The Impacts of Limited Visual Feedback on Mobile Text Entry for the Twiddler and Mini–QWERTY Keyboards

James Clawson, Kent Lyons, Thad Starner, and Edward Clarkson
College of Computing and GVU Center
Georgia Institute of Technology
Atlanta, GA 30332-0280 USA
{jamer,kent,thad,edclark}@cc.gatech.edu

Abstract

In a mobile environment, the amount of visual attention a person can devote to a computer is often limited. In addition to typing rapidly and accurately, it is important to be able to enter text with limited visual feedback. Previously we found that users can effectively type in such "blind" conditions with the Twiddler one–handed keyboard. In this paper we examine blind typing on mini–QWERTY keyboards and introduce a taxonomy for blind mobile text input. We present a study in which eight expert mini–QWERTY typists participated in 5 typing sessions. Each session consists of three twenty minute typing conditions. In the first condition, the control or "normal" condition, the participant had full visual access to both the keyboard and the display. In the second condition, "single blind," we obstructed view of the keyboard. The final "double blind" condition also reduced visual feedback from the display. In contrast to our Twiddler work, we found that in the visually impaired conditions, typing rate and accuracy suffer, never reaching the non–blind rates. Across the blind mini–QWERTY conditions our participants averaged 45.8 wpm at 85.6% accuracy, while blind typing on the Twiddler averaged 47.3 wpm at 93.9% accuracy. We discuss these results in the context of our previous blind typing work and examine the trade–offs between the different keyboards for mobile and wearable computer use.

1 Introduction

The primary concern when entering text into a computer is the user's ability to type quickly and accurately. Reliably entering text into a mobile device such as a wearable computer poses several additional challenges. For instance, in a mobile setting the user's attention may be focused on the physical environment instead of the computer. The user may be concerned with monitoring a piece of industrial equipment, looking at the ground while walking, or being engaged in a face–to–face conversation. In these situations, a user can not always look at her computer and may be forced into situations where she needs to enter text without being able to see either her display or the keyboard she is using. Silfverberg described data entry in these types of situations as "blind" typing [9].

1.1 Blind Typing Scenario

The following scenario of a wearable computer user illustrates the importance of blind typing in everyday office environment tasks:

It is 07:30 Monday morning and Dana is sitting at the desk in her office catching up on email that had come in over the weekend. Dana loves to get into the office early on Mondays as it gives her time to attend to her work before her co-workers arrive to distract her. She is a wearable computer user and is checking email on her wearable. She has a mini-QWERTY keyboard for input and uses a head up display for output. Alone, she is able to focus all her attention on reading and responding to email. In doing so, she alternatingly reads an email and then focuses her attention on her hands which enables her to optimize the text entry process.

At 09:30 Dana attends a meeting using her wearable, ostensibly to take notes. While sitting in the meeting, she starts instant messaging a co–worker opening up a back channel to gossip about the man leading the meeting and to discuss events of the past weekend. As it would be socially unacceptable for Dana to appear as if she were not paying attention to the meeting, all of her typing occurs with her hands under the conference table where no one, including herself, can see that she is busy typing. This way she is able to chat with her co-worker and appear to be paying attention to the meeting at the same time.

The meeting ends at 10:30 and Dana uses the time it takes to walk back to her office to take notes on the important points from the meeting. In this situation, she still can not see her keyboard and, due to the fact that she is in motion, can not focus on her display either. She can peripherally see what she is typing but does not read what she is writing because she needs to attend to the environment in order to navigate.

This scenario represents three different mobile use conditions with limited visual feedback of both the on-screen display as well as the keyboard. In the first situation, the user is not in motion though she is using a mobile device. Since she is alone and stationary, she has full visual access to both the display (enabling her to see what she is typing) as well as the keyboard (enabling her a view of her hands as she types). Once the user moves into the meeting, the social situation dictates that she no longer look at the keyboard. However, using the head–up display, she retains the ability to read the text as it is entered. Finally, the user is wearing her computer and is in motion. She can not see her hands and she needs her visual faculties to navigate her environment. As a result, she receives reduced visual feedback from the display and can not read the text as it is typed. Instead, she is only able to perceive the cursor and character movement in her peripheral vision. Furthermore, she likely only glances as the display in short bursts while her attention is focused on the environment [8].

In this paper, we discuss past work on blind mobile text entry and present a taxonomy of blind typing. We also investigate the effects of limiting both the visibility of the keyboard and visibility of the on–screen feedback for participants typing on mini-QWERTY keyboards (Figure 1).

2 Mobile Keyboards

There are numerous mobile keyboard options available for entering text. Given the tremendous number of mobile phone users, one of the most prevalent text entry devices is the mobile phone keypad. The two most popular ways to enter text on mobile phones are with multi–tap and T9. With multi–tap, multiple letters are mapped onto a single key on the number pad. To type a character, the user cycles through the letters assigned to a key by pressing the button multiple times. Multi–tap users start typing at approximately 8 wpm [1, 3] with experienced users reaching speeds in the 16–20 wpm range [6, 5]. T9 is another common mobile phone entry method which also has multiple characters assigned to each key. It uses a dictionary to disambiguate and select the most likely word the user enters. T9 rates range from 9 wpm for novices to 21 wpm for experts [3].

Recently several new methods have been developed for entering text on mobile phone keypads including LetterWise [6], TiltText [11], and ChordTap [12]. These methods offer novice performance similar to multi–tap (7.3 wpm, 7.4 wpm and 8.5 wpm respectively). In addition, each of these methods offers faster expert typing rates. LetterWise users achieved a rate of 21 wpm after approximately 550 minutes of practice. TiltText users reached 13.6 wpm and ChordTap 16.1 wpm with about 160 minutes of typing practice.

Figure 1. The mini–QWERTY keyboards used in the study.

2.1 Twiddler Keyboard

Many wearable computer users type with the HandyKey Twiddler, a mobile one–handed chording keyboard with a keypad similar to that of a mobile phone (Figure 2). The Twiddler has twelve keys arranged in a grid of three columns and four rows. The device is held with the keypad facing away from the user, and each row of keys is operated by one of the user’s four fingers. Instead of only pressing keys in sequence to produce a character as with traditional keyboards, multiple keys can be pressed simultaneously to generate a chord.

Previously, we evaluated the learning rate for chording on the Twiddler [5, 4]. We conducted a longitudinal study with five participants who had no experience with typing chords on the Twiddler. By the end of the study, each of our participants completed an average of 75 sessions of twenty minutes corresponding to approximately 25 total hours of practice. On average, our participants reached a typing rate of 47 wpm. Surprisingly, one subject achieved a rate of 67.1 wpm.

Figure 2. The Twiddler one–handed chording keyboard shown in typing position where the keypad faces away from the user.

Keyboard	Expert
Mini–QWERTY	60 wpm
Chording (Twiddler)	47 wpm
Multi–tap & T9	16–21 wpm

Table 1. Expert typing rates for different keyboards.

2.2 Mini-QWERTY Keyboards

We have also empirically evaluated typing rates of novice mini-QWERTY keyboard users. A mini-QWERTY keyboard (Figure 1) is a miniature version of the traditional desktop QWERTY keyboard. These keyboards are popular on devices such as Research in Motion's Blackberry, Danger's Sidekick, and palmOne's Treo 600 series.

We recruited 14 subjects and randomly assigned them to one of two different mini-QWERTY keyboards to use throughout the study. Participants completed 20 twenty-minute typing sessions. Averaged over both keyboards, we found participants had a mean first session typing rate of 31.72 wpm ($SD = 7.00$). At the end of session twenty (400 minutes of typing) our participants had a mean typing rate of 60.03 wpm ($SD = 8.40$). The average accuracy rate for session one was 93.88% ($SD = 3.46\%$) an gradually decreased to 91.68% ($SD = 4.13\%$) by session twenty.

Table 1 summarizes the typing rates for these keyboards for expert use. Given our participants ability to type rapidly on both the Twiddler and mini–QWERTY keyboards, we wanted to evaluate them on other factors relevant to mobile text entry, in particular blind typing.

3 A Taxonomy for Blind Mobile Text Input

To varying degrees, previous typing studies have explored different aspects of blind typing. Here, we present a taxonomy of blind conditions and describe how the previous work and our current study fit within this taxonomy. The output of the computer display showing the text being entered is called "on–screen feedback" and it is subdivided into three categories: present, limited, and absent. We have named the feedback obtained by looking at the input device "keyboard visibility" and it shares the same three categories. Table 2 shows the taxonomy populated with previous work as well as the conditions for our mini–QWERTY study.

Silfverberg examined the effect of visual and tactile feedback on a user's ability to successfully navigate a mobile phone keypad [9]. The 2 x 3 study explored the physical affordances of two different phone keypad layouts in three conditions of varying visibility (direct visual feedback, indirect visual feedback and no visual feedback). In the direct visual feedback condition, the participant could see the phone and receive feedback from the display (on–screen feedback and keyboard visibility is present). In Silfverberg's indirect visual feedback condition, the subject placed her hand holding the phone under the desk occluding visibility of the phone keypad. She received feedback from the display after pressing a key to indicate which key had been pressed (on–screen feedback present, keyboard visibility absent). The no visual feedback condition mirrored the indirect visual feedback condition except that the feedback from the display was removed (on–screen feedback and keyboard visibility absent). Silfverberg's study found that limited visual feedback combined with low tactile feedback hinders a user's average error rate; on the other hand, good tactile feedback results in a smaller decrease in accuracy.

In our previous Twiddler work, we also examined blind typing [4]. As the natural hand position for the Twiddler is with the keys facing away from the user (Figure 2), we only evaluated the effect of changing the on–screen feedback across conditions. The blind study was a 3 x 5 design with 3 conditions (normal feedback, dots feedback, and blind) over 5 sessions of typing where each condition lasted 15 minutes. The normal feedback condition displayed the text as it was typed (on–screen feedback present, keyboard visibility limited). For our dots condition, we displayed periods for each character typed instead of the transcribed text. Thus, participants see their position in the supplied phrase but not specifically what they type (on–screen feedback limited, keyboard visibility limited). This condition was designed to simulate monitoring text typed without being able to actually read the letters such as in the mobile scenario discussed above. Finally, our blind condition did not show any on–screen indication of what was typed (on–screen feedback absent, keyboard visibility absent). For both the dots and blind conditions, participants were shown their transcribed text and error statistics when they pressed enter at the end of a phrase.

Blind Typing	On–screen feedback		
	present	limited	absent
Keyboard visibility present	Mini-QWERTY Normal Silfverberg Direct Visual Feedback	Desktop hunt-and-peck	
Keyboard visibility limited	Twiddler Normal	Twiddler Dots	Twiddler Blind
Keyboard visibility absent	Mini-QWERTY Blind Silfverberg Indirect Visual Feedback Desktop touch-typing	Mini-QWERTY Double Blind	Silfverberg No Visual Feedback

Table 2. Taxonomy of different blind typing conditions.

Typing Rates (wpm)					
Participant	1	2	3	4	5
Normal	51.8	37.6	64.2	36.2	41.8
Dots	51.7	37.5	**67.2**	36.0	**43.1**
Blind	**53.7**	37.5	**67.7**	36.6	41.7

Accuracy (%)					
Participant	1	2	3	4	5
Normal	94.4	94.4	93.0	90.2	93.4
Dots	**95.2**	95.0	**94.3**	90.7	94.2
Blind	95.0	**95.4**	**94.1**	91.1	**94.6**

Table 3. Per participant typing and accuracy rates for the three blind Twiddler conditions [4]. Bold indicates a statistically significant difference at the 0.05 level between that condition and the normal condition for that user.

The results of the study are summarized in Table 3. In contrast to Silfverberg's mobile phone results, we found that changing the visual feedback in the Twiddler experiment did not hinder the participants in their typing. In some cases typing improved with the reduced visual feedback. Whenever there is a statistically significant difference between normal typing and one of the reduced feedback conditions, the reduced feedback condition shows an improved typing or accuracy rate. One possible explanation for this effect is that subjects are operating with open–loop motor control in the blind conditions. When there is visual feedback, the user switches to a closed–loop mode and incorporates the visual feedback into her typing process, thus requiring slightly more time.

In the current study on mini-QWERTY keyboards, we investigate the effects of limiting both visibility of the device and visibility of the display on a subject's ability to quickly and accurately enter text. Following on our previous longitudinal study of novice mini-QWERTY keyboard use [2], our new study has eight expert mini–QWERTY typists who type in conditions of limited visibility both of the keyboard and the display. In the first condition, the "normal" condition, the subject has full visual access to both the keyboard and the display (on-screen feedback present, keyboard visibility present) as shown in Figures 3 and 5. The second condition, "single blind," obstructs the view of the keyboard but presents the visual feedback normally (on-screen feedback present, keyboard visibility absent) as shown in Figures 4 and 5. The final condition, "double blind," not only obstructs the view of the keyboard but also reduced visual feedback from the display (on-screen feedback limited, keyboard visibility absent) as shown in Figures 4 and 6.

4 Method

4.1 Design and Procedure

Our method is similar to our past work on text entry [2, 5, 4]. The study is structured as a 3 x 5 within subjects factorial design. We presented the participants three conditions (normal, blind and double blind) during five sessions which lasted approximately 75 minutes each. The sessions were separated by at least two hours and by no more than two days and scheduled over the course of 9 days. Each session was split into three parts delineated by typing condition and separated by five minute breaks. The order of conditions was randomized across participants. Similar to our previous work, participants were compensated $0.125 x WPM x Accuracy, with a $4 minimum per condition.

We recruited 8 subjects from our previous mini–QWERTY keyboard study [2]. All participants are considered expert mini–QWERTY typists as they had previously completed 600 minutes of training; 400 minutes came from our previous study. As our blind study was conducted after a delay of three months, we conducted an additional retraining period of 200 minutes to assure expertise. By the end of training, the learning rates had dropped to minimal levels indicating our participants were expert mini-QWERTY typists. The same effect was seen after 200 minutes of retraining. Our subjects ranged in ages 18-24. Four participants were female, four male, and all were right–handed.

Before the first session, each participant was given verbal instructions explaining the task and goals of the experiment. The researcher also described the three different typing con-

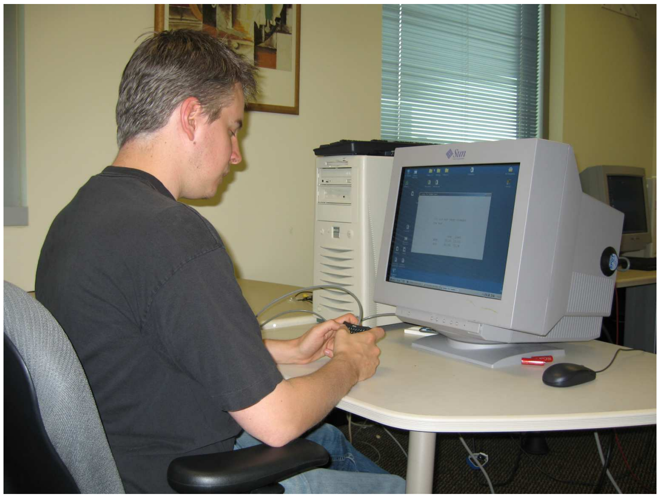


Figure 3. Experimental configuration for normal condition where the user can see the keyboard while typing (keyboard visibility present).

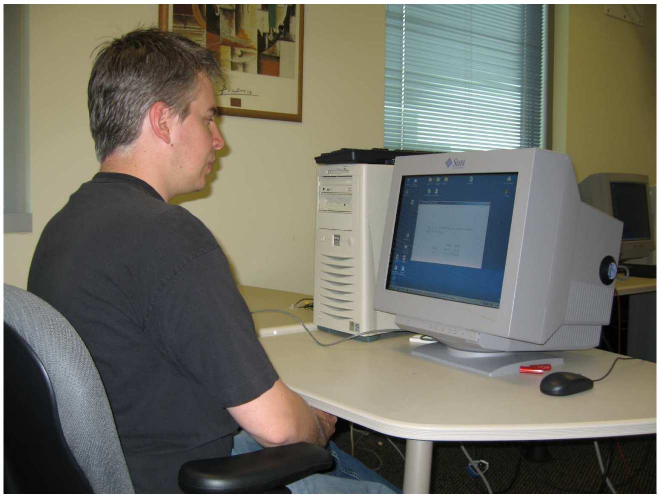
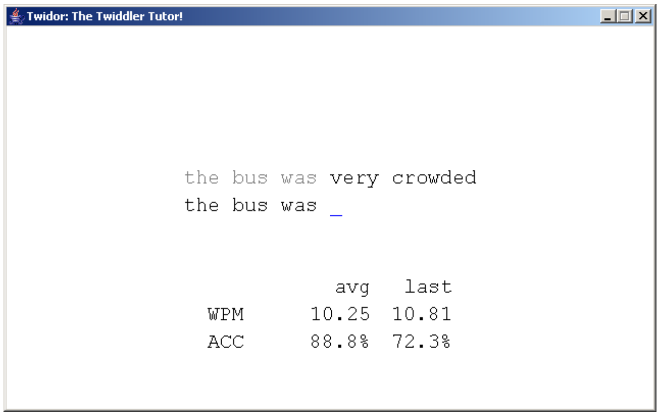


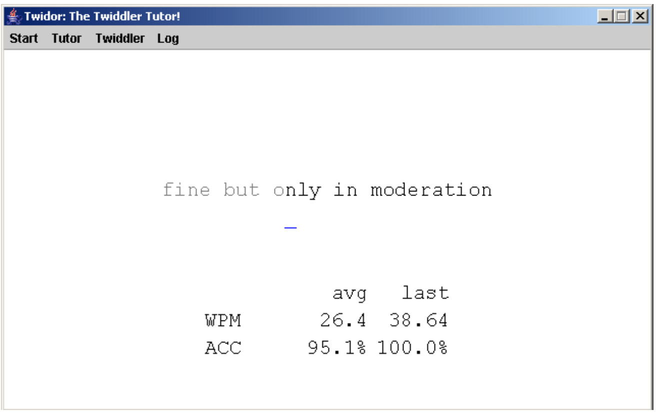
Figure 4. Experimental configuration for blind and double blind condition where the user's hands are held under the desk while typing (keyboard visibility absent).



```
the bus was very crowded
the bus was _

          avg   last
WPM      10.25  10.81
ACC      88.8%  72.3%
```

Figure 5. The experimental software showing visual feedback in the normal and blind conditions (on–screen feedback present).



```
fine but only in moderation
          _

          avg   last
WPM      26.4   38.64
ACC      95.1% 100.0%
```

Figure 6. The experimental software showing visual feedback in the double blind condition (on–screen feedback limited).

ditions being tested. The subjects were instructed to type as quickly and accurately as possible and to use only their two thumbs to enter text.

Each condition began with a warm–up round which consisted of the phrases "abcd efgh ijkl mnop" and "qrst uvwx yz" repeated twice. The warm-up phase was not counted in the statistics. The remainder of the condition consisted of a number of trial blocks, containing ten randomly selected phrases. Each participant completed as many blocks as he or she could in the twenty minute period.

4.2 Equipment and Software

We continued to use the two mini–QWERTY keyboards from our previous work shown in Figure 1. The first is manufactured by Dell (for the Dell Axim) and the other is by Targus (for the Palm m505). We modified each keyboard to connect to a standard desktop computer serial port. The Dell and Targus keyboards transmit at 4800 and 9600 baud, respectively. The study occurred in our usability lab with each of the two keyboards connected to a separate Pentium III workstation.

We employed the Twidor software package (used in our series of studies on the Twiddler chording keyboard), and adapted it to accept data from our modified keyboards. The software is self–administered under researcher supervision. It uses the MacKenzie and Soukoreff phrase set, a set of 500 phrases representative of the English language [7]. The phrases range from 16 to 43 characters with an average length of 28 characters. The phrase set was modified to use only American English spellings and display only lower case letters and spaces (no punctuation or capitalization).

Depending on the condition under test, the software has two different visualization modes. For the normal and blind conditions, the program displays the transcribed text as it is entered (Figure 5). For the double blind condition, the software does not show this feedback. Instead, only a cursor moves across the screen with no characters displayed as the user types (Figure 6). The test software also provided statistical feedback to the participant. We show the typing rate, measured in words per minute (WPM) and the accuracy (ACC) for the most recent sentence typed and the current session average.

5 Results

The 8 participants typed 13,920 sentences across all sessions. Session statistics are weighted by the number of characters in each sentence, and error rates were calculated using Soukoreff and MacKenzie's total error metric which combines corrected and uncorrected errors [10].

In both visually impaired conditions, typing rate suffered considerably (Figure 7, left). In the first session, an analysis of variance (ANOVA) shows that there is a statistical difference between conditions ($p < 0.001$). A post–hoc analysis shows there is not a statistical difference between the blind and the double blind conditions ($p = 0.475$) while there is a difference between the normal condition and the two blind conditions ($p_b < 0.001$ and $p_{db} < 0.001$). The normal typing rate ($M_n = 55.77$ wpm, $SD_n = 6.32$) is approximately the same compared to our previous experiment. In contrast, the typing rates dropped for both blind conditions. The blind typing rate started at $M_b = 36.74$ wpm ($SD_b = 10.49$) for the first session and the double blind typing rate was $M_{db} = 40.15$ wpm ($SD_{db} = 7.92$).

At the end of the our fifth session, the blind typing rate increased to $M_b = 45.03$ wpm ($SD_b = 5.10$) and the double blind rate to $M_{db} = 46.66$ wpm ($SD_{db} = 3.52$). As expected for expert usage, the normal condition did not show a corresponding increase ($M_n = 57.04$ wpm, $SD_n = 4.98$). While the blind rates increased, they are still statistically different from the normal condition ($p_b < 0.001$, $p_{db} < 0.001$). This performance drop represents a decrease of 11 wpm which is approximately 20% of normal typing speed.

The trends seen in the typing rates are also apparent in the accuracy data (Figure 7, right). Typing accuracy was drastically reduced with the introduction of the blind conditions and gradually improved with time. An ANOVA shows statistical difference between conditions ($p < 0.001$). A post-hoc analysis still portrays no statistical difference between the accuracy rates for the blind and double blind conditions ($p = 0.543$) though there remains a difference between the normal condition and the two blind conditions ($p_b < 0.001$ and $p_{db} < 0.001$). After the initial session, the accuracy rate for the normal condition was $M_n = 93.3\%$ ($SD_n = 3.88\%$) while blind was $M_b = 81.0\%$ ($SD_b = 5.76\%$) and the double blind was $M_{db} = 78.9\%$ ($SD_{db} = 7.59\%$).

Examining the accuracy rates at the end of the final session shows that the blind typing condition accuracy increased to $M_b = 85.7\%$ ($SD_b = 6.82\%$) and double blind to $M_{db} = 85.5\%$ ($SD_{db} = 4.92\%$). Again, the normal condition did not show a corresponding increase ($M_n = 93.6\%$, $SD_n = 2.61\%$). While the blind rates increased, similar to the typing rates, they are still statistically different from the normal condition ($p_b < 0.008$, $p_{db} < 0.002$).

It is worth noting the amount of testing that the participants receive in the normal condition was not equal to the time spent in the blind conditions for this experiment. There was not a statistically significant difference between the blind and the double blind conditions, and therefore the difference in the on–screen feedback was not significant. As a result, the two conditions can be viewed as equal when evaluating typing performance from a learning perspective. In effect, the two blind conditions combine giving participants 40 minutes of limited keyboard visibility practice per session. Therefore, the blind data for the fifth session do not strictly represent five typing sessions of 20 minutes, but instead a total of 200 minutes of practice in the keyboard visibility absent condition.

6 Discussion

On the whole, the mini–QWERTY keyboard data show that the participants in the blind conditions initially decrease in performance and slowly recover. This effect contrasts with our past work on the Twiddler where there was no drop in performance when transitioning to limited visual feedback conditions.

The absence of effect is partly explained by the way the Twiddler is held. The Twiddler is held with the keypad facing away from the user (Figure 2) . As a result typists learn to touch type with minimal reliance on being able to view the keys. In contrast, our mini–QWERTY participants learned to type while looking at the keyboard. We observed anecdotally that while typing in the normal condition, subjects would read a phrase displayed on the monitor, look down at the keyboard, type the phrase, press enter to submit the phrase, and look back at the monitor to read the next phrase. This pattern of behavior was no longer valid upon introduction of the blind typing conditions to our expert mini–QWERTY users. The blind conditions are sufficiently different that the participants were forced to partially relearn how to type without looking at the keyboard. This explains the initial decrease in typing rate and accuracy observed as the participants were, in effect, blind typing novices. As they proceeded through the sessions, they gradually relearned how to type and their performance increased. While the performance did rebound, it is important to reiterate that none of our subjects were able to meet or ex-

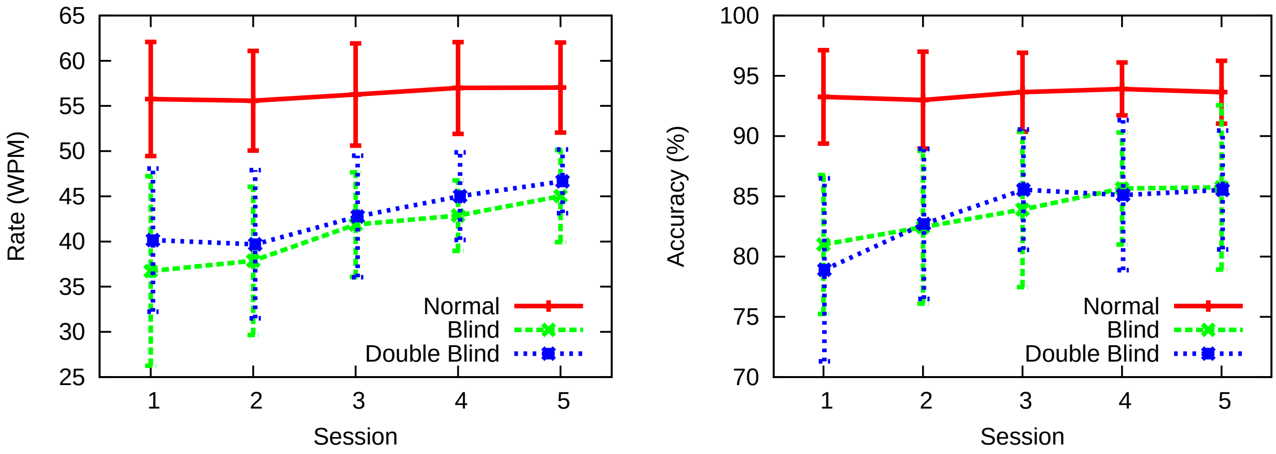


Figure 7. Mean typing rates (left) and accuracy (right) with +/- one standard deviation for the three conditions averaged across keyboards.

ceed their normal typing rate or accuracy while typing in a blind condition.

To explore the possible effect of additional practice on the recovery of performance, we conducted a pilot study with a single participant. The participant typed for an additional three sessions in the blind and double blind conditions. While her typing rate remained consistent, her accuracy continued to improve. After the first session, the pilot subject's data were 65.38 wpm at 93.8% accuracy in the normal condition, 31 wpm at 79.2% in the blind condition and 47.13 wpm at 80.9%. At the end of the eighth session, this subject typed 64.11 wpm with 94.1% accuracy in the normal condition, 48.2 wpm at 92.3% accuracy in the blind condition and 52.69 wpm at 90.6% accuracy in the double blind condition. While we have to be careful in generalizing this data, the pilot shows that additional practice results in an increase of both speed and accuracy. However for this participant, only the accuracy measure appears to recover to the normal rate and the blind typing speed is still slower.

An interesting phenomenon we uncovered during our blind typing work is what we have labeled "the Skywalker effect." With this effect, there is the inverse correlation between typing rates and visual feedback. With visual feedback, participants could see mistakes as they were typing and in turn slowed down, typed more cautiously, and thought more about the text they were inputting. When unable to see the results of key presses, in the words of one of our participants: "I relaxed, trusted that I knew what to do, and just did as well as I could. I wasn't tripped up by seeing all of my mistakes." The Twiddler data from our previous work shows a similar effect. When there was a statistical difference from the control condition, participants either increased typing rate or accuracy when we reduced the on–screen visual feedback.

Another important issue with our study on blind mini–QWERTY typing relates to our experimental setup. With our study, the participants typed in sustained sessions gaining practice with blind typing. This scenario may not be representative of real world conditions where it is unlikely that user's would have multiple sustained sessions of practice with limited visual feedback. Instead, most of the user's experience in blind situations would likely be short and intermittent while trying to accomplish some other primary task similar to our scenario described in the introduction where a user is typing messages during a meeting.

Given enough practice, users can type both quickly and accurately on mini–QWERTY and Twiddler keyboards and both devices are superior to mobile phone keypads when it comes to text entry. However the choice between these keyboards is not straightforward as each offer different advantages and disadvantages for mobile and wearable computing. For example, the Twiddler requires learning how to type on a new device and takes practice before a user can type quickly and accurately enough to use the device as a primary form of mobile text input. Conversely, while mini–QWERTY keyboards are relatively easier to learn, blind typing and accuracy rates suffer greatly in comparison to the Twiddler. The relative drop in performance could be critical and limit use for many mobile situations. Another factor which could limit mobile use is the two–handed nature of the mini–QWERTY keyboards. Selecting between these keyboards would involve weighing the relative costs and benefits they offer.

7 Future Work

Text entry speed, accuracy, and blind typing ability are only a few of the factors that influence the choice of mobile text entry device for a wearable computing system. There are many other factors that influence the decision as well including one–handed vs. two–handed use, size, ergonomics, etc. One key area of future work is to evaluate some of these issues. In particular we are interested in evaluating the costs associated with one–handed vs. two–handed input. In mobile situations, and with wearables in particular, the user is often interacting with the world using her hands. It would be useful to quantify the relative costs associated with occasionally requiring the use of a second hand for text entry. This leads more broadly to testing these devices in a mobile environment which could potentially uncover other unknown factors that could influence mobile text entry.

It might also be useful to continue the study as we did with our pilot described above. At least for that one participant, additional practice allowed her to improve her accuracy. It would be interesting to see if this effect holds in general. Such a study could also be used as a platform to more thoroughly explore the tradeoff between speed and accuracy for different mobile situations.

8 Conclusion

Both the Twiddler and mini–QWERTY keyboards offer rapid mobile text entry (47 and 60 wpm respectively). Mini–QWERTY keyboards offer the further advantage of being very fast to learn assuming the user knows how to type on desktop QWERTY keyboard. However, our current study shows that mini-QWERTYs may not be completely suitable for all mobile text entry situations. In particular, we found that eliminating an expert typist's ability to see her hands drastically reduces both her typing rate and accuracy. This effect is in direct contrast to blind typing on the Twiddler, where there is no decrease. With additional practice, blind mini–QWERTY typing rates and accuracy slowly recover; however, they never reach the rates where the keyboard is fully visible. Across the blind mini–QWERTY conditions our participants averaged 45.8 wpm at 85.6% accuracy, while blind typing on the Twiddler averaged 47.3 wpm at 93.9% accuracy. As a result, selecting a keyboard for mobile or wearable computer use requires careful consideration of learning time, typing rates and accuracy, and the importance of blind typing.

9 Acknowledgements

This work is funded in part by NSF Career Grant #0093291 and the NIDRR Wireless RERC.

References

[1] L. Butts and A. Cockburn. An evaluation of mobile phone text input methods. In *Proceedings of the Australasian User Interfaces Conference*, 2002.

[2] E. Clarkson, J. Clawson, K. Lyons, and T. Starner. An empirical study of typing rates on mini–qwerty keyboards. In *CHI '05: CHI '05 extended abstracts on Human factors in computing systems*, pages 1288–1291, New York, NY, USA, 2005. ACM Press.

[3] C. L. James and K. M. Reischel. Text input for mobile devices: comparing model prediction to actual performance. In *Proceedings of the SIGCHI conference on Human factors in computing systems*, pages 365–371. ACM Press, 2001.

[4] K. Lyons, D. Plaisted, and T. Starner. Expert chording text entry on the twiddler one–handed keyboard. In *Proceedings of IEEE International Symposium on Wearable Computing*, 2004.

[5] K. Lyons, T. Starner, D. Plaisted, J. Fusia, A. Lyons, A. Drew, and E. Looney. Twiddler typing: One-handed chording text entry for mobile phones. In *Proceedings of the SIGCHI conference on Human factors in computing systems*. ACM Press, 2004.

[6] I. S. MacKenzie, H. Kober, D. Smith, T. Jones, and E. Skepner. Letterwise: prefix-based disambiguation for mobile text input. In *Proceedings of the 14th annual ACM symposium on User interface software and technology*, pages 111–120. ACM Press, 2001.

[7] I. S. MacKenzie and R. W. Soukoreff. Phrase sets for evaluating text entry techniques. In *CHI '03 extended abstracts*, pages 754–755. ACM Press, 2003.

[8] A. Oulasvirta, S. Tamminen, V. Roto, and J. Kuorelahti. Interaction in 4-second bursts: the fragmented nature of attentional resources in mobile hci. In *CHI '05: Proceeding of the SIGCHI conference on Human factors in computing systems*, pages 919–928, New York, NY, USA, 2005. ACM Press.

[9] M. Silfverberg. Using mobile keypads with limited visual feedback: Implications to handheld and wearable devices. In *Proceedings of Mobile HCI 2003*, pages 76–90, 2003.

[10] R. W. Soukoreff and I. S. MacKenzie. Metrics for text entry research: an evaluation of msd and kspc, and a new unified error metric. In *Proceedings of the conference on Human factors in computing systems*, pages 113–120. ACM Press, 2003.

[11] D. Wigdor and R. Balakrishnan. TiltText: Using tilt for text input to mobile phones. In *Proceedings of UIST 2003*. ACM Press, 2003.

[12] D. Wigdor and R. Balakrishnan. A comparison of consecutive and concurrent input text entry techniques for mobile phones. In *Proceedings of CHI 2004*, pages 81–88. ACM Press, 2004.