Investigating the Effectiveness of Assistive Technologies on Situationally Impaired Users

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Abstract. Mobile devices are used in increasingly demanding contexts, which compete for the visual resources required for an effective interaction. This is more obvious when considering current visually demanding user interfaces. In this work, we propose using solutions initially designed for blind people in order to ease the visual demand of current mobile interfaces. A comparative user study was conducted with 23 sighted volunteers who performed text-entry tasks with three methods, QWERTY, VoiceOver alike and NavTouch in three mobility conditions. We first analyzed the effect of walking and visual demand, followed by the effect of using assistive technologies in mobile contexts. Results show that traditional QWERTY keyboard outperforms alternative text-entry methods for the blind, as users prefer visual feedback over their auditory counterpart. Moreover assistive technologies and their interaction processes revealed to be cognitively demanding and therefore inadequate in mobile contexts. These findings suggest that technology transfer should be performed with caution, and adaptations must be done to account for differences in users' capabilities.

Keywords: Mobile, Situational Impairment, Blind, Text-Entry

1 Introduction

Mobile devices play an important role in our daily lives. They have become smaller, cheaper, and more powerful, allowing its users to perform an increasingly number of tasks while on the move. Indeed, these objects spend more time near us than any other, whether at home, on the street, at work, in car, in public transports, etc. The use of these devices have evolved from the static and quiet environments of our offices to a more variable and heterogeneous context, leading to an obvious paradigm shift [4].

These contexts pose new challenges to mobile users since they compete for the same human resources that are needed to fully control electronic devices. These problems arising from context are called situationally-induced impairments and disabilities (SIID) [10]. For instance, texting while walking in a busy street can be quite a challenge and hazardous, since visual resources are both required to monitor the surrounding environment and interact with the device. Similarly, reading a text message or email in a public space can be difficult, or even impossible, due to the glare on the screen caused by sunlight. In this type of situation, we argue that users may become "functionally blind"; as the users' visual resources are overloaded and the visual feedback is inadequate.

In this paper, we propose a technology transfer approach [13], where solutions initially created for blind people can be used by sighted people in mobile contexts. While we agree that both users' capabilities are different, there seems to be an overlap of interaction challenges. Focusing on text-entry tasks, we present a user study where participants used two alternative methods on three mobility conditions. Our main goal was to assess the effect of walking and visual demand on participants' performance with methods designed for blind users. We analyzed the obtained results for each method individually, and compare them with each other, in order to draw conclusions and suggestions for future work.

2 Related Work

In a pioneer work, Kristoffersen and Ljungberg [2] stated that mobile devices usually compete for the same human resources required for other mobility tasks. Since then, there have been several empirical studies that try to understand how users are affected by different mobility conditions.

Being vision our primary sense to perceive information, its study becomes very important. Mustonen et al. [6] showed that users, whilst mobile, perceive information differently, for instance, reading speed slows with increasingly walking pace. Additionally, mobility also affects how we use mobile devices: input speed tends to decrease, while error rates increase on text-entry tasks. Lin et al. [3] also examined stylus-based tapping operations under three mobility conditions: seated, walking on a treadmill and walking through an obstacle course. The authors showed that treadmill based conditions were able to generate accurate results for selection time; however accuracy was significantly lower on a more realistic condition. Regarding the effect on cognitive resources, Oulasvirta et al. [7] performed a semi-naturalistic field study showing that visual attention is highly fragmented when interacting with mobile devices.

In order to ease the visual demand of mobile interfaces, several solutions have been proposed. Pascoe et al. [8] proposed minimal attention user interfaces (MAUI) in order to minimize the amount of visual attention, though not necessarily the number of interactions required to operate the device. Other authors have abandoned screens entirely, allowing users to control their devices trough alternative modalities [9].

Indeed, visual attention is a crucial resource when using devices whilst walking. Nevertheless, while these systems only provide alternative interfaces, our work takes a different approach in that we try to reuse knowledge already available from users who can't use visual feedback and apply it on mobile contexts.

In mobile settings there is a competition for the users' attention between the surrounding environment and the mobile device [7]. Users are constantly managing their attentional resources, switching tasks and gaze as needed. This behavior is usually aggravated due to visually demanding interfaces. Consequently, in visually demanding environments, users become “functionally blind”, as they cannot maintain performance on a given task due to an overload of their visual resources.

In this paper, we propose the use of solutions designed for those whom graphical feedback is inappropriate (such as blind people), thus freeing some of the users’ limited visual resources to their main task. According to the Multiple Resource Theory (MRT) [12], this would allow users to perform both tasks simultaneously with less interference and therefore with a smaller loss of performance.

While we intentionally state the similarities between blind and situationally impaired users, we also acknowledge that both user group capabilities are different in that SIIDs tend to be temporary and dynamic, as mobile users can always glance at their devices. Nevertheless, we believe that in visually demanding conditions, both populations are affected by the same problems, and would benefit from similar solutions. Therefore, perhaps a more appropriate question would be: when will mobile users gain with these solutions?

To answer this question, we will focus on text-entry tasks, since this is one of the most demanding tasks in mobile devices and also one of the most common (e.g. contact managing, sms, email, notes, games, etc.). Solutions for blind people include traditional screen readers, which replace visual feedback by its auditory representation. For example, when using an iPhone, VoiceOver[1] makes use of a text-to-speech tool to read interface elements touched by the user. Therefore, when using a virtual keyboard, users can navigate through letters and enter text without looking at the screen. Indeed, touch interfaces for blind people have been recently attracting a great deal of work [14; 1]. For instance, NavTouch [1] method enables blind users to input text by performing directional gestures to navigate a vowel indexed alphabet. Gestures to right and left allow users to navigate the alphabet horizontally, while up and down allow them to jump between vowels. This technique requires no memorization beyond knowing the sequence of letters in the alphabet. Moreover, vowels can be used as shortcuts to the intended letter. Constant audio feedback reads each character to users as they select it, whereas double or split tap is used to accept the selection. Special actions (such as erase) are placed on screen corners.

While these methods can theoretically ease the visual demand of text-entry tasks, due to their auditory feedback, we still do not know how situationally impaired users behave on different mobility conditions. Our main goal is to provide this empirical knowledge to be used in the design of more usable mobile interfaces.

3 Evaluating Text-Entry Solutions

The goal of this user study was to understand the effects of different mobility conditions on text-entry performance and secondly observe how users behave when using assistive technologies whilst walking.

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[1] http://www.apple.com/accessibility/iphone/vision.html (Last visited on 07/04/2011)

3.1 Participants

Twenty three participants (15 males, 8 females) with ages between 18 and 37 years old took part in the study. All participants owned a mobile phone, for at least 5 years, whereas only 6 of them did not use touch screen technology. Regarding text-entry, 2 participants used it on a weekly basis, while the remaining did this task daily. On the subject of preferred text entry methods, 15 participants used QWERTY keyboard (13 virtual and 2 physical), and 8 used MultitTap (2 virtual and 6 physical).

3.2 Apparatus

In this study we used a Samsung Galaxy S device running Android 2.2. The mobile device screen had 480x800 (122.4x64.2 mm) pixels wide. All text-entry methods were developed using Android SDK. Speech feedback was given using SVOX Classic TTS. The evaluation was video recorded and all interactions with the device were logged for later analysis.

3.3 Procedure

This study was conducted individually and started with a brief explanation about its overall purpose and procedure. Afterwards a short questionnaire was conducted to gather demographic data. All text-entry methods were explained, followed by 5 minute practice for each method to counteract learning effects.

Each subject was asked to perform two text-entry tasks with three methods: QWERTY, VoiceOver alike (with QWERTY) and NavTouch [1]. Although two of the featured methods were designed for blind people, visual feedback was intentionally available. Therefore, we could observe the participants' natural behavior when both visual and auditory modalities existed.

In order to realistically test these methods, we designed three mobility conditions: 1) Control – participants were seated in a quiet and controlled environment; 2) Corridor – participants were asked to walk at their own pace in a straight line path without obstacles; 3) Navigation – participants had to orientate themselves within the built track in order to walk in the right direction. The track consisted in poles having numbers and arrows indicating the order and direction the participants had to walk around the track (similar to [11]). This setup was created to simulate the use of mobile devices in an urban environment. We selected mobility conditions in a random order to avoid bias associated with experience. Additionally, before the first mobility condition, we captured the natural walking pace of each participant.

In each mobility condition, participants were asked to enter a set of sentences with all methods in a counter-balanced order. Each trial consisted of 2 sentences, each with 5 words with an average size of 4.48 characters. These sentences were extracted from a written language *corpus*, and each one had a minimum correlation with the language of 0.97. These sentences were randomly selected and read aloud to participants.

3.4 Experimental Design and Analysis

The experiment varied mobility condition and text-entry method. We used a within subjects design, where each participants tested all conditions. Shapiro-Wilkinson tests of the observed values for words per minute, error (deleted characters) rate, minimum string distance (MSD) error rate [5], and walking speed did not show a normal distribution. Therefore, a Friedman test was used in further analysis. For post-hoc tests, we used Wilcoxon signed rank pair-wise comparisons test.

4 Results

Our goal is to understand how users behave when using text-entry methods for the blind whilst on the move. In this section, we will show the results obtained in the user study previously described. First we analyze the differences regarding the three text-entry methods, for each mobility condition. We then describe how each method affected the walking task.

4.1 Text-entry Speed

To analyze text-entry speed we used the words per minute measure, calculated as *(transcribed text – 1) * (60 seconds / time in seconds) / (5 characters per word)*, according to MacKenzie and Tanaka-Ishii [5]. The time to input each sentence was measured from the moment the first character was entered to the last.

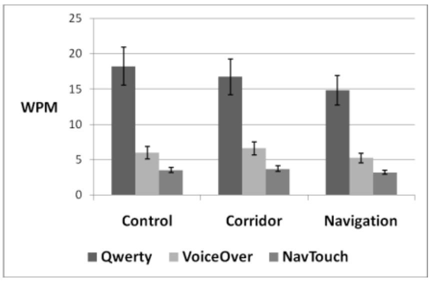

Fig 1: Words per Minute. Error bars denote 95% confidence intervals.

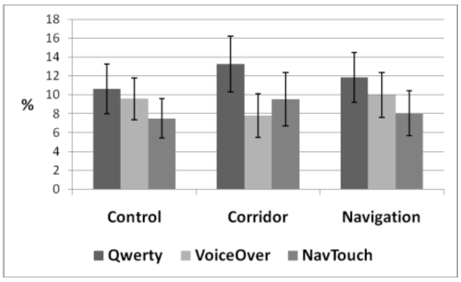

Fig 2: Error Rate. Error bars denote 95% confidence intervals.

Regarding the differences between the three text-entry methods, we found significant differences on WPM in the seated ($\chi^2_{(2)}=96.93$, $p<.01$), corridor ($\chi^2_{(2)}=88.44$, $p<.01$), and navigation ($\chi^2_{(2)}=96.75$, $p<.01$) conditions. A post-hoc test found significant differences between all methods. The QWERTY keyboard was always faster, followed by the VoiceOver alike and NavTouch (Figure 1). This happens possibly not only because all participants were familiar with the QWERTY layout but also because it was the only method that did not need confirmation to every letter.

Regarding the effect of mobility, we found significant differences for the QWERTY keyboard ($\chi^2_{(2)}=9.92$, $p<.01$), VoiceOver alike ($\chi^2_{(2)}=7.06$, $p<.05$) and

Navtouch ($\chi^2_{(2)}=4,7$, $p<.01$) methods. A post-hoc test revealed significant differences in the QWERTY keyboard between the control (18.24 WPM) and the navigation conditions (14.82 WPM); for the VoiceOver alike method in the corridor (6.59 WPM) and navigation (5.23 WPM) conditions and with NavTouch between the corridor (3.68 WPM) and navigation (3.21 WPM) conditions.

These results suggest that all methods were sensitive to visually demand conditions and auditory feedback was ineffective. Also, the QWERTY keyboard varyed the most with a loss of 3.42 words per minute from control to the navigation condition.

4.2 Error Rates

As a measure of effectiveness, we used error rate, which was calculated as *(letters deleted / letters inserted) *100.*

Comparing error rates between all text-entry methods, we found differences in the control ($\chi^2_{(2)}=4.54$, $p<.1$), corridor ($\chi^2_{(2)}=7.57$, $p<.05$) and navigation conditions ($\chi^2_{(2)}=5.53$, $p<.1$). After the post-hoc analysis, we found that in the control and navigation situations the QWERTY method had, with a minor effect, higher error rates (10.63% for the control and 11.85% for the navigation) than NavTouch (7.49% for the control and 8.07% for the navigation). In the corridor condition (see Figure 2) the QWERTY keyboard not only had a significantly higher error rate (13.27%) than NavTouch (9.55%), but was also higher than the VoiceOver alike method (7.79%).

When analyzing the error rates in the different mobility conditions we found no significant differences.

4.3 Quality of the Text

To measure the quality of the text transcribed we used the minimum String Distance Error Rate metric calculated as *MSD(presentedText,transcribedText) / Max(|presentedText|,|transcribedText|) * 100* .

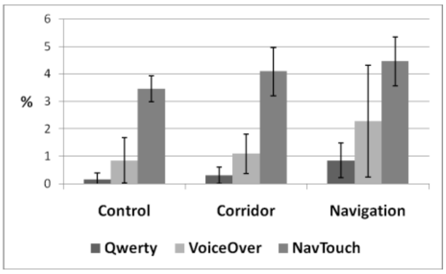

Fig 3: MSD Error rate. Error bars denote 95% confidence intervals.

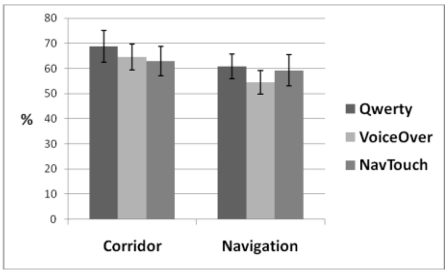

Fig 4: Speed rate. Error bars denote 95% confidence intervals.

Concerning the quality of the text we obtained significant differences in the 3 text-entry methods for the control ($\chi^2_{(2)}=93.23$, $p<.01$), corridor ($\chi^2_{(2)}=73.51$, $p<.01$) and navigation ($\chi^2_{(2)}=64.77$, $p<.01$) conditions. Overall, NavTouch produced the worst quality text in all mobility conditions (Figure 3). No significant differences were found between the VoiceOver alike and QWERTY keyboard.

A detailed analysis on transcribed sentences revealed that most participants, using NavTouch, usually entered the letters correctly, however forgot to double tap to insert white spaces between words, resulting in a MSD error rate around 4%. A possible explanation to this behavior may be due to the lack of practice.

Regarding the effects of mobility, we found a significant difference of quality in the QWERTY method. After applying the post-hoc test we found significant differences between the navigation (0.85%) and control (0.16%) condition. These results suggest that the QWERTY is more sensitive to visually demanding conditions.

4.4 Walking Speed Rate

To measure the walking speed we used the speed rate calculated as: (*Speed in the test / Control Lap speed) *100*).

Regarding the speed rate of the volunteers, we found minor effect differences between the 3 methods in the corridor situation ($\chi^2_{(2)}$=4.06, $p<.1$) and significant in the navigation ($\chi^2_{(2)}$=13.38, $p<.01$). After applying the post-hoc test Wilcoxon, we found significant differences in the corridor situation between QWERTY (68.77%) and VoiceOver (64.54%) and between the 3 methods in the navigation condition. In the latter, QWERTY was the method with the best speed rate (60.86%), NavTouch came next (59.25%), and finally VoiceOver (54.53%).

Regarding the effect of mobility on speed when using the 3 methods the values were significantly different. The speed when using the different methods was significantly better in the corridor than in the navigation situation. QWERTY decreased from 68.77% to 60.86%, the VoiceOver alike decreased from 64.54% to 54.53%, and NavTouch decreased from 62.92% to 59.25.

These results suggest that the navigation course was more demanding, thus participants needed to decrease walking speed to compensate the mobility condition.

5 Conclusions and Future Work

Mobile devices have become ubiquitous and always near its users. Nevertheless current mobile interfaces are visually demanding and eventually compete for the same resources needed for monitoring the surrounding environment.

In this work, we propose the use of text-entry solutions for blind people on mobile contexts, thus reducing the visual demand of mobile interfaces and allowing situationally impaired users to maintain their performance on mobility tasks.

We undertook an evaluation with three text-entry methods (QWERTY, VoiceOver, and NavTouch) in three mobility conditions, in order to understand the behavior of situationally-impaired people when using assistive technologies. Visual feedback was always provided, leaving to participants the choice of the most adequate gaze behavior. Results show that the users compensate the difficulty of the mobility conditions sacrificing walking speed. With this compensation, the QWERTY keyboard outperformed the remaining methods, speed and text-quality wise, suggesting that audio-based methods are ineffective, at least, when in presence visual feedback. Indeed, when debriefing participants they stated that preferred to use the graphical interface and tend to overlook audio feedback. Since users continued to use their vision to interact with NavTouch and VoiceOver, the two steps, selection and confirmation, needed for every key, seemed to increase workload and, consequently, decrease performance. Other reasons for QWERTY's outperformance may be that our mobility conditions were not demanding enough to require users to stop looking at the mobile interface or simply the fact that the participants were already familiar with QWERTY keyboards. Therefore, we intend to reevaluate these methods after a few practice sessions and in more demanding conditions. We also intend to include a new method that resorts to audio feedback and QWERTY's layout.

Additionally, we intend to evaluate assistive technologies with no visual feedback and compare both text-entry and walking performance with the results in this paper.

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