Blind People and Mobile Touch-based Text-Entry: Acknowledging the Need for Different Flavors

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ABSTRACT

The emergence of touch-based mobile devices brought fresh and exciting possibilities. These came at the cost of a considerable number of novel challenges. They are particularly apparent with the blind population, as these devices lack tactile cues and are extremely visually demanding. Existing solutions resort to assistive screen reading software to compensate the lack of sight, still not all the information reaches the blind user. Good spatial ability is still required to have notion of the device and its interface, as well as the need to memorize buttons' position on screen. These abilities, as many other individual attributes as age, age of blindness onset or tactile sensibility are often forgotten, as the blind population is presented with the same methods ignoring capabilities and needs. Herein, we present a study with 13 blind people consisting of a touch screen text-entry task with four different methods. Results show that different capability levels have significant impact on performance and that this impact is related with the different methods' demands. These variances acknowledge the need of accounting for individual characteristics and giving space for difference, towards inclusive design.

Categories and Subject Descriptors

H.5.2 [**Information Interfaces and Presentation**]: User Interfaces – *Input devices and strategies, User-centered design.*

General Terms

Design, Experimentation, Human Factors.

Keywords

Blind, Mobile, Touch screens, Text-Entry, Individual Differences.

1. INTRODUCTION

Touch-based phones have paved their way into the mobile scene and turned the richness of the user interfaces into a differentiating factor between brands. Further, multi-touch surfaces played a paramount role in these gadgets extraordinary adoption both by manufacturers and end-users. Touch-based devices present a wide set of possibilities but a comparable number of new challenges. These devices have incrementally decreased the number of tactile cues and simultaneously amplified the interaction possibilities, thus increasing the visual demands imposed to their users.

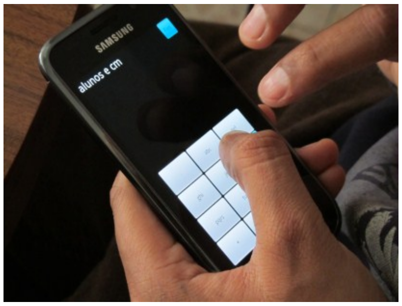

Figure 1 – A blind user entering text in a touch screen device

While a blind person is likely to be able to interact with a keypad-based phone to place a call without the need for any assistive technology, it would be a herculean task to do so with today's touch screen devices. The magnitude of this problem increases as we load the screen with interface elements, as happens with text-entry interfaces, where all letters are placed onscreen. Assistive screen reading software, like Apple's VoiceOver, enables a blind person to overcome these issues by offering auditory feedback of the visual elements onscreen. Still, as aforementioned, mobile interfaces are extremely visual and a large amount of information is lost in this visual-audio replacement. Possible examples are the need of a good spatial ability to have a notion of the device and the interface components therein, or cognitive capabilities to memorize letter placement on screen. Visual feedback makes these attributes dispensable or less pertinent, while its absence makes them relevant and worthy of consideration.

Our goal is to identify and quantify the individual attributes that make a difference in a blind user when interacting with a mobile touch screen. The mapping between individual capabilities and interface demands will then enable us to suggest the best interface for a particular individual or inform designers about the most promising methods and attributes, thus promoting inclusive design. In this paper, we focus our attention on mobile touch-based text-entry, a very visual, common, useful and demanding task. We present four different non-visual text-entry methods and evaluate them with 13 blind users (Figure 1). Results showed that different methods present different advantages and disadvantages and that these are related with users' individual abilities. Spatial ability, pressure sensitivity and verbal IQ were revealed as

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determining characteristics to a particular user's performance and good indicators of the suitable methods for each person.

2. RELATED WORK

In this section we present and discuss previous work on touch-based mobile text-entry solutions for blind people. Also, we look into individual differences and how they have been addressed in the past in different contexts.

2.1 Touch-based Text-Entry Solutions

In the past five years, several manufactures have included basic screen reading software in their touchscreen devices. Apple's VoiceOver[1] is a successful example. Users can explore the interfaces' layout by dragging their finger on the screen while receiving audio feedback. To select the item, the user rests a finger on it and taps with a second finger (i.e. split-tapping [6]) or alternatively lifts up the first finger and then double-taps anywhere on the screen. This approach is application independent, allowing blind people to use traditional interfaces with minimum modifications.

While we acknowledge that progresses on assistive technologies have been made, users still face some several problems when interacting with touch interfaces [7]. One of the major issues relates to text-entry. This is one of the most visually demanding tasks, yet common on innumerous mobile applications (e.g. contact management, text messages, email).

Indeed, several authors have been approaching this problem. Yfantidis and Evreinov [14] proposed a new input method, which consists in a pie menu with eight alternatives and three levels. Users can select each letter by performing a gesture on one of the eight directions of the layout. The character is read and users accept it by lifting the finger. The remaining levels of the interface are accessed by moving the finger towards some character and dwelling until it is replaced by an alternative letter. The interface layout and letter arrangement can be edited to accommodate the users' needs and preferences.

NavTouch [4] also uses a gesture approach, allowing blind users to navigate through the alphabet using only 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) were placed on screen corners.

More recently, Bonner et al. [1] 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.

Overall, there has been an effort to provide blind and visually impaired users with alternative touch-based text-entry methods. In fact, different interaction techniques are used, from single to multi-touch primitives, directional and scanning gestures, fixed and adaptive layouts. However, there is no knowledge of which methods are better for each individual user. Most approaches neglect the individual differences among blind people and how they relate to users' performance.

2.2 Acknowledging Individual Differences

Current mobile devices force users to conform to inflexible interfaces, despite their wide range of capabilities. Users must struggle to use the interface as-is, and may or may not surpass their difficulties. Several design approaches have highlighted this issue in order to offer users better and more adequate interfaces.

Gregor and Newel [3] go beyond this idea and stated that while it is important to understand that a user is different from the next one, even for a single user, his capacities and needs are likely to diverge across time (dynamic diversity). Persad et al. [10] also acknowledge this diversity proposing an analytical evaluation framework based on the Capability-Demand theory, where users' capabilities at sensory, cognitive and motor levels, are matched with product demands. More recently, Wobbrock et al. [13] introduced the concept of ability-based design, which consists in an effort to create systems that leverage the full range of human potential. Our work extends all this knowledge in a way that both the users' capabilities as the device demands should be explored to foster inclusive mobile design. By doing so we will be able to provide more inclusive devices and adapt interfaces accordingly to the variations within the users, maximizing each individual performance. In this sense, a previous experiment [5], where we interviewed psychologists, occupational therapists, rehabilitation technicians, and teachers that work daily with blind users, suggested that individual differences between blind people are likely to have a wider impact on their abilities to interact with mobile devices than among sighted people. Tactile sensibility, spatial ability, verbal IQ, blindness onset age and age are mentioned as deciding characteristics for mobile performance.

When considering blind people, a capability that should not be ignored is tactile sensibility. Besides being crucial to capture information at the expense of vision, approximately 82% of all people who are blind are aged 50 or more [16] and as diabetes is one the main causes of blindness, changes in this sensorial capability are fairly common and should be accounted for. In [8] several physical requirements were identified in order for mobile devices to be accessible with limited sensibility for older adults. Despite the fact that these studies acknowledged key requirements, these characteristics were not quantified nor related with the different users' abilities.

Cognitive capabilities such as short-term memory, attention and spatial ability should also be meaningful when developing interfaces for the blind. Mobile interaction requires a cognitive effort that, for someone lacking sight, is much more demanding. Although there are studies that relate cognitive ability with mobile device usage for sighted older adults [2], there is an enormous gap in terms of studies relating cognitive ability and mobile phone interaction of a visually impaired person. The research reported in this paper tries to overcome this gap by studying the impact of individual differences among the blind on mobile touch-based text-entry tasks.

3. EVALUATION

Touch-based interfaces still pose several challenges to blind users. Recently, a number of efforts have been made to make these devices more accessible, particularly several text-entry methods have been proposed. Although each one present their own

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[1] http://www.apple.com/accessibility/iphone/vision.html (last visited on 03/05/2011)

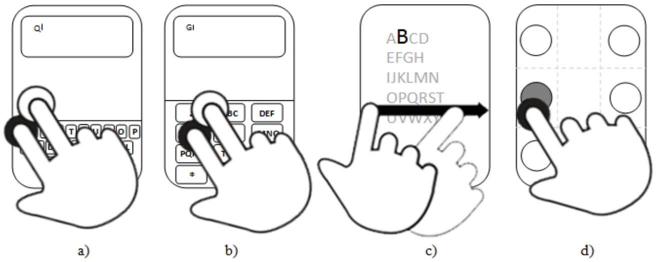

Figure 2. From left to right: QWERTY, MultiTap, NavTouch, and BrailleType.

advantages and limitations, to our knowledge there are no comprehensive studies that relate them to blind users' individual capabilities. Our goal was to relate text-entry demands with the individual differences among blind people.

3.1 Research Goals

The main purpose of this study is to understand the relation between a blind person's individual attributes and mobile touch interface demands, particularly in a text-entry context. In detail, we aim to answer the following research questions: 1) Which are the method's advantages and disadvantages? 2) How are individual differences related with each method and its demands?; 3) Which individual differences have greater impact in user abilities and performance?.

3.2 Text-Entry Methods

In this study, we sought for a set of text-entry methods that could highlight different users' capabilities. This set includes fixed and adaptive layouts, different target sizes and number of on-screen keys, scanning and gesture approaches, and multiple selection mechanisms. We then studied blind people using those methods and report their performance, highlighting some individual differences at sensory, cognitive and functional ability.

All text-entry methods, and their characteristics, used in this evaluation are described in Table 1. *QWERTY* and *NavTouch* have been previously presented elsewhere. *MultiTap* and *BrailleType* are presented here first hand. These two methods intend to explore the user's acquired knowledge both in terms of mobile keypads and Braille usage. All methods provide text-to-speech and audio feedback to the users' interactions.

The ***QWERTY*** text-entry method is identical to Apple's VoiceOver and consists in the traditional computer keyboard layout with a screen reading software (Figure 2-a). Users can focus the desire key by touching it (*painful exploration* [1]), and enter the letter by split-tapping or double tapping anywhere. On the strong side, this method enables blind users to input text similarly to a sighted person with a simple screen reading approach. On the other hand, it features a large number of targets of small size, which can be difficult to find, particularly for those who are not proficient with the QWERTY layout.

The ***MultiTap*** approach uses the same exploration and selection mechanism of the previous method. However, the layout presented is similar to keypad-based devices. We chose this method since this is a familiar letter arrangement to most users. There are twelve medium size buttons, each one featuring a set of characters, thus reducing the number of targets on screen. To enter a letter, users must split or double tap multiple times, according to the character position in that group (Figure 2-b).

NavTouch [4] is a gesture-based approach with adaptive layout, i.e. users can perform gestures anywhere on the screen, therefore not being restricted to a fixed layout. This method is based on a navigational approach: gestures to left and right navigate the alphabet horizontally (Figure 2-c); while gestures up and down navigate vertically (i.e. between vowels). Vowels are only used as shortcuts to the intended letter, thus users can choose whatever path they feel more comfortable. Speech feedback is given as users navigate the alphabet. To select the current letter users can perform a split or double tap.

BrailleType takes advantage of the capabilities of those who know the Braille alphabet. The touch screen serves as a representation of the Braille cell, having six large targets representing each of the dots positions. These targets were made large and mapped to the corners and edges of the screen to allow an easy search. Users can perform a *painless exploration*, while receiving auditory feedback about each dot they are touching. To mark/clear a dot, a long press is required (Figure 2-d). After marking all the necessary dots for a Braille character, in whichever order the user desires, a double-tap in any part of the screen accepts it. A swipe to the left clears the Braille cell if one or more dots are marked or erases the last entered character if the matrix is empty. As ***MultiTap***, this method seeks to provide a less stressful first approach with touch screen devices by reducing the number of onscreen targets.

Table 1. Text-entry methods' characterization

Method	**Layout**	**Size**	**Explor.**	**Selection**
QWERTY	Fixed	Small	Scan	Split/double tap
MultiTap	Fixed	Med.	Scan	Split/double tap
NavTouch	Adaptive	-	Gesture	Split/double tap
BrailleType	Fixed	Large	Scan	Long press and double tap

3.3 Procedure

The study comprised two phases: one to portray the users, their attributes and abilities, and a second one to analyze their speed and accuracy, capabilities and limitations, with the aforementioned text-entry methods. All the evaluations were performed in a formation centre for the blind.

3.3.1 *Individual attributes and abilities*

The characterization phase encompassed an oral questionnaire, sensory (pressure sensibility and spatial acuity), cognitive (verbal IQ and spatial ability), and functional (braille, mobile keypad and computer writing performance) evaluations.

To assess the participants' tactile capabilities, two different components of tactile sensibility were measured. Pressure sensitivity was determined using the Semmes-Weinstein monofilament test (Figure 3) [11]. In this test, there are several nylon filaments with different resistance levels, bending when the maximum pressure they support is applied. This way, if a user can sense a point of pressure, his pressure sensibility is equal to the force applied by the filament. Five monofilaments of 2.83, 3.61, 4.31, 4.56 and 6.65 Newton were used, starting the stimuli with the least resistant one. Pressure was applied in the thumb, index and middle fingers in random order, so we could prevent arbitrary identification of a stimulus by the person being tested.

Spatial acuity was measured using a Disk-Criminator (Figure 3) [9]. This instrument measures a person's capability to distinguish one or two points of pressure on the skin surface. The Disk-Criminator used is an orthogonal plastic instrument that has in each side a pair of metal filaments with relative distances ranging from 2 to 15 mm, with 1mm increments. Each of these filament pairs was, applied randomly in the aforementioned three fingers. There were made 10 stimuli per finger, randomly, alternating between a pair of filaments and a unique filament. The participant had to indicate when he/she felt one or two points of pressure. When he/she was able to correctly identify 7 out of 10 stimuli, his/her level of spatial acuity was the distance between filaments.

The cognitive evaluation focused two components of the cognitive ability, a verbal and a non-verbal. The verbal component was evaluated in terms of working memory: short-term memory and main responsible for the control of attention. The non-verbal component, which consists of abilities independent of mother language or culture, was evaluated in terms of spatial ability: the ability to create and manipulate mental images, as well as maintain orientation relatively to other objects.

To evaluate working memory, the subtest Digit Span of the revised Wechsler Adult Intelligence Scale (WAIS-R) was used [12]. In a first phase, the participant must repeat increasingly long series of digits presented orally, and on a second, repeat additional sets of numbers but backwards. The last number of digits of a series properly repeated allows calculation of a grade to the participant's working memory and, subsequently, to the user's verbal intelligence quotient (Verbal IQ). Spatial ability was measured using the combined grades of the tests Planche a Deux Formes and Planche du Casuiste (Figure 3). These two tests are part of a cognitive battery for vocational guidance [15]. Their goal is to complete, as fast as possible, a puzzle of geometrical pieces.

To assess previous device-wise functional abilities and experience, the users were asked to input text with a mobile phone, a Perkins Braille typewriter and a personal computer. All users were asked to write three individual sentences in each of the devices. The Perkins typewriter and personal computer were made available by the researchers. The computer keyboard featured silicone marks on letters 'F' and 'J' to ease exploration. The mobile task was performed with the user's own device. All participants, excepting two, owned a device with a screen reader.

3.3.2 Experimental evaluation

The evaluation was set up with a within-subject design where all participants were evaluated with all four text-entry methods, one method per session, with one week recess between sessions. In all sessions, with the help of the experimenter, participants started by learning each method and interacting with it for 15 minutes. They were encouraged to ask questions and allay all doubts. If by the end of 15 minutes the participant was unable to write his name or a simple, common four-letter word, the evaluation was halted.

After the tutorial, participants were instructed to write a set of five sentences as fast and accurately as they could (no accentuation or punctuation). Each sentence comprised 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 language of 0.97. The sentences' selection was managed by the application and randomly presented to the user to avoid order effects. The order in which the sessions (methods) were undertaken was also decided randomly to counteract order effects.

All focused and entered characters were registered by the application. The option to delete a character was locked. If a participant made a mistake or was unable to input a certain letter, she/he was told not to worry and simply carry on with the next character. It was made clear to all participants that we were testing the system and not their writing skills. Upon finishing each sentence, the device was handed to the experimenter to load the next random sentence and continue with the evaluation. The session ended with a brief subjective questionnaire on the text-entry method. All these steps were repeated in all sessions (methods).

Figure 3. Individual abilities: Semmes-Weinstein test (left); Disk-Criminator (middle); Planche a Deux Formes (right).

Table 2. Participant's characterization. U[User]; G[Gender];A(O)[Age(Onset];PS[Pressure Sensitivity in Newton];SA[Spatial Ability];VIQ[Verbal IQ];MP[Mobile Phone in WPM]; PC[Computer in WPM];BR[Braille Reading in WPM];BW[Braille Writing in WPM]. The lower the PS, the better the tactile sensitivity. The opposite for SA and VIQ.

U	G	A(O)	PS	SA	VIQ	MP	PC	BR	BW
1	M	26(10)	3,61	1,8	105	15,8	45,8	49,4	26,4
2	M	32(15)	2,83	10,0	111	11,9	44,6	21,3	13,4
3	F	52(5)	4,31	10,0	78	4,0	11,5	8,8	14,9
4	F	34(27)	4,31	8,5	99	12,6	41,8	2,6	8,2
5	M	24(2)	3,61	5,5	65	14,2	45,3	63,7	27,3
6	M	45(20)	2,83	7,8	114	6,7	21,8	9,4	11,6
7	M	62(3)	4,31	4,8	104	7,9	23,7	64,7	25,8
8	F	46(25)	3,61	6,2	84	7,7	20,3	26,5	17,8
9	M	60(0)	4,31	4,0	134	9,6	24,8	80,8	13,4
10	M	48(26)	4,31	4,8	84	10,6	33,9	19,2	22,0
11	M	49(34)	4,31	3,3	78	N/A	N/A	N/A	N/A
12	F	49(17)	4,31	5,5	78	7,1	26,7	3,8	7,9
13	M	46(3)	4,31	7,0	84	N/A	4,7	9,0	11,7

3.4 Apparatus

We used the Samsung Galaxy S touch screen device, which runs Android operating system. This device features a 4 inch capacitive touch screen with multi-touch support. No tactile upper and bottom boundaries were created. All text-entry methods were implemented as Android applications. All audio feedback was given using SVOX Classic TTS, Portuguese language pack. In BrailleType, a timeout of 800ms was used to accept a selection. An application to manage text-entry methods, user sessions and sentences required to type was also implemented. This application informed which sentence to type and logged all the participants' interactions (focus and entry), for later analysis.

3.5 Participants

Thirteen blind participants (light perception at most) were recruited from a formation centre for visually impaired people. The participant group was composed of 9 males and 4 females, with ages ranging from 24 to 62 (M=44). All of the participants knew the Braille alphabet, although one user stated that he did not know how to write with a Perkins Braille typewriter and was not able to read due to poor tactile sensibility and lack of practice. This same user does not use a computer or send text messages on a mobile phone. With the exception of another user, who was not able to write text on a mobile phone as well, all of the participants, with more or less difficulty, write text messages on their mobile phones and use the computer. Only one of the users had previous experience with mobile touch screen devices. Their characterizations are depicted in Table 2.

4. Results

The goal of this study was to assess the advantages and limitations of different touch-based text-entry approaches, and to acknowledge if in fact, and how, different blind people, with different individual attributes, can benefit from a method over others. We start by analyzing the different methods from the standpoint of user performance and preference. Then we focus on individual characteristics and how they diverge across methods, finishing with some case studies, thus giving us a better insight on why certain methods are better suited to a particular person.

4.1 Methods

In this section we focus on the different text-entry methods through the analysis of the users' performance in terms of speed and accuracy. We also examine their preference, opinions and frustrations regarding the presented methods.

4.1.1 Text-entry Speed

To assess speed, the words per minute (WPM) text entry measure calculated as *(transcribed text – 1) * (60 seconds / time in seconds) / (5 characters per word)* was used. One participant, after 15 minutes in the practice session was still struggling with the QWERTY and the MultiTap methods, so he did not perform the test with these two methods.

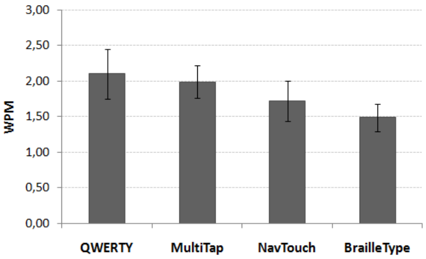

Figure 4. WPM (average) across the different methods. Error bars denote 95% CI.

Figure 4 shows the users' average WPM with the four methods. QWERTY was the fastest method (M=2.1, SD=0.7) followed very closely by MultiTap (M=2.0, SD=0.48). BrailleType was the slowest of the methods (M=1.49, SD=0.43) with NavTouch being a little faster (M=1.72, SD=0.55). Given the normality of the data (according to the Shapiro-Wilk normality test) a one-way repeated measures analysis of variance was conducted to see if these differences were significant. There was a statistically significant difference of Method on Text-Entry Speed (Wilk's Lambda=0.29, $F_{3,58}$=45.54, p<.01). A Bonferroni post-hoc comparison test indicated that QWERTY and MultiTap techniques were significantly faster than NavTouch and BrailleType. QWERTY did not differ significantly from MultiTap, but NavTouch was faster than BrailleType. Even though QWERTY and MultiTap require searching for a specific character or group of characters along the screen, they still proved to be faster as they offer a more direct mapping between input and desired output. Both NavTouch and BrailleType require multiple gestures and inputs to access a specific character, which resulted in slower performances. BrailleType, besides having multiple inputs per character, was hindered by the fact that it uses a timeout system, an aspect that contributed for making the method the worst in terms of speed.

4.1.2 Text-entry Accuracy

Accuracy was measured using the the MSD Error Rate, calculated as *MSD (presentedText, transcribedText) / Max(|presentedText|, |transcribedText|) * 100*. Figure 5 presents the MSD Error Rate of the participants in the different methods. Since the data did not present a normal distribution, the Friedman test was used verify statistically significant differences among the methods. Results indicated that there was a statistically significant difference in Text-Entry Accuracy between the Methods ($X^2(3)=15.27$, $p<.01$). A Wilcoxon Signed Rank Test was used between each pair of methods to understand where these differences resided.

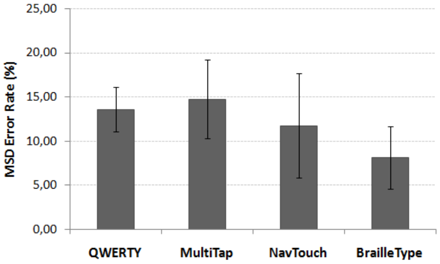

Figure 5. MSD Error Rates. Error bars denote 95% CI.

BrailleType was significantly less error prone than both QWERTY and MultiTap. NavTouch was only significantly different from MultiTap. The fastest methods were also the most error prone, while BrailleType, the slowest method, was the one with the best results accuracy-wise.

4.1.3 Users' Feedback

User feedback was registered through a brief questionnaire at the end of each session. This questionnaire was composed of four statements to classify using a five-point Likert scale (1=strongly disagree, 5=strongly agree). The participants' ratings to the several methods are shown in Table 3**.** The Wilcoxon Signed Rank Test was used to assess significant differences.

Table 3. Questionnaire results for each method (Median, Inter-quartile Range). '*' indicates statistical significance.

Method	Easy to comprehend*	Easy to use*	Fast method	Would use
QWERTY	4.0 (2)	4.0 (2)	4.0 (3)	3.0 (3)
MultiTap	4.0 (2)	4.0 (1)	3.5 (2)	4.0 (3)
NavTouch	5.0 (1)	4.5 (2)	3.0 (3)	3.0 (2)
BrailleType	5.0 (1)	5.0 (1)	3.0 (1)	3.5 (1)

Participants strongly agree that Navtouch is an easier method to understand than MultiTap (*Z*=-2.26, p=.024) and that BrailleType is also easier to understand than both MultiTap and QWERTY methods (*Z*=-2.21, p=.027 and *Z*=-2.058, p=.040). Users also strongly agree that NavTouch is easier to use than the QWERTY technique (*Z*=-1.98, p=.047) and that BrailleType is easier than both QWERTY and MultiTap (*Z*=-2.24, p=.025 and *Z*=-2.07, p=.039). BrailleType and NavTouch, the methods where users performed less mistakes, were also the slowest in terms of WPM, which was reflected in the questionnaire.. In terms of preference, MultiTap was the elected followed by BrailleType, probably due to the resemblance to the traditional and familiar multi-tap and Braille methods. However, if we observe the Inter-quartile range values, we can see that there wasn't a consensus on most methods, in fact, only with BrailleType users seem to collectively agree that they would use the system.

The questionnaire was also composed of an open question about the difficulties faced and general opinion on the text-entry methods. Table 4 shows the main difficulties observed as well as mentioned by the users on each method.

Table 4. Main difficulties observed and perceived by users.

Method	Difficulties
QWERTY	Targets small and close, split-tapping near edges.
MultiTap	Split multi-tapping
NavTouch	Accidental touches, lose track of text
BrailleType	Timeouts, lose track of text

With QWERTY, the main cause of errors and frustration were the proximity and small nature of the targets. Most users found them to be a bit too tiny and close to each other, making it hard to select and split-tap the desired one, especially when the user has large fingers. Since most users would grab the device with the left hand, and use the other to interact, searching with the index finger and split-tapping with the middle finger, targets near the right edge would also become hard to split-tap. Dexterity problems and some indecision on how to hold and interact with the mobile phone were apparent on some users.

With MultiTap most errors occurred due to difficulties in multi-tapping, more specifically in finding the right timing to navigate between characters of a group. This was particularly apparent in the beginning, as some users would tend to not time well their taps, resulting in accepting undesired characters. Even though most are perfectly accustomed to multi-tap on their mobile keypads, some users had difficulty adapting this technique to a sensitive touch device. These adaptation difficulties were also apparent with the NavTouch method. Users would frequently touch/rest their fingers on the screen resulting in errors. Some users would also accidently fail doing the directional gestures, tapping the screen instead of actually doing fling gestures. A concern of some users was the difficulty they found in keeping track of the current text, as they would tend to get confused or even forget the current state of the text as they navigated through the alphabet.

BrailleType, in spite of being the method where fewer errors were committed, they would still happen and their main cause were timeouts. Since focusing each target would read their cell number, but not actually select it until a pre-determined time elapsed, confident users, wanting to write faster, would forget to actually wait for the timeout to select the targets. This resulted in trying to accept incorrect Braille cells. It was evident that most users by the end of the last sentence wanted a shorter timeout, or possibly none whatsoever.

Besides these particular difficulties on each method, common problems such as figuring how to properly hold and interact with the device, as well as involuntary touches were frequent on every method. The general opinion on the methods was in line with what we expected. Users seemed to agree that NavTouch and BrailleType were simpler, easier and safer systems albeit slower (too slow for some participants). On the other hand, the QWERTY and MultiTap methods were perceived as slightly more complex, where errors are more frequent, but that allow writing at a faster pace. It is worth remembering that one participant was unable to use both the QWERTY and MultiTap methods, but had no problems using the other two methods.

4.2 Individual Differences

Now that we have observed how the different methods fared against each other, we will take a closer look at some individual traits to try to understand if they can explain the differences in the users' performance. In this section, we center our attention in three main groups of characteristics: age related, sensory, cognitive, and a more functional group based on the experience in mobile devices, computer and Braille.

4.2.1 Age Related Differences

In terms of WPM, younger users always performed better than older users, independently of the text-entry method used. This difference was statistically significant for QWERTY ($F_{1,58}$=6.67, p<.05) and MultiTap ($F_{1,58}$=23.12, p<.05) methods. It is interesting to note that although younger users were always faster, the difference between the two age groups is less pronounced on NavTouch and BrailleType methods. In terms of accuracy, younger users also performed better, committing fewer errors whatever the method tested. This difference, however, was only statistically significant for MultiTap method ($X^2(1)$=4.75, p<.05).

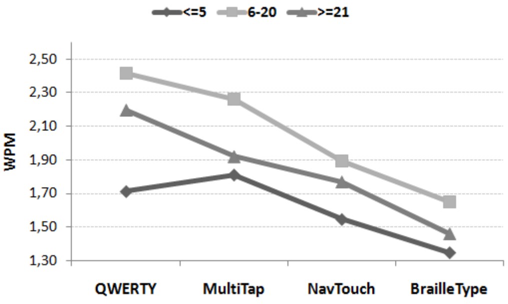

Figure 6. Age of onset impact on WPM.

Users, who were blind before the age of 6, had the slowest performance across all methods, as seen in Figure 6. This difference was statistically significant for QWERTY ($F_{2,57}$=6.096, p<.05) and MultiTap ($F_{2,57}$=5.31, p<.05), with the post-hoc Tukey HSD multiple comparisons test revealing significant differences between the early blind and users who lost their sight between 6 and 20 years of age. NavTouch and BrailleType methods seem to get smaller differences in performance on different age of onset groups, than the other two methods. The MSD Error Rate of the different groups was significantly different only for QWERTY ($X^2(2)$=13.53, p<.01), with users with the oldest age of onset committing fewer errors than the earlier blinds. Just like with the WPM metric, congenitally blind users or that acquired blindness at a very early stage of their lives had the worst performance across all methods.

4.2.2 Sensory and Cognitive Differences

Figure 7 shows the differences of WPM, for users with different levels of pressure sensitivity. There was a significant statistical difference on the MultiTap method ($F_{1,58}$=11.54, p<.01), as users with better pressure sensitivity performed far better. This was probably due to a combination of the very sensitive nature of the screen and the need for multiple touches of the multi-tap technique. No statistically significant results were found for the MSD Error Rate measure.

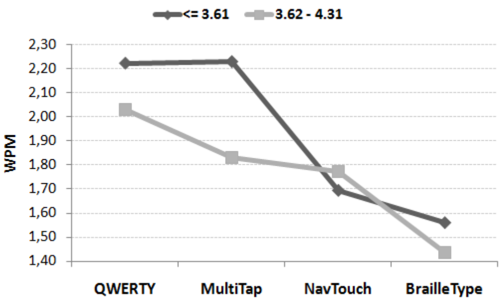

Figure 7. Pressure sensitivity impact on WPM.

For QWERTY and MultiTap, two methods where exploration of the screen is vital, spatial ability was significant ($F_{2,57}$=4.43, p<.05 and $F_{2,57}$=9.95, p<.01, respectively). Participants with the best spatial ability values performed much better than the others, a gap non-existent on NavTouch and BrailleType methods (Figure 8). Users with better spatial ability also committed significantly fewer errors on MultiTap ($X^2(2)$=12.35, p<.01).

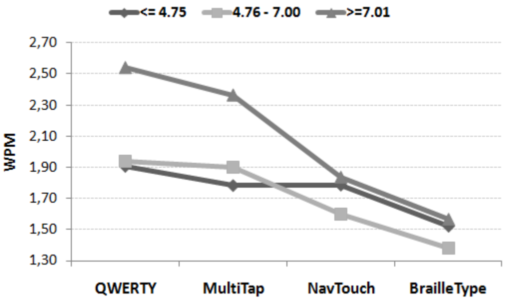

Figure 8. Spatial ability impact on WPM.

Users with a verbal IQ inferior to 85 were always slower independently of the method. This was significant across all methods (QWERTY: $F_{2,57}$=4.33, p<.05; MultiTap: $F_{2,57}$=7.08, p<.01; NavTouch: $F_{2,63}$=3.66, p<.01; BrailleType: $F_{2,63}$=6.89, p<.01). Users with smaller values of verbal IQ also committed significantly more errors on MultiTap ($X^2(2)$=12.56, p<.01) and NavTouch ($X^2(2)$=6.81, p<.05) methods. These two methods seem to have had a greater impact of short term memory and attention.

4.2.3 Functional Differences

There wasn't a statistical significant difference on the QWERTY method, in terms of speed and accuracy, on users with different levels of computer experience. The same is applied to the MultiTap method when comparing users with different levels of mobile device experience. This result suggests that the knowledge acquired from button-based devices do not transfer to their touch counter-parts. However, experience in Braille was significant in terms of Braille reading experience, on the speed of the users with the BrailleType method ($F_{2,57}$=3.60, p<.05). Faster users at reading Braille, and thus knowing extremely well the Braille alphabet, were faster than the others.

4.3 Case Studies

To understand specific behaviors when performing text-entry tasks, in this section we highlight some key observations about specific participants. Starting by looking at the most critical user (Participant 7), the one who was unable to do the test with the QWERTY and MultiTap methods, even after all the practice session time and help from the experimenter. He was an older person, the oldest of the group of participants (62 years old), with an early age of onset (3 years old), bad pressure sensitivity (4.31) and although he had a good verbal IQ (104), he had poor spatial ability (4.75). As we have seen before, these characteristics were significantly related with inferior performances, especially on the two methods the user couldn't cope with, so their combined effect must have contributed for this inability. He was the only user who didn't perform the test in these two methods and, coincidently or not, he was the only user in our study that had this combination of traits. We could argue that maybe he is a *Luddite* or a technophobe, however the mobile and computer assessments made beforehand would state otherwise (7.9 and 23.7 WPM respectively). The user does have experience with technology, and yet his individual attributes seem to put him in a disadvantage, especially when facing certain methods.

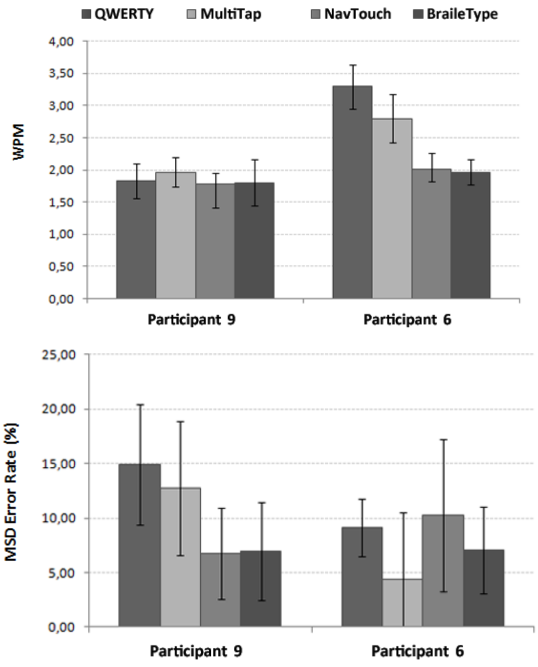

Figure 9. Two users' WPM (top) and MSD ER (bottom).

The impact of individual differences can be observed in more cases. Figure 9 shows the performance of two participants with clearly different outcomes both speed-wise and in terms of accuracy. Participant 9 is a congenital blind, with poor pressure sensitivity (4.3) and spatial ability (4.0). These characteristics certainly influenced his performance as he got much better results with NavTouch and BrailleType. In terms of WPM he was constant in all methods, an indication that he had more difficulty with QWERTY and MultiTap, as the other two are clearly slower methods. Although maintaining speed across methods, Participant 1 performed far more errors on the more demanding methods.

Participant 6, however, is the opposite: has an older age of onset (20 years old) and much better tactile sensitivity (2.83) and spatial ability (8.0). This is reflected in the results, since he was faster with the more demanding methods, and made as much errors, if not less, with these than with the "safer" methods. The performance on MultiTap, a method highly demanding on spatial ability and pressure sensitivity is a good example of the impact of these individual characteristics, especially if we compare the performance of the two participants. These examples illustrate how important individual attributes are in regards to what methods are most accessible to a certain user.

4.4 Discussion

After analyzing each method in detail and revealing individual differences with impact in user's performance we answer the proposed research questions as follows:

1) Which are each method's advantages and disadvantages?

A parallel contribution of this paper comes with the presentation and comparative evaluation of four different text-entry methods. QWERTY (similar to Apple's VoiceOver) and MultiTap (the touch screen counterpart of the original keypad text-entry method) presented themselves as faster input methods. NavTouch (a directional approach) and BrailleType (a coding approach), less direct methods, provide a slower but less erroneous experience.

2) How are individual differences related with each method and its demands?

Results showed that text-entry interfaces with a large number of onscreen elements, like QWERTY and MultiTap, are more demanding to what concerns spatial ability. Users with low spatial skills are likely to perform poorly or even be unable to use those methods. On the other hand, NavTouch and MultiTap, are more demanding to what concerns to memory and attention, as the user has to keep track of the evolution within a selection. Also, results suggest that users with low pressure sensitivity have problems with repeated multi-touch interactions (e.g.,multi split-tapping).

3) Which individual differences have greater impact in user abilities and performance?

Spatial ability, pressure sensitivity and verbal IQ play an important role in the blind user's ability to use and perform accurately with a touch screen and particularly with touch-based text-entry methods. Also, age and age of blindness onset seem to have an impact in users' overall abilities. Previous experience with mobile and other input devices seem to have a reduced impact, or none, in the users' skill to use a new text-entry method.

5. CONCLUSIONS

Individual differences among the blind have a great impact on the different mobile interaction proficiency levels they attain. General-purpose interfaces and assistive technologies disregard these differences. In this paper, we argue that both the users' capabilities as the interaction demands should be explored to foster inclusive design. By doing so, we will be able to provide more inclusive devices and interfaces accordingly to the variations within the users, maximizing each individual performance.

Results in a comparative text-entry method evaluation showed that different methods pose different demands. How these demands are surpassed depends on specific individual attributes. This indicates that different designs suit different blind people. It is paramount to understand these relations and provide informed design diversity to account for individual differences.

6. ACKNOWLEDGMENTS

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