Towards Mobile Touch Screen Inclusive User Interfaces: Differences and Resemblances between Motor-Impaired and Able-Bodied Users

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Abstract. Touch screen mobile devices are highly flexible and customizable, allowing designers to create inclusive user interfaces that are accessible to a broader user population. However, the knowledge to provide this new generation of user interfaces is yet to be uncovered. Our goal is to thoroughly study mobile touch interfaces, thus providing the tools for informed design. We present an evaluation performed with 15 tetraplegic and 18 able-bodied people that allowed us to identify their main similarities and differences within a set of interaction techniques (*Tapping*, *Crossing*, and *Directional Gesturing*) and parameterizations. Results show that despite the expected error rate disparity, there are clear resemblances, thus enabling the development of inclusive touch interfaces. *Tapping*, a traditional interaction technique, was among the most effective for both target populations, along with *Crossing*. The main difference concerns *Directional Gesturing* that in spite of its unconstrained nature shows to be inaccurate for motor impaired users.

Keywords: Mobile, Touch, Tetraplegic, Able-bodied, Interaction techniques.

1 Introduction

The spectrum of motor abilities is wide and diverse. In the last decades, efforts have been made to compensate this diversity and provide an inclusive access to technology, above all, to desktop computers. The same does not apply to mobile device accessibility, which is still in its infancy. Small devices and keys, less processing capabilities, along with the context it is designed to be used in may have been the main reasons for this lack of accessibility and overall limited understanding.

Meanwhile, mobile phone touch screens are increasingly replacing their traditional keypad counterparts. These interfaces present challenges for mobile accessibility: they lack both the tactile feedback and physical stability guaranteed by keypads, making it harder for people to accurately select targets. This becomes especially relevant for people who suffer from lack of precision, such as tetraplegic users. However, these interfaces offer several advantages over their button-based *equivalents*. Particularly, they can easily display different interfaces in the same surface or adapt to users' preferences and capabilities [1]. The ability to directly touch and manipulate data on the screen without any mediator provides a natural and engaging experience. Additionally, the use of PDAs is a viable alternative to traditional input devices (i.e. mouse and keyboard), allowing the same interface to be used in different places and contexts. Furthermore, the high customization degree of touch screens makes them amenable to custom-tailored or adaptive solutions that better fit each user's needs. This may as well be a determinant factor for inclusive design as devices used by motor impaired people can be the same as the ones used by the able-bodied population, with slender interface tuning [2, 3, 4].

However, there is no comprehensible knowledge of the values and flaws of each touch interaction technique in what concerns users' motor ability. To be able to provide flexible and customizable touch user interfaces we first need to understand how users with dissimilar motor aptitudes cope with the different demands imposed by interaction techniques and interface parameterizations.

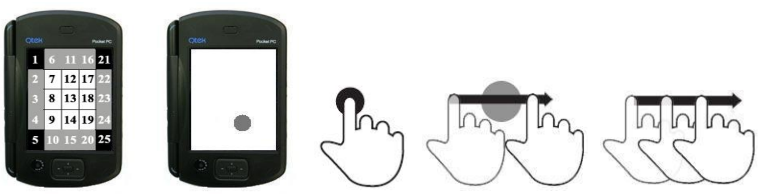
In this paper, we present an evaluation with 15 tetraplegic and 18 able-bodied people aimed at understanding the differences and similarities between populations. We studied a set of interaction techniques (*Tapping*, *Crossing*, and *Directional Gesturing*) and parameterizations (*Size* and *Position*). The results show that despite the expected error rate disparity, there are clear resemblances, thus giving space for inclusive adaptive user interfaces.

2 User Study

Touch screen devices pose both challenges and opportunities for researchers. Recently, significant efforts have been applied to make these interfaces accessible to motor-impaired people. Wobbrock et al. [5] proposed a stylus-based approach that uses edges and corners of a reduced touch screen to enable text-entry tasks on a PDA. Similarly, Barrier Pointing [6] uses screen edges or corners to improve pointing accuracy. By stroking towards the screen barriers and allowing the stylus to press against them, users can select targets with greater physical stability.

Although these works insightfully explore the physical properties of the device to aid impaired people interacting with touch screens, there is still little empirical knowledge about their performance with other interaction techniques. On the other hand, a great deal of research has been carried out to understand and maximize performance of able-bodied people using these devices [7, 8].

Our primary goal with this research was to evaluate different motor ability-wise participants with different interaction techniques, towards an adaptive/customizable inclusive touch design space. By understanding the limitations and needs of each population, along with the advantages and flaws of each technique and



a) b) c)

Figure 1 – (a) Qtek 9000. Screen areas: black – corners; gray – edges; white – middle; (b) Onscreen target; (c) Tapping, Crossing, and Directional Gesturing.

parameterization, we will be able to understand how to design interfaces that maximize each user's performance. Further, we will be able to build more inclusive interfaces.

2.1 Interaction Techniques and Variations

We considered two basic interaction methods: tapping the screen or performing a gesture. When performing a gesture, users could cross a target or just use directional gestures (Figure 1.c).

Tapping the screen consisted in selecting a target by touching it. In this technique, targets were presented in 3 different sizes (7, 12, and 17 mm), derived from previous studies for able-bodied users [7, 8], and in all screen positions: edges, corners or middle, thus covering the entire surface.

Crossing, unlike *Tapping*, did not involve positioning one's finger inside an area. Instead, a target was selected by crossing it. Previous work, on desktop interaction, has shown that this technique offers better performance for motor-impaired users than traditional pointing methods [9]. In our experiment, targets were shown in the middle screen positions (see Figure 1.a) in 3 different sizes.

Directional Gesturing was the only technique that did not require a target selection. Users could perform directional gestures anywhere on the device's surface. This technique was chosen both due to its unconstrained nature and, as well as *Tapping*, because it is a common interaction technique in novel touch-based devices.

2.2 Participants

Fifteen tetraplegic people were recruited from a physical rehabilitation center. The target group was composed by 13 male and 2 female with ages between 28 and 64 years with cervical lesions between C4 and C6. All had residual arm movement but no hand function. Regarding technologic experience, all participants had a mobile phone and used it on a daily basis. However, none of them had a touch screen mobile phone. Eighteen able-bodied participants (5 females) with ages comprehended between 20 and 45 years old were recruited word-to-mouth in the local university. All of them had previous contact with mobile touch phones.

2.3 Apparatus

We used a QTEK 9000 PDA (Figure 1.a) running Windows Mobile 5.0. The mobile device screen had a resolution of 640x480 pixels for a size of 73x55 mm, , with noticeable physical edges. The evaluation software was developed in C# using .NET Compact Framework 3.5 and Windows Mobile 5.0 SDK. The evaluation was video recorded and all interactions with the device were logged for later analysis.

2.4 Procedure

Participants were told that the overall purpose of the study was to investigate and compare different touch interaction techniques. We then conducted a questionnaire and informed the subjects about the experiment and all interaction techniques were explained and demonstrated.

To attenuate learning effects, participants were given warm-up trials before the evaluation of each technique. During these trials they were able to move the mobile device to a comfortable position. All sessions were performed in a quiet environment (the university, their homes or rehabilitation center facilities). Motor impaired participants carried out the trials sitting on their wheelchairs with a table or armrest in front of them. Able-bodied participants completed the trials sitting in a chair in front of a table and were free to choose how to hold the device. The interactions with the touch screen were stylus-free; however participants were free to issue selections with any part of their hands/fingers.

Each subject was asked to perform target selections with each technique (*Tapping* and *Crossing*). For the *Directional Gesturing* condition, there were no targets and participants only had to perform a gesture in a particular direction (e.g. north). There were sixteen possible directions, including diagonals and repeated directions with edge support (e.g. north using the right edge as a guideline). For the *Tapping* condition participants were asked to select targets in all screen positions, as shown in Figure 1.a. For the *Crossing* condition we only used the middle area (9 positions).

Participants were not informed on whether the selection was successful or not. However, they received feedback that an action was performed. The next target appeared following a two second delay after each action. We selected tests in a random order to avoid bias associated with experience. In each method-size experience, target positions were also prompted randomly to counteract order effects.

The experiment varied interaction technique, target size and screen position. We used a within-subjects design, where each participant tested all conditions. For the position analysis, we created one extra factor, *Vertical Distance*, which reflects the target position in relation to the users' support (level 1 refers to the closest position to participants' arm support while level 5 refers to the most distant ones).

Shapiro-Wilkinson tests of the observed values for *Task Errors* did not fit a normal distribution for able-bodied participants and all interaction techniques. Therefore, a Friedman test was used in further analysis. Post-hoc tests were performed using Wilcoxon signed rank pair-wise comparisons with a Bonferroni correction. On the other hand, observed values for *Task Errors* for motor impaired participants showed to fit a normal distribution. Thus, a repeated-measures ANOVA was used in the analysis.

3 Results

Our goal is to understand and relate the capabilities of both user populations (i.e. motor-impaired and able-bodied) when using different touch techniques. We present the results highlighting their main similarities and differences considering each

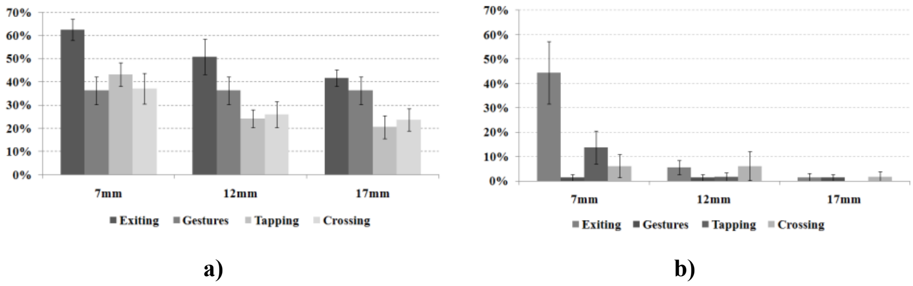


Figure 2 – *Error Rate* for a) Motor impaired and b) Able-bodied.

technique, target size and interaction area. This knowledge will enable designers to predict how both motor-impaired and able-bodied users will perform using their touch interfaces and employed techniques.

3.1 Target Size

Motor Impaired. Considering *Tapping*, there was a significant effect of *Target Size* on *Task Errors* ($F_{1,42}$=25.10, p<.001). A multiple comparisons post-hoc test found significant differences between small and medium sizes, as well as between small and large sizes (Figure 2.a). These results suggest 12 mm as an approximate suitable value for targets to be tapped by motor-impaired users. Regarding *Crossing*, a significant effect was also found ($F_{1,42}$=6.56, p<.01), however between the smallest and largest sizes.

A comparison between techniques reveled a significant effect in the medium ($F_{1,56}$=8.04, $p<.001$) and largest ($F_{1,56}$=3.83, $p<.05$) sizes, in which *Directional Gesturing* perform worst than *Tapping* and *Crossing*. This suggests that *Directional Gestures* are only worth considering when targets size is small.

Able-bodied. There was a statistically significant difference in *Task Errors* depending on *Target Size* for *Tapping* ($\chi^2_{(2)}$=26.261, $p<.001$). Post-hoc analysis revealed significant differences between the smallest and both medium and largest sizes (Figure 2.b). As for motor impaired participants, results suggest that *Error Rate* starts to converge at 12 mm. Regarding *Crossing*, no significant differences were found between target sizes.

Additionally, we found a significant effect of *Interaction Technique* in the smallest size ($\chi^2_{(2)}$=13.765, $p<.001$). Further analysis revealed that *Directional Gestures* is significantly more accurate than *Tapping* (Z=-3.237, $p<.001$), which suggests that when users are faced with small targets, gesture approaches are more adequate.

Differences and Similarities. Regarding each interaction technique, *Tapping* seems to be the most similar between user populations. Particularly, both perform worse with small target sizes (7 mm), and *Error Rate* begins to converge at 12mm. Nevertheless, we suspect that able-bodied users can achieve similar accuracy results with smaller targets [7, 8].

The main difference between these two types of users lies in the magnitude of errors, particularly in the *Directional Gesturing* technique. Motor-impaired users have great difficulty performing gestures in a specific direction, especially diagonals, while able-bodied users have no difficulty using this technique. Indeed, results suggest that gesture approaches, either *Directional Gesturing* or *Crossing*, can be used as suitable alternatives to *Tapping* when the interface only has small targets.

3.2 Screen Area

In this section we will analyze participant performance according to different interaction areas: edges, middle, and vertical distance.

Motor Impaired. Considering *Tapping*, there were no significant differences on *Task Errors*, regardless of target size, or its position on an edge or not. Similar results were obtained for *Directional Gesturing*, as no significant differences were found on *Task Errors* for gestures supported by edges or anywhere else onscreen.

Regarding *Vertical Distance*, we found a significant effect for *Tapping* on medium ($F_{1,42}$=3.59, $p<.05$) and largest ($F_{1,42}$=5.19, $p<.05$) sizes. Post-hoc tests showed that targets closer to users' arm are easier to tap. For *Crossing* and *Gestures*, no significant effect was found between vertical areas.

When comparing all interaction techniques in common ground, i.e. on the middle of the screen, there was no significant effect on *Task Errors*, suggesting that users have similar accuracy while interacting in the middle of the screen with *Tapping*, *Crossing* and *Directional Gesturing*. In this analysis we have discarded diagonal gestures as they were seen as drastically decreasing the success of *Directional Gesturing* approach for motor impaired users.

Able-bodied. Considering edges, we found a significant difference on *Task Errors* for *Tapping* (Z=-2.987, $p<.05$). Results showed that for small sizes, targets are easier to acquire on the middle of the screen. When considering *Directional Gesturing*, no significant differences where found between gestures on the edge or elsewhere on the screen. Moreover, this technique have shown to be more accurate than *Tapping* on screen edges (Z=-3.066, $p<.05$) for small target sizes.

Regarding *Vertical Distance*, there was a significant effect for *Tapping* in the smallest size ($\chi^2_{(4)}$=24.172, $p<.001$). A post-hoc analysis showed that targets near the bottom edge are significantly harder to acquire. This result was not observed in *Crossing,* since it had similar accuracies for all vertical areas.

Considering interaction in the middle of the screen, regardless of target size, we found no significant differences, which suggest that users have similar accuracy with *Tapping*, *Crossing* and *Directional Gesturing*.

Differences and Similarities. When considering interaction on the middle of the screen, both target populations perform equally with *Tapping*, *Crossing*, and *Directional Gestures*, suggesting that the main differences between interaction techniques are in the remaining of the screen (i.e. edges). Indeed, one could argue that

Gestures performed with edge support would be more accurate to both able-bodied and disabled users. However, results have shown that both user populations have similar *Error Rates* performing a *Gesture* on the edge or anywhere else on the screen. Nonetheless, for able-bodied users, performing *Directional Gestures* on edges is significantly easier than *Tapping* small targets. In fact, when these were placed near edges, particularly the lower edge, *Tapping* accuracy was 3 times lower (18% *Error Rate*). On the other hand, motor impaired users had greater difficulties *Tapping* targets in the upper edge, due to restrictions of reach.

4 Towards Inclusive Design

After analyzing the results for both user populations regarding their performance with each interaction technique, we are now able to draw some conclusions about their main differences and similarities as it was proposed in the beginning of this study:

Traditional *Tapping* is a suitable interaction technique. Taking into account all interaction techniques, *Tapping* has shown to be the one with more resemblances between motor impaired and able-bodied users. This technique presented the lowest *Error Rates* for both target populations and 12 mm has show to be a good compromise for target size as accuracy begins to converge.

Magnitude of errors is much higher for motor-impaired users. Despite some similarities between motor impaired and able-bodied users' experiences with touch interfaces, one of the main differences resides in the magnitude of errors. As expected disabled users have a much lower accuracy rate. Overall, error rates are 5.6%, 6.1%, and 26.1% times higher for *Tapping*, *Crossing* and *Directional Gesturing*, respectively.

Able-bodied users can easily perform *Directional Gestures.* *Directional Gesturing* proved to be an accurate interaction technique for able-bodied users. In fact, this technique has shown to be a suitable alternative to *Tapping*, particularly when small targets are placed near the edges. Unlike motor impaired people, who have many difficulties performing specific gestures, able-bodied can easily take advantage of it.

Middle of the screen consistency. Both user populations can use all interaction techniques on the middle of the screen with similar accuracy. Neither for able-bodied or motor impaired users was found a significant effect in *Error Rate* when interacting with the center area of the display. This suggests that is the remaining of the screen (edges) that can favor or hinder interaction.

Reach restrictions. One main difference between target populations is their ability to reach far-away targets. Motor impaired users have greater difficulties *Tapping* targets far from their arms' support, thus resulting in lower accuracy rate. Conversely, able-bodied users do not have this difficult, however when targets are small they present some difficulties in *Tapping* targets near the bottom edge. This may be due to the restrictions imposed by the physical edges, preventing users to fully land their fingers on targets.

5 Conclusions and Future Work

Touch screen mobile devices are able to exhibit different interfaces in the same display, allowing designers to create more suitable interfaces to their users' needs. These devices carry with them the promise of a new kind of user interfaces; one that is accessible to a broader user population. To fulfill this vision we undertook an extensive evaluation with 15 tetraplegic and 18 able-bodied users in order to provide empirical knowledge to be used in the design of future touch interfaces. Our goal was to indentify the main resemblances and differences between these two populations, while comparing different interaction techniques, target sizes and positions.

Results showed that traditional interaction techniques, such as *Tapping*, can be used by motor impaired users, however with higher *Error Rates* than those obtained by able-bodied users. On the other hand, *Directional Gesturing* while extremely easy to perform by those with no impairments, proved to be quit inappropriate to the remaining. *Crossing* targets has also shown to be a suitable alternative to motor impaired, particularly if we consider the difficulty in *Tapping* small targets. Indeed, future touch interfaces have to take into account their users' capabilities and provide the most adequate mechanisms to ensure an efficient and effective experience.

Following this work, we intend to instantiate our findings and develop a touch interface that can adapt itself to its users, regarding interaction technique, target size and position.

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