Mobile Text-Entry and Visual Demands: Reusing and Optimizing Current Solutions

Hugo Nicolau, Tiago Guerreiro, David Lucas, Joaquim Jorge

IST / Technical University of Lisbon / INESC-ID

Avenida Professor Cavaco Silva, Room 2-N9.25

2780-990 Porto Salvo, Portugal

{hman, tjvg}@vimmi.inesc-id.pt, david.lucas@ist.utl.pt, jaj@inesc-id.pt

Phone: +351 21 423 35 65

Fax: +351 21 314 58 43

Purpose: Mobile devices are increasingly used for text entry in contexts where visual attention is fragmented and graphical information is inadequate, yet the current solutions to typing on virtual keyboards make it a visually-demanding task. This work looks at assistive technologies and interface attributes as tools to ease the task.

Methods: We performed two within-subject experiments with 23 and 17 participants, respectively. The first experiment was to understand how walking affected text-entry performance and additionally to assess how effective assistive technologies can be in mobile contexts. On the second experiment, we developed and evaluated adaptive keyboards featuring character prediction and pre-attentive attributes to ease visual demands of text-entry interfaces.

Results: We found both text-input speed and overall quality to be affected in mobile situations. Contrary to our expectations, assistive technologies proved ineffective with visual feedback. The second experiment showed that pre-attentive attributes do not affect users' performance on task-entry tasks, even though we measured a 3.3 – 4.3% decrease on *Error Rates*.

Conclusions: We found that users reduce walking speed to compensate challenges placed by mobile text-entry. Caution should be exercised when transferring assistive technologies to mobile contexts, since they need adaptations to address mobile users' needs. Also, while pre-attentive attributes seemingly have no effect on experienced QWERTY typists' performance, they showed promise for both novice users and typists in attention-demanding contexts.

Keywords: Mobile, Text-entry, Pre-attentive, Assistive Technology

Introduction

Mobile devices play an important role in our daily lives. They have become smaller, cheaper, and more powerful, allowing their users to perform ever more diverse tasks while on the move. Indeed, these artifacts spend more time closer to us than any other IT contraption, whether at home, on the street, at work, in car, in public transports, etc. Furthermore, portable communications devices have evolved from the static and quiet environment of our homes and offices to more variable and heterogeneous contexts, causing obvious changes in their use [13]. Worse, operating devices in mobile environments poses new challenges to users since apparatus and context often compete for the same human resources, inducing situational impairments and disabilities (SIID) [24]. For instance, texting while walking on a busy street can be quite challenging and prove hazardous since the visual system is both engaged on monitoring the surrounding environment and on interacting with the device. Similarly, reading text messages or email in public spaces can be difficult, or even impossible, due to screen glare caused by sunlight. In such situations we argue that users may become "functionally blind", as their visual resources are overloaded and visual feedback is inadequate.

These problems become especially relevant when performing visually demanding tasks, such as text-entry. Indeed, text input is one of the most demanding tasks in mobile devices and one of the most common between applications, such as managing contacts, SMSing, emailing, note-taking, gaming, chatting, twitting, etc. This paper looks first to investigate how visual demands, whether context- or interface-induced, affect users' text input performance and second to propose new solutions to cope with these challenges. We performed two experiments that explore new approaches to deal with limited visual resources of people operating mobile devices while on the move. In the first user study, we examine how walking affects text-entry performance and vice-versa. Moreover, to eliminate visual demands of current interfaces we studied solutions previously designed for visually impaired or blind people for whom visual feedback is unsuitable. In a second study, we took a different approach. Instead of replacing visual feedback, we adapted the traditional *QWERTY* keyboard to optimize this communication channel towards fast and effective interaction. In what follows we survey closely related work on interfaces for mobile and blind users and then describe each experiment and lessons learned. Next we summarize and discuss our findings and draw recommendations and guidelines for interface design as well as indicating directions of future work.

Related Work

In this section, we present and discuss previous research on mobile interaction. Particularly, we focus on understanding the challenges of mobile usage and proposed solutions to improve user performance in walking contexts.

Effect of Walking on Users' Performance

In a pioneer work, Kristoffersen and Ljungberg [9] stated that mobile devices usually compete for the same human resources required for other mobility tasks. Since then, several empirical studies have tried to understand how users are affected by different mobility conditions. In particular, much work delved in walking scenarios, as this is a common activity. Barnard et al. [2] evaluated reading comprehension and word search tasks while walking under different lighting conditions. They found that contextual variations, particularly, light intensity and mobility lead to changes in user behavior and increased task times. Mustonen et al. [17] performed a similar user study, concluding that reading speed is significantly affected by mobility.

Lin et al. [11] carried out a Fitts' law experiment of stylus tapping whilst walking and found that time to complete single target tapping tasks did not increase, however users compensated by reducing their walking speed and perceived an increased workload. Mizobuchi et al. [16] studied stylus text input and tried to reveal a relationship between walking speed and task difficulty. The authors found that text-input was slower whilst walking and observed that users generally decrease walking speed while typing. However, they found no relationship between these two variables. Similarly to our work, the authors analyze the effect of walking in text-input. However, their study focused on stylus input. More recently, Nicolau and Jorge [18] also studied how mobility and hand posture affect touch typing tasks, showing that mobility decreased input quality, leading to specific error patterns. Still, the authors focused their analysis on motor, rather than visual demands.

Bergstrom-Lehtovirta et al. [3] investigated how walking speed correlates to target acquisition performance, showing that to maintain selection accuracy users need to reduce speed by 26%, as compared to their preferred pace. Schildbach and Rukzio [23] looked at target selection using thumbs and reading tasks, showing a decrease in performance and increase in perceived workload. The authors built a test track, similar to the one described in experiment 1 (see next section), simulating a realistic context where users needed to shift their visual attention while performing tasks. Indeed, attention fragmentation is a real issue whilst on the move; in a field study Oulasvirta et al. [19] reported up to eight-fold differences between measurements of attentional resource fragmentation from static to mobility conditions. Our work builds on these findings, as we investigate how increased visual demands impact text-entry tasks, which are themselves visually demanding by nature.

User Interfaces for Walking

Previous research targeted the visual demands of mobile interfaces from different approaches. Pascoe et al. [21] proposed *minimal attention user interfaces* to reduce the visual attention required to operate an interface by minimizing the number of available actions. Hudson et al. [7] minimalist approach, *whack gestures*, allows users to perform simple interactions with minimal attention. Other authors [13, 5, 31] developed eyes-free techniques resorting to audio feedback and gestures. Li et al. [10] use audio feedback to allow users to interact with their mobile devices while maintaining a phone conversation. Speech interaction has also been researched as an alternative modality to manipulate devices without visual or motor demands [22]. While these methods provide alternative interfaces with reduced functionality, our approach explores interfaces that are already familiar to most mobile users. Particularly, in Experiment #2 we redesign interface elements, without reducing functionality, in order to ease the visual demands required to operate them.

User Interfaces for Blind Users

Previous research illustrated how graphical interfaces can sometimes be inappropriate whilst on the move [19]. Indeed, both blind and “situationally blind” users seem to experience overlapping interaction challenges, as both groups are unable to process visual feedback. In this section, we present different text-entry interfaces designed for those people to whom the visual modality is an unsuitable information carrier.

For functionally blind people, screen reading software provides the most popular solution. Apple's VoiceOver[1] is a successful example of this technique. It allows users to explore the interface layout by dragging their finger over the screen while receiving audio feedback. To select an item, users can split-tap [8] or double-tap anywhere on the screen.

Yfantidis and Evreinov [30] proposed a new text input method, based on a pie menu with eight options and three levels. At the first level, users select a letter by performing a gesture on one of eight directions. The character is read and users accept it by lifting the finger. Users access the remaining levels of the interface by moving the finger towards a character and dwelling until it is replaced by an alternative letter. NavTouch [6] also uses a gesture approach, allowing blind users to navigate through the alphabet using four directions. One can navigate horizontally or vertically, using vowels as shortcuts to the intended letter. Speech feedback is constantly received and split or double-tap is used to confirm a selection. To complement navigation, special functions (e.g. erase, menu) are located on screen corners. More recently, Bonner et al. [4] presented No-Look Notes, a keyboard with large targets that uses an alphabetical character-grouping scheme (similar to keypad-based multitap approaches). The layout consists in a pie menu with eight options, which are read upon touch. Split-tapping a segment sends the user to a new screen with that segment's characters, ordered alphabetically from top to bottom. Users select the desired character in a similar way to group selection. Performing a swipe to the left or right, allows the user to erase or enter a space, respectively.

While some authors have identified similarities between health induced impairments and disabilities (HIID) and SIID [24, 28], to our knowledge we are the first to apply assistive technologies for the blind to mobile contexts, as explored in the next experiment.

Experiment 1: Reusing Knowledge

In this experiment, we try to reuse knowledge already available from users who cannot use visual feedback and apply it on mobile contexts. We hypothesize that mobile users become *functionally blind*, as they cannot sustain performance on a

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[1] http://www.apple.com/accessibility/iphone/vision.html (last visited on 03/02/2012)

given task due to their visual system being overloaded. Therefore, in this experiment, we adopted solutions designed for those for whom graphical feedback is inappropriate (such as blind people), thus freeing some of the users' limited visual resources to their main task. According to Multiple Resource Theory (MRT) [27], this would make it easier for people to perform both tasks simultaneously with less interference and therefore with smaller performance penalty.

While we stress the similarities between blind and situationally-impaired users, we also acknowledge that either group abilities 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 suffer the same problems, and could hence benefit from similar solutions. Therefore, perhaps a more appropriate question would be: when and how can mobile users benefit from assistive technologies? While previous research has focused on assistive technologies for motor impaired people [29], visual demands are still unexplored.

This user study sought first to understand the effects of different mobility conditions on text-entry performance and secondly to observe how users behave when using assistive technologies while walking.

Participants

Twenty three participants (15 male, eight female) with ages between 18 and 37 years took part in the study. All participants had owned a mobile phone, for at least five years, whereas only six of them did not use touch screen technology. Regarding text-entry, two participants used it on a weekly basis, while the remaining did this task daily. As for preferred text entry methods, 15 participants used QWERTY layouts, 13 on virtual- and 2 on physical keyboards, while 8 used MultitTap (2 virtual and 6 physical).

Apparatus

This study used a Samsung Galaxy S device running Android 2.2 with a screen 480x800 (122.4x64.2 mm) pixels wide. We focused our research on QWERTY keyboards, since this is one of the most common mobile layouts, and picked one alternative input method. In summary, we used three text-entry methods: 1) a traditional *QWERTY* keyboard, used as a control condition; 2) a *VoiceOver*-like method (using QWERTY), since this is a common accessibility method for blind users; 3) *NavTouch*, because it uses a gesture approach. All text-entry methods were developed using Android SDK. In the *QWERTY* keyboards, letters were entered using a lift-off strategy, thus enabling participants to correct land-on errors. Speech feedback was given using SVOX Classic TTS. The evaluation was recorded on video and we logged all interactions with the device for later analysis.

Procedure

The study was conducted individually and started with a brief explanation about its overall purpose and procedure. Afterwards each participant filled a short questionnaire to gather demographic data. All text-entry methods were explained, followed by a five minute practice trial for each method to counteract learning effects. Each subject was asked to perform two text-entry tasks using three different methods: *QWERTY*, *VoiceOver* alike (with QWERTY) and *NavTouch* [6]. Although two of the featured methods were designed for blind people, visual feedback was intentionally made available. Therefore, we could observe the participants' natural behavior when both visual and auditory modalities were present.

In order to realistically test these methods, we designed three mobility settings: 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 path without obstacles; 3) Navigation – participants had to orient themselves within the built track to walk in the right direction. The track featured poles with numbers and arrows indicating both the order and direction the participants had to walk along a prescribed route (similar to [23], see Figure 1). This setup was created to simulate the use of mobile devices in an urban environment. We picked mobility conditions in a random order to avoid bias associated with experience. Additionally, before testing the first mobility condition, we recorded each participant's preferred speed when walking in a straight line.

For each mobility condition, participants were asked to copy a set of sentences using all methods in a counter-balanced order. Each trial consisted of two sentences, each five words long with an average 4.48 characters/word. The sentences were extracted from a written language *corpus*, and each had a minimum 0.97 correlation with the language. We built the phrase set based on the procedure of MacKenzie and Soukoreff [15] applied to Portuguese language. Each sentence was randomly selected and read aloud to participants. Also, the sentence was always visible on the device's screen in order to reduce misspelling errors.

Experimental Design and Analysis

The experiment varied both *mobility* condition and *text-entry method*. We used a within-subjects design, where each participant tested all conditions. We applied Shapiro-Wilkinson [20] tests to observed values for *words per minute*, *error* (deleted characters) *rate*, *minimum string distance* (MSD) *error rate* [14], and *walking speed*. However, the results did not show a normal distribution. Therefore, we applied a non-parametric (Friedman) test to further analyses. For post-hoc tests, we used Wilcoxon signed rank pair-wise comparisons test [20].

Results

Our goal was to understand how users behave when using text-entry methods for the blind whilst on the move. In this section, we report the obtained results and analyze both *mobility* and *method* effects.

Text-Entry Speed

To analyze text-entry speed we measure words per minute, calculated as

Figure 1. Left - Navigation course; Right - Participant during text-entry task.

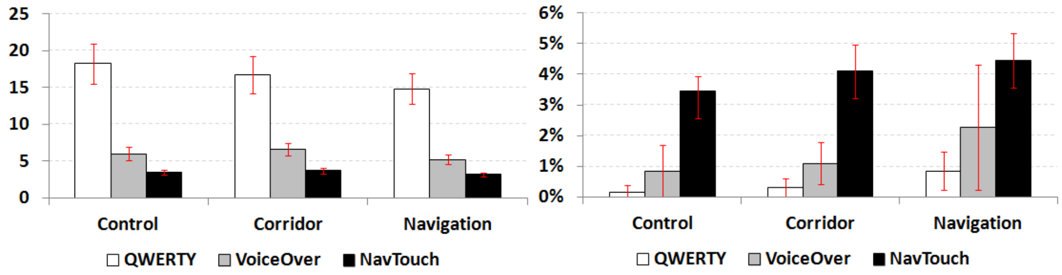

Figure 2. Left - Words per minute for each condition; Right - Error rate for each condition. Error bars denote a 95% confidence interval.

*(transcribed text – 1) * (60 seconds / time in seconds) / (5 characters per word).* We measured the time to input each sentence from the moment the first character was entered to the last. Figure 2 illustrates the *wpm* for each condition.

Regarding the differences between 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. *QWERTY* keyboard was always faster, followed by *VoiceOver* and *NavTouch*. This result was probably due to two main reasons: QWERTY familiarity and the two-step selection process of assistive technologies. Both *VoiceOver* and *NavTouch* required navigation and confirmation actions for each letter, making these methods less efficient. As for *mobility*, we found significant differences for the *QWERTY* keyboard ($\chi^2_{(2)}$=9.92, *p*<.01), *VoiceOver* ($\chi^2_{(2)}$=7.06, *p*<.05) and *NavTouch* ($\chi^2_{(2)}$=4,7, *p*<.01). For the *QWERTY* keyboard we found significant differences between the *control* (18.24 *wpm*) and the *navigation* conditions (14.82 WPM); for the *VoiceOver* method we observed differences between the *corridor* (6.59 *wpm*) and *navigation* (5.23 *wpm*) conditions; as for *NavTouch* we saw differences between the *corridor* (3.68 *wpm*) and *navigation* (3.21 *wpm*) conditions.

These results suggest that all three methods were sensitive to visually demand conditions. However, assistive technologies were ineffective regarding input rate. On the other hand, the *QWERTY* keyboard performance varied the most with a loss of 3.42 *wpm* between the *control* and *navigation* conditions.

Error Rate

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

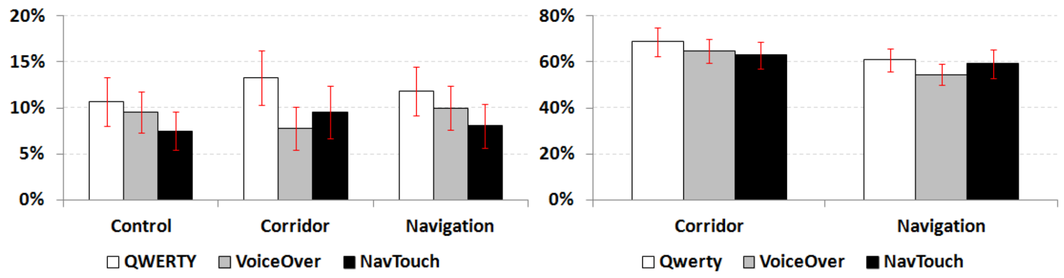

Figure 3. Left - MSD error rate for each condition; Right - Walking speed for each condition. Error bars denote a 95% confidence interval.

Comparing *error rates* between 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* ($\chi_{2(2)}$=5.53, *p*<.1) conditions. After post-hoc analysis, we found that in the *control* and *navigation* situations the *QWERTY* keyboard had 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* method (7.79%). Regarding *mobility*, we did not found any significant effect.

Quality of Transcribed Text

To measure the quality of transcribed text we used the Minimum String Distance Error Rate metric calculated as *MSD(presentedText,transcribedText) / Max(|presentedText|,|transcribedText|) * 100* .
Concerning the effect of *text-entry method*, we obtained significant differences 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 text quality in all mobility conditions (Figure 3). No significant differences were found between the *VoiceOver* and *QWERTY* keyboards. A detailed analysis on transcribed sentences revealed that most participants usually entered the letters correctly when using *NavTouch*; however, they 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 the lack of practice.
Regarding the effect of mobility, we found a significant difference for the *QWERTY* method. After applying the post-hoc test we found significant differences between the *navigation* (0.85%) and *control* (0.16%) conditions,

suggesting that the *QWERTY* keyboard is the most sensitive to visually demanding contexts.

Walking Speed

To measure *walking speed* we used the speed rate calculated as: (*Speed in the test / Control Lap speed) *100*). Figure 3 shows mean walking speed for each condition.

We found an effect of *method* on *walking speed* in the *corridor* ($\chi^2_{(2)}$=4.06, p<.1) and *navigation* ($\chi^2_{(2)}$=13.38, p<.01) conditions. In the corridor conditions differences were found between *QWERTY* (68.77%) and *VoiceOver* (64.54%), while in the *navigation* condition *QWERTY* was the method that allowed the fastest walking speed (60.86%). *NavTouch* came next (59.25%), followed by *VoiceOver* (54.53%).

As for *mobility*, users walked significantly faster in the *corridor* than in the *navigation* conditions for all text-entry methods: *QWERTY* decreased from 68.77% to 60.86%, *VoiceOver* 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, and therefore participants needed to decrease walking speed to compensate mobility challenges.

Lessons Learned

People reduce speed to compensate for task demands. Results show that users compensate the visual demand of contexts by naturally reducing walking speed. This was also observed in previous research [16, 11, 3].

Users overlook audio feedback. Although results show the *QWERTY* keyboard as the most sensitive to mobility conditions, it still outperformed the remaining methods, both speed and text-quality wise. This suggests that audio-based methods are ineffective, at least, when visual feedback is available. Indeed, when debriefing participants they stated a preference to use the graphical interface and tended to overlook audio feedback.

Assistive technologies are slow. Since participants continued to use their vision to interact with *NavTouch* and *VoiceOver*, the two-step, navigation and confirmation process needed for every character, seemingly increases workload and consequently decreases performance. This suggests that modifications may be needed to effectively transfer solutions between health and situationally impaired domains.

Mobility conditions were not demanding. Other reasons to QWERTY's outperforming the other methods may lie in that our mobility conditions were not demanding enough to require users to stop looking at the mobile interface. Further research should focus on more demanding settings.

Experimental procedure. One of the main challenges when evaluating mobile users is guaranteeing consistency between participants. Although our conditions were controlled, we found large variations on both efficiency and effectiveness measures between participants. While this may be due to individual differences, we believe that other factors may be involved. For instance, participants had different gaze behaviors, which can affect performance. Similarly, walking speed can also compensate for visual demands, thus introducing a lack of consistency between participants and text-entry conditions. Even though solutions should be evaluated in mobility settings in order to capture realistic data, performance should also be assessed in more controlled conditions [11].

Experiment 2: Optimizing Visual Feedback

When on the move, the surrounding environment competes with the mobile device for users' attention [19]. Indeed, users constantly manage their attentional resources, switching tasks and gaze as needed. As they cannot maintain performance on a given task due to an overload of their visual resources, they usually compensate by decreasing walking speed. Paradoxically, Experiment 1 showed that when presented with audio-based interfaces they still prefer to use visual feedback. A possible explanation for this behavior may be that speech usually requires more attention and cognitive resources than visual stimuli.

In this experiment, we investigate an alternative approach, which optimizes visual feedback. Note that this significantly differs from minimal attentional user interfaces [21], which tend to restrict functionality to minimize cognitive engagement. Our solution relies in the theory of vision, which allows graphical elements to be rapidly found, thus reducing the time required to resume the interaction process after attention is shifted away from the interface.

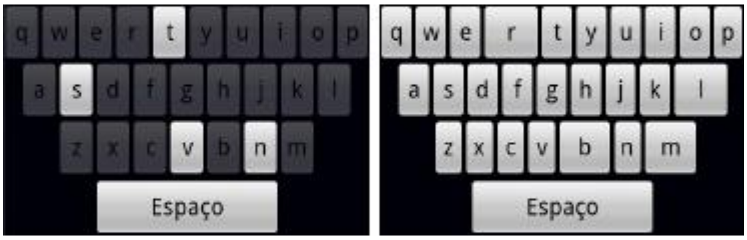

Figure 4. Adaptive keyboards. Left - Color variant; Right - Size variant.

According to Triesman [26], some visual proprieties allow the human brain to rapidly identify a target independently of the number of distracters. These features are called pre-attentive. That is, they occur because of automatic mechanisms operating prior to engaging attention. These are also called pop-out effects and directly correlate to the target's visual distinctiveness from the surrounding environment. The simple features that lead to pop-out are color, size, orientation, and motion. Anything that pops out can be seen in a single eye fixation which takes less than a tenth of a second. This represents the difference between visually efficient at-a-glance processing and cognitively effortful search.
The goal of this experiment was, first, to investigate using pre-attentive attributes on text-entry tasks during visually demanding conditions and second, to understand the consequences of misplacing pop-out effects.

Text-Entry Conditions

We chose two pre-attentive attributes to aid users in text-entry tasks. Although other features could be used, we picked size and color since these are being adopted by some manufactures in an attempt to improve input performance. Therefore, text-entry conditions differed as follows:
QWERTY. We adopted a traditional *QWERTY* keyboard, similar to the one used in Experiment 1 as the control condition. Letters were entered using a lift-off strategy, thus enabling participants to correct land-on errors.
QWERTY Size Variant. We used size as a pre-attentive attribute to aid users identifying and selecting the most probable characters. As participants typed, key sizes varied according to their probability to be entered next: the four most probable keys had increased width [1] allowing participants to easily identify and select the intended character as shown in Figure 4 (right image).
QWERTY Color Variant. We also used Color to indicate the most probable characters. In this condition, the most probable keys were highlighted, while the remaining characters were darkened as can be seen in Figure 4 (left).

Accuracy Conditions

To investigate the effect of prediction accuracy on performance for each keyboard variant, we tested two accuracy conditions:

Low Accuracy. The adaptive keyboard predicted users' needs with 20% accuracy; that is, 20% of the time the user entered a character, that key could be found among the four highlighted. Since this was a controlled experiment, we were able to effectively control character prediction. The interface gave audible feedback to participants, whenever they selected an incorrect character. In this case, the character was not input to ensure precise and consistent conditions between participants.

High Accuracy. The adaptive keyboard predicted users' needs with 100% accuracy. This was used as a control condition, assuming that the highlighted characters are always the most probable.

Participants

We recruited 17 participants (eleven male) from our local university to perform this user study. Participants' average age was 26 (*sd*=5). Sixteen volunteers had used a mobile phone for more than five years. Eight had a touchscreen device and used it daily for at least six months. Regarding mobile text-entry experience, three participants wrote text on a weekly basis, while the remaining input text daily. Six participants used a QWERTY keyboard (one physical and five virtual) and eleven used a MultiTapping keyboard (six physical and five virtual).

Apparatus

Again, we used a Samsung Galaxy S running Android 2.2 with a capacitive screen 480x800 (122.4x64.2 mm) pixels wide. The QWERTY virtual keyboard was similar to the one available in the Android SDK. All action performed in the keyboard were logged for further analysis.

Procedure

At the beginning of the experiment participants were told that the overall purpose of the study was to investigate how text-entry performance was affected by visually demanding conditions. We asked participants to fill in a questionnaire and were informed how the experiment would progress.

For each text-entry condition participants were to copy four different sentences, displayed one at a time, at the top of the screen. In contrast to Experiment 1 in this user study there was a controlled consistency of visual demands between text-entry conditions and participants. We applied a widely used methodology to investigate the effect of visual demand: the occlusion method [25]. This method consists in blocking visual feedback in order to simulate visually demanding conditions. Thus, in this experiment the screen was turned off for 1.5 second in intervals of the same value. Nevertheless, in order to simulate a real mobility scenario, participants were still able to input text with no visual feedback. To control learning effects, there was a five minute practice trial before each text-entry condition (chosen randomly).

We used copy typing to reduce the opportunity for spelling and language errors, and to make it easier to identify errors. Participants were instructed to type phrases as quickly and accurately as possible. After each text-entry condition participants filled a satisfaction questionnaire about the method.

Each participant entered a total of 20 different sentences extracted from a written language *corpus*, each with five words, with 4.48 characters per word and a minimum correlation of 0.97 with participants' native language. Sentences were chosen randomly to avoid bias associated with experience. A debriefing session was conducted at the end of the study.

Experimental Design and Analysis

The experiment varied *text-entry methods*. We used a within subjects design, where each participant tested all conditions. In summary the study design was: 17 participants x four sentences x five text-entry conditions (one control method + two alternative methods x two accuracy conditions) = 340 sentences overall.

For dependent variables that fit a normal distribution, we used a repeated-measures ANOVA and Bonferroni post-hoc test in further analyses. Greenhouse-Geisser's sphericity corrections were applied whenever Mauchly's test of sphericity showed a significant effect. We adopted a Friedman test for observed values that did not fit a normal distribution. Post-hoc tests were performed using Wilcoxon signed rank pair-wise comparisons with Bonferroni corrections [20].

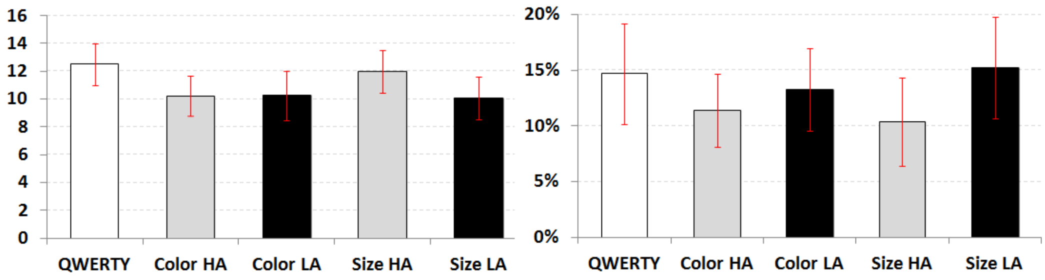

Figure 5. Left - Words per minute for each condition; Right - Error rate for each condition. Error bars denote a 95% confidence interval.

Results

Our main goal when performing this experiment was to understand how pre-attentive attributes affected text-entry tasks during visually demanding tasks. In this section we report our findings regarding input speed, error rate, and participants' opinions.

Text-Entry Speed

We measured text input speed by computing words per minute (*wpm*) [14]. Results showed a significant effect between text-entry conditions ($F_{4,64}$=10.888, *p*<0.01). Participants achieved an average of 12.5 (*sd*=3.14) and 11.99 (*sd*=3.2) wpm with the *QWERTY* and *Size* variant conditions, which were significantly higher than the average 10.23 (*sd*=3.02) wpm for the *Color* variant (see Figure 5). Regarding *Low Accuracy* conditions, only the *Size* variant with an average 10.05 (*sd*=3.26) wpm was significantly slower than its *High Accuracy* counterpart (*p*<0.05). This suggests that the *Size* variant, despite being faster, is more sensitive to prediction accuracy. Moreover, even for the *High Accuracy* conditions, alternative methods did not aid users in achieving higher input rates as compared to the traditional *QWERTY* keyboard.

Error Rate

We used error rate to measure text-entry accuracy, computed as *attempts to input an incorrect character / letters entered * 100*. Results for *Error Rate* followed the same pattern as input speed as can be seen in Figure 5; that is, alternative text-entry methods did not show a statistical effect over traditional *QWERTY* keyboard. Still, participants achieved better results with those methods: *Error Rates* were an average 11.4% (*sd*=6.93) and 10.37% (*sd*=8.26) for *Color* and *Size*

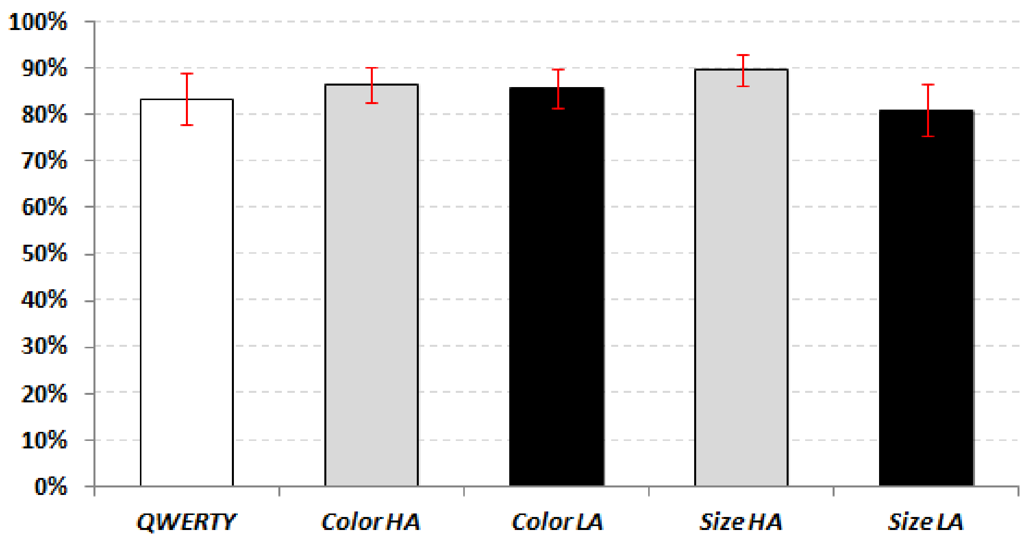

Figure 6. Correct entry without visual feedback. Error bars denote a 95% confidence interval.

variants, respectively. However, these results were not significantly lower than the average 14.68% (*sd*=9.52) of *QWERTY* condition (Z=-2.154, *p*>0.017; Z=-2.059, *p*>0.017). Again, we found significant differences between *High* and *Low Accuracy* conditions in the *Size* variant (Z=-2.638, *p*<0.017).

Correct Entry without Visual Feedback

We analyzed the correct input rate without visual feedback as a measure of accuracy when users are not focusing their visual attention on the keyboard. We calculated this as the ratio *correctly entered characters during occlusion / entered characters during occlusion * 100*. There were significant differences between text-entry conditions, $\chi^2(4)=14.722$, *p*<0.05 (see Figure 6). Similarly to *input* and *error rate*, the *Size* variant showed significant differences between the *High* (89.66%) and *Low* (81.05%) *Accuracy* conditions. No other significant differences were found, which means that the *Low Accuracy* condition for the *Color* variant did not significantly affect participant performance. Participants entered on average 86.51% (*sd*=8.01) and 83.35% (*sd*=11.74) correct characters while the screen was occluded with *Color* variant and traditional *QWERTY*, respectively.

Participant Opinions

At end of each session we asked participants to rate each text-entry method using a six-point Likert scale (1 – very easy; 6 – very hard) regarding ease of use. The median [quartiles] attributed by participants were 1.5 [2], 2 [1], 2 [1] for *QWERTY*, *Color* and *Size* variants, respectively. Results show very similar ease of use between keyboard variants and no significant differences were found. According to Low *Accuracy* results, participants perceived a higher difficulty for both keyboards ($\chi^2(4)=18.299$, $p<0.01$): 3 [1.25] (Z=-2.919, $p<0.01$) and 3.5 [1.25] (Z=-2.652, $p<0.01$) for *Color* and *Size* variants, respectively.

Lessons Learned

Pre-attentive attributes do not affect performance. Results show that when pre-attentive attributes are applied to character predictions they usually do not affect users' performance; that is, performance neither increases nor decreases. One exception is the *Color* variant, which significantly reduced input rate.
Size adaptation is sensitive to prediction accuracy. *Low Accuracy* conditions show a negative effect on the *Size* variant. There were higher *Error Rates* when wrong predictions were made, while the *Color* variant remained consistent between *Accuracy* conditions. We suspect that this was due to the decrease in width of the most probable characters, making them harder to hit.
Familiarity effect. We believe that the absence of significant effects between text-entry methods was partly due *QWERTY* familiarity. Since all participants were well acquainted to the keyboard layout, searching for keys was probably not a very demanding task. That is, pre-attentive attributes were ineffective because participants did not require any such aid in finding the required keys. Nevertheless, we need further research to confirm this hypothesis.
Low attention demands. Although external demands on the visual system were simulated by virtually occluding the device screen, participants did not shift their attention to other tasks. This most certainly affected the need to search for the next character and, consequently, the usefulness of pre-attentive attributes.

Discussion

In this section we discuss the major findings and lessons learned from both experiments.

Effectiveness of Assistive Technologies

Overall, we found that alternative text-entry methods did not perform as well as the traditional *QWERTY* keyboard. The chosen techniques were designed for blind people. None provides any visual feedback. Thus, these solutions completely replace the visual channel by its audio counterpart. Worse, assistive technologies that rely on audio-only technologies seem to increase the cognitive load in comparison to visual-only solutions. Particularly, *VoiceOver* and *NavTouch* required a two-step selection process. Users needed to navigate to the intended letter and then perform a selection. Participants state that this process was too cumbersome. Future attempts at reusing knowledge from health-induced impairments and disabilities should focus on identifying and dealing with these challenges and adapt to the needs of mobile users. Nevertheless, while alternative methods did not outperform the *QWERTY* keyboard, they were consistent between mobility conditions.

Effectiveness of Pre-Attentive Attributes

Pre-attentive attributes make it easier to find some interface elements, by making them stand out. Theoretically, this should have been an effective way to help users when their attention was constantly shifting between tasks. However, in general, neither *Size* nor *Color* pre-attentive attributes did significantly affect text-entry performance or error rates. We believe that this was due to two main reasons. First, owing to their familiarity with the *QWERTY* layout, participants did not perform visual search tasks and pre-attentive attributes of keys were ignored [12]. The second reason is related to our approach to evaluation, which suppressed visual feedback instead shifting participant's attention from the keyboard. In fact, their gaze never shifted away from the text-entry task, eliminating the need to resume it. More effective methodologies are needed to simulate and evaluate visual demands in a laboratorial context, e.g. requiring users to shift attention away from the keyboard following a visual or auditory stimulus to perform a different task.

Conclusion

Mobile devices have become ubiquitous and constantly within reach. This has brought new challenges to designing safer and better systems. Indeed, current mobile interfaces are visually demanding and often compete for the same resources people need to monitor and safely navigate their surroundings.
In this work, we propose two approaches to reduce visual demands of mobile text-entry methods and allow situationally-impaired users to maintain performance on

mobility tasks. The first is to reuse solutions designed for the blind. The second is to redesign interfaces to ease task resumption when user attention is fragmented.
Our first experiment showed that users compensate the challenges of mobility conditions by reducing walking speed. Moreover, the *QWERTY* keyboard outperformed the remaining methods, both speed and text-quality wise. This suggests that audio-based methods are ineffective, when visual feedback is available. Indeed, when debriefing participants they stated a clear preference for the graphical interface and tend to overlook audio feedback. Still, the *QWERTY* keyboard performance was the most affected by mobility conditions.
Our second experiment evaluated two adaptive keyboards allowing users to easily and rapidly identify the next intended character. Results showed that our approach did not increase performance. However we believe this approach can potentially be effective either when used by inexperienced *QWERTY* typists or by any user in visually demanding settings.

Future Work

Either approach did not reveal a significant performance improvement over traditional input methods. Further research is needed to assess how alternative solutions will behave in more demanding conditions. For instance, one remaining research question is related to the effect of the absence of graphical feedback when using assistive technologies. How would users behave if no visual feedback was given and how it relates to our results? Also, an open challenge when transferring technology between domains consists in finding what modifications are required to cope with mobile users' varying needs and capabilities.
We also intend to further explore the use of pre-attentive attributes, given that they have the potential to increase users' performance on mobile contexts, particularly those which place high attention demands.
Finally, extending the current problem domain to cover a wider variety of mobility challenges and impairments (e.g. tremor, and time pressures) could also provide cues to designing more effective interfaces that could adapt to different context demands.

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