of target position, since they saw good results regarding the targets near borders, even if users preferred, in terms of comfort, the targets in the middle of the screen.

Some work related to the target’s size is very important to consider here. Therefore, some studies [6] [1] [8] revealed that the minimum target size should be around 3 mm for able-bodied users and the recommended being at least between 9.2 and 9.6 mm. With that, we can establish a minimum size for pointing targets of about 7 mm, a medium size of 12 mm and another of 17 mm, to make our tests more elucidative and comparable.

With this we understand that target’s position is important, since we have to take into consideration some places to test possible ideas of best choices for future main targets. Taking into account work related to users with motion impairment, like Barrier Pointing [4] and EdgeWrite [14], we see the importance physical edges have in the interaction between users and touch-screen mobile phones. In those studies, we can notice also that fatigue and tremor reduces a user’s ability to make smooth, accurate and controlled movements. As seen in examples and studies, the use of screen edges is a great help to users with motion impairments, not only in making the right gesture, but also to select the correct target, with more precision.

Another important study [9] was developed to detect which areas are the best for interaction with the touch-screen. This study elaborated a map of zones, testing where the user was more accurate selecting targets. These targets were also tested in different sizes. The results showed a higher pressing convenience in the targets closer to the center of the screen, and more errors near the bottom edge and bottom right corner. Another result was related to the target size, which showed the larger size the higher performance and subjective satisfaction.

A study [3] described a non-hand-based gesturing, an input technique using head tilt, in both static and mobile contexts. The idea came because of the challenge in designing interfaces capable of dealing with everyday situations while interacting with mobile devices like walking or cycling. Another important issue is that most devices require hands to operate many of the applications. The goal of the study was for participants to move a cursor by tilting their head and to click on a target shown on a phone screen. Results showed that in static contexts, the position and velocity control mechanism tested allowed the user to hit targets of 30 pixels (7º in the position control conditions) with a high degree of accuracy with the position control mechanism allowing faster targeting. The study also showed that there was a marked drop off in performance (significantly reduced accuracy and increased movement time) when the participants performed the same task on the move using the position control performing significantly less accurately than velocity control in mobile conditions.

Another important feature is the feedback given to the user. This feedback can be done in several ways, being the most common (and important in the context of this work) sounds or vibrations. A study [12], had a task of completing a maze with a tactile pen, in a touch-screen monitor. Without any visual aid, participants had to focus on audio or haptic feedback. As results, it was possible to verify a difference in the time taken to complete the task, where the time required with the haptic feedback was lower than for audio feedback. One reason for this is that users have to listen first and then perform the action in the audio feedback, which is much quicker and effective with the feedback provided by vibration, with the movement of the tactile pen. Conclusions to this study show a better result with haptic feedback comparing to audio feedback. Most users admitted at the end of the tests that they preferred haptic feedback.

Another study shows the use of a mobile phone to make access to the computer. This study [7] shows how, using a Palm, a user with motor impairments may have free access to a computer, simulating mouse and keyboard. Clearly was visible that the introduction of text through remote control is slower than a normal keyboard, and the use of a tool for word prediction would increase the speed. In general, there was an improvement both in terms of fatigue, being much less with the use of the Palm, as well as at the level of interaction.

Another relevant work regarding a different interaction with touch-screen devices is HybridTouch [13]. This comes to try to solve a problem of finger obstruction in the touch screen. Using a touchpad attached to the rear surface of a PDA, users can manipulate the PDA by simultaneously touching the front surface with a stylus pen held by the dominant hand and the rear surface with a finger of the nondominant hand. HybridTouch enables a user to scroll the screen of a PDA vertically and horizontally, by touching and moving a finger of the nondominant hand on the touchpad. By combining the manipulation conducted on the touchpad with that of a stylus pen on the front surface of the PDA, users can easily zoom an image in or out, and draw figures on a larger canvas than the PDA screen can display. Some problems are found, concerning manipulations on the rear interface of a PDA, such as: a finger on the rear surface is not visible and it is often difficult for users to recognize its movement; moving a finger vertically is easy, but moving it horizontally is difficult, due to anatomical constraints; moving a finger repeatedly is fatiguing (this may happen when a user has to scroll a long document or a large image).

Another tool of interest for the introduction of text is named QuikWriting [10]. Its advantage is to construct sentences
using a stylus, without taking it from contact with the screen. The area of writing is centered with the stylus, just after first contact. There is a central point where every gesture finishes, which will depend on which character to insert. The characters are ordered to be easier to access to the ones more used.

**UNDERSTANDING TOUCH SCREEN INTERACTION**
The main objective of this work was to evaluate how can motor impaired users benefit and improve interaction in touch screen mobile phones. To achieve this, some other goals were defined. We defined and evaluated different interaction techniques, therefore studying which may be the best ones to achieve the main goal. Studying different screen positions and target sizes helped follow the path to meet the objectives defined. This path constructed a very detailed conclusion on how should motor impaired users interact with touch screens, especially with mobile devices.

**Research Questions**

1. Which are the best screen positions users are able to tap?
2. Do targets on the edge of the screen enable people to have more accuracy than the targets outside the edge?
3. Are gestures made on the edges easier than gestures made in the middle of the screen?
4. Which are the gestures users can make with less difficulty?
5. Which is the best dimension for target acquisition and accuracy, regarding the different positions that targets can have?
6. Are gestures better to perform related to tapping?

**Methodology**
To start, we distinguish some main aspects, in order to be able to compare them later and analyze the results. Supported with past researches, we know the help corners and edges give to motor impairment users [8] [14]. But a flaw in these studies is that they don’t assure corners and edges as the best possible choice of interaction, for motor impaired users. Therefore, we compared different approaches that would tell us that answer. The two basic ways the user can interact are: **tapping the screen** or **making a gesture**. When tapping, the user can do it in three different areas: edges, corners and screen surface. When making a gesture, the user can be crossing a specific target (and therefore making a selection), acknowledge a selection by exiting the screen in a specific target or just using directional gestures. Those gestures can be made in the middle of the screen or using the edges as guidelines. These gestures are simple gestures, i.e. left or up.

Going a bit more on details, we have different approaches related to tapping and to gestures:

1. Four different corners tapping
2. Four different edges tapping
3. Tapping in different areas of the same edge
4. Middle screen tapping

5. Select targets by crossing them with gestures
6. Select targets by making a gesture and exiting the screen in the target
7. Making gestures using the edges
8. Making gestures using the middle of the screen surface

Using all the different interaction techniques, we can also verify the best screen zones. Therefore, we built up a map of different zones, where the user was asked to select. With the different measures we logged and the user’s opinion, we established the most accurate and more comfortable zones of the screen. Even relating to the edges of the screen, we tried to see the best location targets can have along the edges.

For each approach, we tested different target sizes, in order to justify not only the best interaction technique, but also the best size targets can have for these users. Therefore, in each test, in each zone of the screen, we asked the user to tap targets with three different sizes: 7, 12 and 17 mm.

**Participants**
Fifteen motor impaired participants (2 females) of average age 42.1 were chosen to perform these tests. The strength, accuracy and control vary from person to person, but all of them had regular upper body strength and coordination, where arms, hands and fingers are the most affected body parts. To get to know their limitations and capabilities in a more functional way, we asked the users to perform some simple physical exercises [2] before the procedure. For comparison, eighteen able-bodied participants (5 females) also performed these tests. Almost all participants had at least once contact with touch screen mobile phones, being familiarized with them, even if some had some problems regarding finger strength for tapping on the screen.

**Apparatus**
During the experiment we used a QTEK 9000 PDA (Fig.21) with a 73 x 55 mm screen dimension and 640x480 pixels resolution, running Windows Mobile 5. The software was implemented in C#, using the .NET Compact Framework 3.5 and Windows Mobile 5.0 SDK.

**Procedure**
Users had to perform each of the interaction techniques apart from each other. Since targets have three different sizes, for each position there was three different asked selections. To select these targets, the user had to tap them, to cross them with a gesture or to exit a gesture in the target. For tapping, red circles appear in the screen. For exiting targets, the circles are green. These targets are placed only on borders (edges and corners). Finally for crossing targets, the circles are blue. For gestures, the user sees a red arrow in the desired position and direction. For middle screen gestures, the user is asked to do 8 different: North, South, East, West, Southwest, Southeast, Northeast and Northwest. For gestures made in the edges, only the two possible ways are asked. All the tests were done in a
comfortable place, always while the users were sited in their chairs.

Another aspect is the feedback the user had. Since we wanted to take out best interaction techniques, the users weren’t informed about the mistakes they can possibly make, at least during the procedure. Doing this we also avoid the frustration regarding a miss attempt. Therefore, this procedure was a one-try test. The only feedback users had from the device was an audio feedback for each input made by the user.

Results
Exiting is a test that evaluates a kind of interaction regarding gestures, with targets positioned in borders and corners of the touch screen. Therefore and still thinking about the different screen positions in the map of zones, there are 8 different zones (4 corners + 4 borders) evaluated. Since we are evaluating three target sizes as well, 24 different targets were asked to select, using this interaction style. From the 15 user tests, there was a 51.67% average error rate. There is a decrease in errors when the target size increases. This is expected, since for larger target sizes, users need less accuracy regarding target acquisition. In Exiting, there were more than 56% errors in the smallest size and decreasing more than 10% for the next target size. Finally, for 17 mm size, there was more than 35% error rate.

As expected, the larger targets are, the better results go, not only because of better visual feedback, but also because of the obvious increase of target area. Some users said they had more difficult making south and east gestures, since they had less shoulder support to make them accurately and effectively.

Going a bit more on details, we can distinguish between left and right hand. Some screen positions can be easier than others, regarding this interaction technique. Here, again we see the difficulty in the smaller size, with the lower border being the worst place for targets, but even so, the overall reveals bad results, making this size expendable.

For medium size targets, target acquisition becomes easier, where left handed users made fewer errors in the lower border (curiously the worst position for right handed users) and top right corner (17%), the same position where right handed users made fewer errors (0%).

Regarding the larger size, for left handed users, the best results (33%) came in the upper border and for right handed users the left border had fewer errors (11%).

As for conclusion, we can take out that for left handed users, gestures to the upper border are easier to accomplish, and for right handed users, west gestures and the upper border seem to be the best choices for target acquisition.

Regarding accuracy, we have to make relative calculations depending on the target size. As for 7 mm targets, the average distance to center was 62%. For 12 mm targets, this average was 46%. Finally for 17 mm targets, the average distance to center was 40%.

Tapping was the most extensive test of all, with twenty-five different screen positions and with three different sizes, making a total of seventy-five different taps each user had to make per test. The overall results, for the 15 impaired users, showed a 29.33% error rate. For the target size of 7 mm, the error rate had an average higher than 40%. Results become better when the size increases to 12 mm, going to an error rate a bit higher than 23%. Regarding the size of 17 mm, this error rate becomes even better, with almost 20%.

Talking about the different sizes, in the different screen positions, we see that for the 7 mm size, the lower border is bad for tapping, as well as the upper one. When it comes to bigger targets, the lower border showed the best results, even having a position with 0% error rate, for the size of 17 mm. The right border had also good results, even in the 7 mm size, with 20% error rate. 7% was also noticeable at the center of the screen, for 17 mm size, as well as the lower right corner.

Again we can separate the results in terms of preferred hand used. Here, we see higher problems for left handed users regarding the upper border, with 83% error rate in the 7 mm size. Even so, good results appeared closer to the right border, with a surprising 0% error rate for the smaller size. For bigger targets, we start to see differences, showing improvements in taps made near the left border (therefore closer to the left hand). In the 17 mm size, results showed that the left and lower border are the best for left handed users, with many screen zones at 0% error rate. Regarding right handed participants, we see the opposite in terms of error rate. At the 7 mm size, the worst zone is the lower right corner. For bigger targets, the results change and the lower border becomes the best zone for taps. In the 17 mm size, we see that almost every position in the lower border is near or exactly 0% error rate (Erro! A origem da referência não foi encontrada.). The right border is also easier for right handed participants, with few errors. The worst zone is around left upper corner, since is the more far away position that right handed users had to tap.

As for accuracy, where users have more accuracy with larger targets, even if they do taps further away from the center.

Figure 1 – Tapping, Exiting, Crossing and Gestures
Crossing has the purpose of making a gesture that crosses targets in different sizes and positions in the middle screen. Therefore, nine different screen positions were tested as well as three different sizes, making a total of twenty-seven tests. This interaction technique showed better results regarding the 7 mm size, with 34.81% error rate, compared to the other two interaction techniques with targets. For the biggest target size, this interaction is still very good, with 22.96% error rate, getting close to Tapping. The difference between the error rate in 12 (24.44%) and 17 mm (22.96%) is very small, showing that users can still be accurate at 12 mm.

Comparing the different screen positions, we see that almost all have the same error rate (except the smaller size, 7 mm). This indicates that crossing targets is accurate enough not only at 12 mm but also at 17 mm. Even if in the last size users made more errors than in Tapping, in this case users were consistent in the two sizes, and could acquire targets in every zone, since no position had error rate higher than 40%.

Again we can go a bit more on details, making a distinction between left and right handed users. Even if in this time, to make the correct target selection with cross users could always pick their favorite or best possible gesture, we can still be able to find best screen zones for the two different possibilities. Left handed users had fewer errors, compared to right handed users. Even so, the results are very good, especially in the two bigger sizes. The best position for left handed users was the upper left corner and the bottom border, with a 0% error rate. The same doesn’t happen with right handed users, where the best results only appear in the 17 mm size targets, with 11% error rate in some positions.

Looking for worst positions to make crossing gestures, for left handed, the gestures made in the center of the screen were harder to accomplish. For right handed users, gestures made near the corners are worse, especially the corners more far away from the user and the right hand (i.e. the upper left corner).

Regarding accuracy, we see the great accuracy users had in this interaction technique. Users were very accurate in all the three different sizes, making this interaction the best in terms of accuracy, regarding target acquisition.

Gesture is the last interaction technique tested, with two different approaches: using or not using borders as gesture aids. Therefore, and since we have eight different gestures to make, and four borders with two possible border per gesture, we asked users to make sixteen different gestures.

There are no relevant differences between gestures made using borders as aids (35% error rate) and gestures in the middle of the screen (37.50% error rate). This difference was shown while the users were making the gestures, since they had more problems of strength than accuracy, therefore some gestures they could do with no difficulty, while some other gestures were harder to accomplish because of the lack of strength.

The error rate for the different gestures has to be strictly analyzed, not only related to the different positions and gestures, but also regarding preferred hand for the different users. Some gestures are already noticeable as being easier to accomplish, such as North (26.67%), East (26.67%), NorthLeft (20%), NorthRight (26.67%) and EastUp (13.33%). These gestures were, in general, the easier gestures, especially North, in three different positions. Thus the reason can be what was explained before, as these gestures are easier to accomplish with the help of the shoulder or arm.

Looking closer to the results, separating the users preferred hand (Figure 2), some other conclusions can be analyzed. Therefore, some gestures were easier for left handed users, such as East (16.67%), NorthRight (16.67%) and EastUp (16.67%), while some other gestures were easier for right hand users, such as Northeast (11.11%), NorthLeft (11.11%) and EastUp (11.11%). As conclusions, is possible to see the ease of North and East gestures, for both hands, and West gestures for right handed users.

As for accuracy, the more accurate gestures were WestUp, NorthLeft and SouthRight, all near 1 mm average distance to the perfect vector of gesture. All these gestures are gestures that use the screen borders. But again we have to compare left handed users with right handed users, since the gestures are always affected by the preferred hand. Regarding left handed users, the more accurate gestures were West, NorthLeft, SouthRight and WestBottom. For right handed users, SouthWest, NorthLeft and WestUp were the more accurate gestures. As conclusion, we see that the use of borders is a help to make more accurate gestures. Users could use the borders to obtain gestures more close to

![Error Rate by Preferred Hand](image-url)

*Figure 2 – Gestures Error Rate by Preferred Hand*
the perfect vector, since the borders are lines where users can find a path, even if they don’t have much finger control.

As overall results, as shown in Figure 3, regarding able-bodied users, the results showed great results using Gestures, with 1.39% errors, followed by close from Tapping with 1.63%. Crossing and Exiting were where able bodied users made more errors, with 3.29% and 3.24% respectively. The best interaction for motor impaired users was Crossing, with an error rate of 28.89%, followed by Tapping, with 29.33% and Gestures, with 36.25%. Exiting was the worst one, with an error rate of 51.67%.

<table>
<thead>
<tr>
<th>Errors by Interaction Technique (%)</th>
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</thead>
<tbody>
<tr>
<td>Impaired</td>
</tr>
<tr>
<td>Exiting</td>
</tr>
<tr>
<td>Tapping</td>
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<tr>
<td>Crossing</td>
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<tr>
<td>Gestures</td>
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</tbody>
</table>

Figure 3 – Overall Error Rate

Comparing the different target sizes, we can also compare the three tests that use targets as goal. As shown in Figure 4, for motor impaired users, Exiting is again the worst technique, even for target size of 17mm. For smaller targets, crossing is the best way to select a target. When it comes to larger targets, Tapping can assure almost the same results as Crossing.

<table>
<thead>
<tr>
<th>Error Rate (Impaired)</th>
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<tbody>
<tr>
<td>% Error Rate</td>
</tr>
<tr>
<td>7 mm</td>
</tr>
<tr>
<td>12 mm</td>
</tr>
<tr>
<td>17 mm</td>
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<tr>
<td>Exiting</td>
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<tr>
<td>57%</td>
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<tr>
<td>46%</td>
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<tr>
<td>36%</td>
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<tr>
<td>Tapping</td>
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<tr>
<td>40%</td>
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<tr>
<td>23%</td>
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<tr>
<td>19%</td>
</tr>
<tr>
<td>Crossing</td>
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<tr>
<td>35%</td>
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<tr>
<td>24%</td>
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<td>23%</td>
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</table>

Figure 4 – Motor impaired users overall error rate by target size

Users were asked which interaction they thought was their best, as well as which was the best way to interact with the device (gestures or pointing). Able-bodied users have more preference for Crossing, while impaired users prefer Tapping. Gestures appear with three votes as well as Crossing, for impaired users, and a bit less than Tapping, for able-bodied users.

Another asked question was about the way of interacting with the touch screen: gestures or taps. The results show again a disparity between motor impaired and able-bodied users. Thirteen able-bodied users found gestures easier to perform, while five found taps better. Nine motor impaired users thought making taps is easier, while six found gestures a better way.

Overall Discussion

Many results could be analyzed with these tests. First of all, we can start by distinguish some overall conclusions, regarding the four different interaction techniques. As seen before, Exiting showed bad results not only with the error rate, but also regarding user’s opinion. Therefore, this was obviously the worst interaction technique, showing that users not only don’t like to use as interaction, but also they make many mistakes, even users with no motor impairments.

When it comes to see the best interaction, we had to analyze a lot of issues. Many impaired users said they had preferences for Tapping. This comes from the difficulty in moving the arm effectively for gestures. Taps are easier to make, as well as more accurate, since users have less contact with the screen. On the other hand, able bodied users preferred to make gestures, where Crossing was the most voted choice.

The most important results come with the error rates and accuracy impaired users had. As seen before, regarding Tapping, the results showed good results with target sizes of 12 and 17 mm (23.20% and 19.47% respectively) just where it passes Crossing, which is the best interaction technique for target selection as overall (28.89%). For able-bodied users, the results showed Gestures as the best way to interact with the touch screen, with only 1.39% error rate. The worse interaction technique was Exiting, with 52% error rate for motor impaired users, being also the only interaction with no votes for preferred interaction by users.

An analysis One-Way ANOVA revealed significantly differences between the interaction techniques, and a post-hoc analysis, Tukey’s test, showed that these differences occur between Exiting and Tapping, as well as between Exiting and Crossing. In other words, Exiting was significantly worse than Tapping and Crossing.

Some results might have been different if the touch screen in the PDA was different. This touch screen was a pressure touch screen, which implies some strength for the PDA to recognize a touch or a gesture. This made some users
perform incomplete gestures, since their arm strength and control wasn’t enough to maintain a fluid and accurate gesture. Even for taps, some users took some time to adapt to the screen, making simple touches in the surface, with no pressure, passing undetected by the PDA.

**Home Control Interface**

After studying which are the best ways tetraplegic users can or cannot interact with a mobile phone, we created a way to validate those results, with a home control interface. Therefore, the interaction techniques from the previous chapter are going to be used as ways of interaction with the mobile device, to elucidate the benefits, increase of control and accuracy users can gain by observing the results from our previous study, regarding screen positions and target sizes.

**Background**

Easy House [5] was created to enable tetraplegics to control their household appliances. It was found that users needed a system easily adaptable to a changing environment while providing the control mechanisms suitable to deal with each user’s limitations, using low-cost technology. The functionality of the system used the X10 domotic protocol through a set of actuators to control the home appliances. The limited functionality provided by this protocol seemed to be enough to cope with most of the tasks performed. Gestures and Speech were chosen due to their suitability with tetraplegics.

Even having good results, some future work was described as possibilities to explore. One of them is the portability, because it’s based on a laptop. Although the control interfaces used - mainly speech - can provide some level of portability, the laptop still needs to be close to users, limiting its action range. By providing a mobile extension that can be connected to the existing system it would be possible to bring the system closer to users, allowing them to control the system using a small device. Therefore, this future work can now be developed, in conjunction with the research done previously, regarding the best interaction technique for touch screen mobile phones, in order to obtain a better and more portable control interface. A PDA using a similar interface, based on the conclusions obtained in the previous study, can provide a much better system for impaired users to operate and control their house appliances.

**Goals**

The objective of this work was to understand if the results we got are somehow accurate, when it comes to build an interface using those results as support. The main goal was to see if a motor impaired person is not only capable of executing the different interaction techniques but also if he can control his houses with it. Another important aspect is if the user is comfortable using this domotic control, and if compared to a laptop domotic control, the results improve.

This work, as said before, was a way to validate, as a case study, the results obtained from our main project, which was to understand touch screen interaction for tetraplegic people. Therefore, the case study elucidates the benefits and improvements that can be taken from our results in that main study, regarding mobile touch screen interaction.

**Methodology**

Looking at the results obtained from the previous study, regarding the different interaction techniques, screen zones and target sizes, we got to some conclusions. With those conclusions, some aspects were studied in a real interface, which suited for the domotic control project described before. Therefore, different interfaces were built in order to satisfy the conclusions obtained. Crossing had less error rate from all the different interaction techniques, followed by Tapping. The interaction technique with the worst results was Exiting. With these results, four different interfaces were built, using the following interaction techniques:

1. Crossing
2. Exiting
3. Tapping
4. Crossing + Tapping

![Figure 5 – Crossing and Crossing Tapping Interface](image)

![Figure 6 – Exiting and Tapping Interfaces](image)
was only caused by the difficulty in performing some gestures or if the screen positions were also a problem.

Regarding target sizes, we used a size between 12 mm and 17 mm (14 mm), which looking at the previous results, showed to be enough to obtain good results.

Subjects
Only one tetraplegic, PF, was taken into account in the user analysis, making this a case study. Although this may be bad for future conclusions regarding the target population, it creates a closer link between user and researchers, making us go into more details and deep analysis. This user didn’t belong to the group of impaired users from the previous study, and is the same user that tested the project Easy House, a domotic control through a laptop.

In terms of place, all actions performed were done in his bedroom, in bed.

Apparatus
During the experiment we used a QTEK 9000 PDA with a 73 x 55 mm screen dimension and 640x480 pixels resolution, running Windows Mobile 5. The software was implemented in C#, using the .NET Compact Framework 3.5 and Windows Mobile 5.0 SDK.

In the laptop, the software used belongs to the project Easy House, which controls the system in PF’s house. This software was implemented in C# as well.

Procedure
The system was the same in all the different interaction techniques. The system only had 4 options at most, having different levels of selections. The first level is the division level, where the user can pick which division he wants to get access to. Since PF’s house has more than 4 divisions, we had to create another level with divisions. After choosing the desired division, in the second level we have the different appliances the user can control in that division. When the user selects a specific object to control, the actions available appear in the last level. Therefore, we have 3 different levels: divisions, objects and actions.

The only difference between the interfaces is the location of objects. In Exiting, the targets are in the corners and borders. In Crossing and Tapping targets are displayed as a cross, where users can select by crossing or tapping.

To guarantee that the best interaction technique from these results is not because of learning skills through experience, the tests were made as follow: Crossing, Tapping, Exiting and finally the mix between Crossing and Tapping. Between the tests, the user had time to rest and some time to get used to the new interaction.

Research Questions
1. Are the results obtained similar to the results taken from the previous study?
2. Which interaction technique had better results?
3. Does the user improve usability using the PDA instead of the laptop?

4. Was the user satisfied with these interfaces, and which was his favorite?

Results
Looking at the Figure 7, the results improved when the user started to get familiarized with the interface, and with the different interaction techniques. Even so, it was clear that taps were much easier and faster than gestures. That happens because a gesture demands a longer contact with the screen, and taps are much quicker for selection. Since this user has some difficulties in terms of finger and arm strength, making taps is much easier and faster.

![Figure 7 – Mean Time to complete each task](image)

Regarding errors, there were very few errors, showing that the interface was well built. The interfaces were built gathering the information from the previous chapter, therefore already having a good positioning and size for targets.

![Figure 8 – The user PF performing the tasks](image)

As for user opinion, PF said he found much easier to perform taps than gestures, not only in terms of speed but also in terms of accuracy and fatigue. The user said he found gestures a much harder way of interact and that at some point he felt tired and less accurate to select targets. Finally, the user said that using a PDA instead of the laptop is more comfortable and easier, since he has a higher area to select and a smaller device to handle in bed. He found the interface very easy to use and handle, having preferences for Tapping or TappingCrossing.
CONCLUSIONS

The main goal of our work was to understand touch screen interaction, in ways that could help tetraplegic users improve and overcome difficulties created by their disabilities, especially regarding interaction with these devices. Many problems exist in their everyday lives, and through a user analysis we could find out how to deal with some of those problems. Finding good solutions to interact with a mobile touch screen phone not only improves their contact with such devices, but also can help in so many other ways, such as improving independence and control in their own houses, where nowadays they need help for each small action.

The real challenge was centered in finding, through analysis of previous work and studying the limitations and capabilities, how can users improve their interaction with mobile touch screen phones. We conducted a series of tests with 15 tetraplegic users, studying four different interaction techniques: Tapping, Exiting, Crossing and Gestures. 20 able bodied users also made the tests, for comparison. In those studies, we not only evaluated the way users could interact with a PDA, but also we studied different positions in the screen, as well as different target sizes. Therefore, the study could get conclusions on the best way users can interact with small touch screen devices and also on best possible choices for target position, as well as their size.

The results showed Tapping as a good choice of interaction, which is the everyday way of interact with normal touch screen devices. Crossing was also effective, but some users had more problems to perform accurate gestures than taps. Even if, for smaller targets, Crossing had fewer errors, for larger targets, Tapping improved error rate and had better results. The fact that tetraplegic people have different limitations is always complicated to get to conclusions on a global scale. Some users might have more arm/hand control than others, showing that results are never completely accurate and effective for everyone. Another visible problem in these studies was the PDA screen. The PDA used in the tests had a touch screen that needed some pressure to detect contact. Therefore, and since some users have less arm strength, they found more difficult to perform gestures, since it would require more constant contact with the screen.

To strengthen our objectives, a domotic control interface was built, using the results from the main study regarding best interaction technique as well as target size and position. Four different tests were created, using four different interaction techniques: Crossing, Exiting, Tapping and CrossingTapping. This last one was a test where the user could select targets not only by tapping them, but also by crossing them with gestures. This study had the goal to validate our main research, in a form of case study. This case study had three sessions, with a tetraplegic person, PF, in his house. Each test had several tasks to perform, through the interface of domotic control, such as turning on the lamp in his bedroom.

This domotic interface was an extension to a previous work, EasyHouse [5], which evaluated different interactions for domotic control in a laptop. Our extension was an improvement to this work, since it makes the system more portable and comfortable to use, as well as more accurate and effective, with the use of a PDA. Therefore, creating this interface was a way to validate our main study regarding touch screen interaction.

The results from this case study with PF showed very good results, not only in selecting the right target, but also in terms of ease of use and speed of selection. The user approved the project and showed interest in use it to improve his independence on the house, controlling more objects and devices at home, when at his bed, with a simple touch screen PDA. Along the three sessions, it was clear signs of learning how to use the interface, regarding target positions as well as interaction control and accuracy regarding the different interaction techniques. The interaction technique more easily used by PF was taps, since he can’t maintain a constant strength contact with the screen, performing poor and inaccurate gestures. Taps were, therefore, his best way of interacting, not only in terms of speed, but also in terms of accuracy and fatigue. Even so, Crossing continued being much better than Exiting, in terms of selecting targets by gestures, validating the results taken from our main study. The user found Exiting difficult to accomplish, especially with middle screen targets. Since in Crossing, the user have the freedom to execute the gestures he can better perform, results were better in this case. The combination of Crossing with Tapping didn’t show many improvements, since the user used almost always taps to select the targets.

The objective of understanding how tetraplegic people can benefit by using an effective interface in touch screen mobile phones was accomplished, even if we cannot conclude it is advantageous to every tetraplegic, because this limitation varies from person to person, and some users can benefit more than others. But the overall showed improvements when interacting with the touch screen.

FUTURE WORK

Despite the good results obtained, some future work would reinforce this research. Some touch screen mobile phones have screens without pressure, making their interaction much easier, especially for people with low arm strength. Therefore, a screen like that would drive us to a new level of interaction, making studies more accurate and improving usability, especially for gesture interaction.

The Home Control Interface was an extension to a previous work, EasyHouse [5], which was a system for domotic control, in a laptop. Since the user was pleased with the system, and showed good results while using it, it can be, in a near future, installed and adapted to his needs, in order to increase his autonomy and independence throughout the process of controlling house appliances.
Future work regarding our results is the most interesting part. Using the guidelines found in this work, some future work in finding interaction strategies that use them can be done. One example is Crossing, which we got to conclusions that people liked and could use it in an effective way, and they often use the same gesture to select most of the targets. It would be interesting to use Crossing with this limitation but with metaphors that allow the use of the entire screen. Applications that might use these results, such as best screen positions and target sizes, for each interaction technique, is a way to build suitable interfaces, capable of decreasing effort and inaccuracy by tetraplegics in target selection with touch screen mobile devices. Using Tapping as well, using our results for target position and size, can be used to create better interfaces, more usable and user friendly.

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REFERENCES


