

Twiddler Typing: One-Handed Chording Text Entry for Mobile Phones

Kent Lyons, Thad Starner, Daniel Plaisted,
James Fusia, Amanda Lyons, Aaron Drew, E. W. Looney

College of Computing and GVVU Center
Georgia Institute of Technology
Atlanta, GA 30332-0280 USA

{kent,thad,plaisted,visyz,amandal,adrew,ewlooney}@cc.gatech.edu

ABSTRACT

An experienced user of the Twiddler, a one-handed chording keyboard, averages speeds of 60 words per minute with letter-by-letter typing of standard test phrases. This fast typing rate coupled with the Twiddler's 3x4 button design, similar to that of a standard mobile telephone, makes it a potential alternative to multi-tap for text entry on mobile phones. Despite this similarity, there is very little data on the Twiddler's performance and learnability. We present a longitudinal study of novice users' learning rates on the Twiddler. Ten participants typed for 20 sessions using two different methods. Each session is composed of 20 minutes of typing with multi-tap and 20 minutes of one-handed chording on the Twiddler. We found that users initially have a faster average typing rate with multi-tap; however, after four sessions the difference becomes negligible, and by the eighth session participants type faster with chording on the Twiddler. Furthermore, after 20 sessions typing rates for the Twiddler are still increasing.

Author Keywords

Text entry, mobile phones, chording, multi-tap, keypad input

ACM Classification Keywords

H.5.2 User Interfaces: Input devices and strategies

INTRODUCTION

With 1.32 billion users, mobile phones have become ubiquitous in many parts of the world [4]. Similarly, the use of wireless text messaging is becoming widespread, with predictions of a rate of over 1 trillion messages per year being reached shortly [6, 12]. These statistics are remarkable considering the inefficiencies and poor design of current text entry methods for mobile devices.

With wireless messaging revenues at stake in the tens of billions of US dollars, mobile phone manufacturers can differentiate their products with text entry methods that are faster, easier to learn, less physiologically stressful, or more convenient than competitors' products. For example, in a recent survey, 92% of 15-40 year old mobile phone users stated that speed was important when sending and receiving messages [3]. Increased text entry speed may also open new

markets for wireless email, which is desired by 81% of consumers surveyed [3]. Wireless email is predicted to drive the next stage of the industry's European data revenues [4]. Increased text entry speeds may also help unexpected segments of the user population. For example, the Deaf population has adopted wireless texting as a convenient means of communication within the community.

In this paper, we demonstrate a chording method of text entry on a 3x4 button keypad where expert rates average 60 wpm on letter-by-letter entry. We show that chording novices average over 26 wpm after 400 minutes of practice and have rates comparable to their multi-tap rates within 80 minutes of practice. Finally, we discuss how this chording method may be incorporated into a mobile phone design.

Multi-tap

One common mobile phone text entry method is multi-tap, a system in which multiple letters are mapped to the same key and the user presses that key to cycle through the letters until the desired one appears on the screen. Users hold the keypad towards them and can enter text with one or two hands using one or two fingers/thumbs. Once the desired letter appears, users can press the next key to start the process again for the next letter, wait for the timeout, or use a kill key function. This is a feature that deactivates the current key after a specified amount of time. Previous research has predicted maximum expert words-per-minute (wpm) typing rates of 20 to 27 wpm [14]. Usability studies have found rates of 15.5 wpm [9] and 5.3-10.5 wpm [5] which are far below many other keyboard input devices.

Chording

Many wearable computer users [7, 17] type with the HandyKey Twiddler (Figure 1). This is a mobile one-handed chording keyboard with a keypad similar to a mobile phone. It has twelve keys arranged in a grid of three columns and four rows on the front of the device. Each row of keys is operated by one of the user's four fingers. Additionally, the Twiddler has several modifier buttons such as "Alt" on the top operated by the user's thumb. Users hold the device in the palm of their hand like a cup with the keys facing away from their bodies. All five fingers on a hand can be used to type. Unlike multi-



Figure 1: On the left, typing using multi-tap on the Twiddler keypad. On the right, chording with the Twiddler one-handed keyboard typing the letter ‘s’ (M0L0).

tap, the Twiddler is a chording keyboard. Instead of pressing keys in sequence to produce a character, multiple keys are pressed simultaneously. Each letter of the alphabet can be typed on the Twiddler by pressing one or two keys concurrently. The Twiddler also has the feature of multi-character chords (MCCs). For instance, the keyboard has chords for some frequent words and letter sets such as ‘and’, ‘the’, and ‘ing’. Users can also define their own MCCs. This has positive implications for the number of keystrokes per character (KSPC) needed to type [8].

Fingers	Char	Fingers	Char	Fingers	Char
L000	a	RL00	i	ML00	r
0L00	b	ROL0	j	M0L0	s
00L0	c	R00L	k	M00L	t
M000	e				
0M00	f	RM00	l	MM00	u
00M0	g	R0M0	m	M0M0	v
000M	h	R00M	n	M00M	w
R000	Space				
0R00	Delete	RR00	o	MR00	x
00R0	Backspace	R0R0	p	M0R0	y
000R	Enter	R00R	q	M00R	z

Table 1: Keymap for chording on the Twiddler.

Table 1 shows the default chording layout for the Twiddler. The four character string under the Fingers column denotes what keys to press for a chord, one character for each row on the Twiddler. ‘L’ is for the left column of buttons, ‘M’ the middle and ‘R’ the right. A ‘0’ denotes the corresponding button is not pressed. The designation for ‘a’ is ‘L000’ which indicates the user should press the left button on the top row. To generate ‘m’ (‘R0M0’), the user would press the right key on the top row and the middle key on the third row at the same time. Note that the designation of left to right is from the user’s perspective of holding the keypad facing away. This creates a left-to-right mirror between the table and Figure 1 (right). Figure 2 (right) shows the representa-

tion of the chording layout from the user’s perspective.

We collected data of an expert Twiddler user typing at an average rate of 60 wpm on a letter-by-letter basis (no multi-character chords); this is far faster than reported multi-tap values. This higher achievable text entry maximum coupled with the affordances of the same button layout as mobile phones suggests that the Twiddler has great potential as a replacement text entry mechanism for mobile phones.

We present a longitudinal study comparing the usability of multi-tap and chording on the Twiddler with ten participants. We gathered data and evaluated the two methods for learnability, crossover values of performance, and typing rates. We discuss the design implications from the data and discuss the viability of the Twiddler as a high-speed text input device for mobile phones.

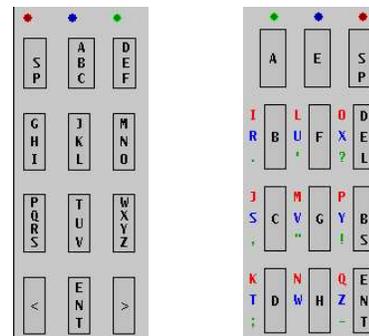


Figure 2: Layouts: multi-tap (left), chording (right)

RELATED WORK

Several studies compare text entry techniques to multi-tap [9, 18, 1, 5]. Table 2 provides a summary including the results of this study. Where it could be derived, the experience column shows the approximate number of minutes the novice user spent typing with the given method before the maximum words per minute were calculated. Studies that were not longitudinal in nature but characterized subjects as “novice” or “expert” are marked accordingly.

The study presented here has a very similar method to the LetterWise [9] and Opti keyboard layout studies [11]. These works were designed to determine the learning rates of different typing methods using longitudinal studies. The Opti study was designed to test different soft keyboard layouts and used a within subject 2x20 factorial design of keyboard layout (2) and session (20). The LetterWise study tested two different input techniques that both rely on the 3x4 grid of a mobile phone keypad. This study did not use an actual mobile phone keypad, opting for a different keypad with the same layout. The study is also a 2x20 factorial design employing a within subjects session factor and a between subjects typing method.

Method	Keyboard	Experience	WPM
Chording, MCCs	Twiddler	expert	65.3
Chording	Twiddler	expert	59.7
Chording	Twiddler	400 min	26.2
LetterWise [9]	desktop keypad	550 min	21.0
T9 [5]	Nokia 3210 phone	expert	20.36
Multi-tap	Twiddler	400 min	19.8
Multi-tap [9]	desktop keypad	550 min	15.5
TiltText [18]	Motorola i95cl phone	165 min	13.57
Multi-tap [18]	Motorola i95cl phone	165 min	11.04
T9 [5]	Nokia 3210 phone	novice	9.09
Multi-tap [5]	Nokia 3210 phone	novice	7.98
Multi-tap [5]	Nokia 3210 phone	expert	7.93
Multi-tap [1]	desktop keypad	n/a	7.2
Two key [1]	desktop keypad	n/a	5.5

Table 2: Comparison of text entry rates for mobile phone keypads.

METHOD

Participants

Twelve participants were recruited from the Institute’s student body. All of the subjects were informed of the significant time commitment required for the study and were compensated for their participation calculated at the rate of \$1 x WPM x Accuracy over the entire session, with a minimum of \$8 per session. Two participants dropped out within 8 sessions due to time constraints. Of the ten subjects that completed the study, eight are male and nine right-handed.

Eight of the participants reported that they owned or used a mobile phone on a regular basis, and none of the subjects had used a Twiddler before this study. We chose only native English speakers as our test phrases were in English. We also recruited participants without long fingernails that might have impeded typing speed.

Equipment and Software

The experiment was conducted in the College’s usability laboratory. This was a stationary test where participants sat at a computer running our test software developed in Java. The computer stations were Pentium III based PCs. The Twiddler was attached to the computer via a serial cable and continually sent the state of all of its buttons to the computer at 2400 baud, resulting in a key sample rate of approximately 45Hz. The software parsed the serial stream as text input.

The faceplates of the three Twiddlers used for this study were modified to have labels for multi-tap. Labels are appropriate since multi-tap is designed to be used while the keypad is

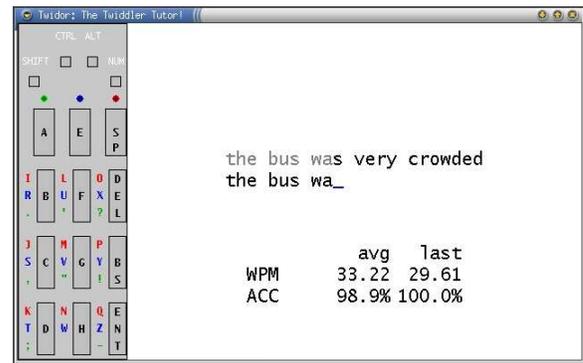


Figure 3: Experimental software showing the chording layout, phrase and statistics.

facing the user; however, when chording, the Twiddler keypad faces away from the user. To prevent subjects from turning the chording keypad to look at the keys, the chording labels on the Twiddler were covered. The labels also posed another potential problem due to left and right mappings. The test software displays key presses to the user as if the Twiddler were held as intended. If they turned the keypad around for the chording condition, the participants would have to mirror the image in their heads.

Design

The experiment is a 2 x 20 within-subjects factorial design. We presented the participants with two conditions: multi-tap and chording during 20 sessions over the course of three weeks. Sessions were scheduled Monday through Friday where each session was separated by at least two hours and no more than two days. Each session lasted approximately 45 minutes and consisted of two parts delineated by typing condition. Participants were randomly assigned to a condition (balanced across participants) for the first session. This condition was tested first followed by the second condition. The order of presentation alternated from session to session.

Depending on the condition under test, the testing software presents the participants with the key layout for either multi-tap or chording (Figure 2) and statistics of performance. A phrase is presented on the screen and beneath that the transcription that resulted from the subject’s key presses (Figure 3).

Each half session began with a warm-up round. The warm-up consists of typing the two phrases, “abcd efgh ijkl” “mnopqrst uvwx yz” twice. During the warm-up phase the program also highlights the correct buttons to press to type the next letter in the phrase. The warm-up data was not used in measuring performance. Once the warm-up phase ended, the highlighting was turned off but the key layout remained. The subjects were instructed to begin typing for the trials, and data recording began.

Each half session consisted of several blocks of trials. Each block contained ten text phrases of approximately 28 char-

acters each and were selected randomly from the set of 500 phrases developed by MacKenzie and Soukoreff [10]. These are phrases specifically designed as representative samples of the English language. The phrases contain only letters and spaces, and we altered the phrases to use only lower case and American English spellings.

The experimental software presented blocks of phrases until twenty minutes had expired. As participants' typing rates increased throughout the study, the number of blocks completed also increased. In the first session, participants typed 5 to 8 blocks total and completed 12 to 21 blocks by the final session.

During the first and last sessions, we also asked each participant to type using a standard desktop QWERTY keyboard for two blocks for a total of 40 phrases. We collected this data as a baseline typing rate for each participant.

The software collects data at the level of button presses. Every key press and release is recorded to a log file. When a button is pressed or released, the system logs the time-stamp (obtained with Java's *System.currentTimeMillis()* system call), the character generated (if any), and the state of all of the Twiddler's buttons. The current text entry method is logged as well as the phrases presented to the participant. With this data we can determine when each key was pressed and released, the duration each button was held, the time between releasing one button and pressing the next, and the resulting transcribed text.

Procedure

Each participant was given written, verbal, and visual instructions explaining the task and goal of the experiment. The researcher explained how to type for both methods on the Twiddler and demonstrated how to hold the device for each condition. He also explained its key layout mimics a mobile phone, mapping number keys to Twiddler keys. Finally, he showed the participants how to press each letter of the alphabet for both methods. For multi-tap, he explained that the keypad is held facing the participants. The participants were informed they could wait for the timeout or utilize the kill button, and they could use one or two index fingers/thumbs to type. For chording, the researcher showed the participants how to strap the Twiddler onto their hand. He also showed how to press each key with the tip of the finger and how to press multiple keys simultaneously to generate chords.

The software is self-administered (under researcher supervision), and participants have unique anonymous log in IDs. The subjects are asked to copy a presented phrase by typing on the Twiddler keyboard. They are instructed to type as quickly as possible while minimizing errors. The program provides statistical data as feedback so the participants can monitor their progress. In addition to the phrase to be typed and the statistics, the program also displays the keyboard lay-

out for the current method for reference.

Once started, the program initiates the warm-up phase for the appropriate method. Once the four warm-up phrases are typed, the program instructs the participants that the timed trials will start next. After each block of ten phrases the program pauses to show the participant's statistics of rate and accuracy for that block. After 20 minutes, the program shows the statistics for that half of the session and instructs the participant to take a five-minute break. After the break, the program switches to the second input method. The participant changes grip on the Twiddler to be compatible with the method and the second half of the session proceeds like the first.

RESULTS

Data Summary

For each of our ten participants, we collected approximately 2100 transcribed phrases. In total for both conditions over all 20 sessions and 10 users we collected 600,000 transcribed characters.

Text Entry Speeds and Learning Curves

The mean entry rates for session one were 8.2 wpm for multi-tap and 4.3 wpm for chording. As sessions continued, the means improved and reached 19.8 wpm for multi-tap and 26.2 wpm for chording by session 20. While both showed improvement, the performance scores for the chording condition rapidly surpassed those of multi-tap (Figure 4).

An analysis of variance (ANOVA) of text entry speed shows a main effect for typing method ($F_{1,9} = 45.2, p < 0.0001$) and for session ($F_{19,171} = 36.8, p < 0.0001$). There is also a significant method-by-session interaction ($F_{19,171} = 3.62, p < 0.0001$).

The main effect of session was expected as was the method-by-session interaction. The participants learned to type faster over the course of the 20 sessions. Initially the participants on average typed faster with multi-tap, but after a few sessions the difference eroded and by the eighth session chording was faster ($T_9 = 3.1, p < 0.05$). The significance of the differences also increased as the sessions continued.

For each typing method, we derived exponential regression curves to model the power law of practice (Figure 4) [2]. The equations for the curves are below. The x values are the number of 20 minute sessions and the y values are the predicted rate in words per minute for that session. The curves have R^2 values of greater than 98% indicating that the curves are well fitted to the data, accounting for over 98% of the variance. As can be seen, multi-tap rates begin to plateau while the chording method shows steadily increasing typing speeds.

$$\begin{aligned} \text{Twiddler: } y &= 4.8987x^{0.5781}, R^2 = 0.9849 \\ \text{Multi-tap: } y &= 8.2235x^{0.2950}, R^2 = 0.9961 \end{aligned}$$

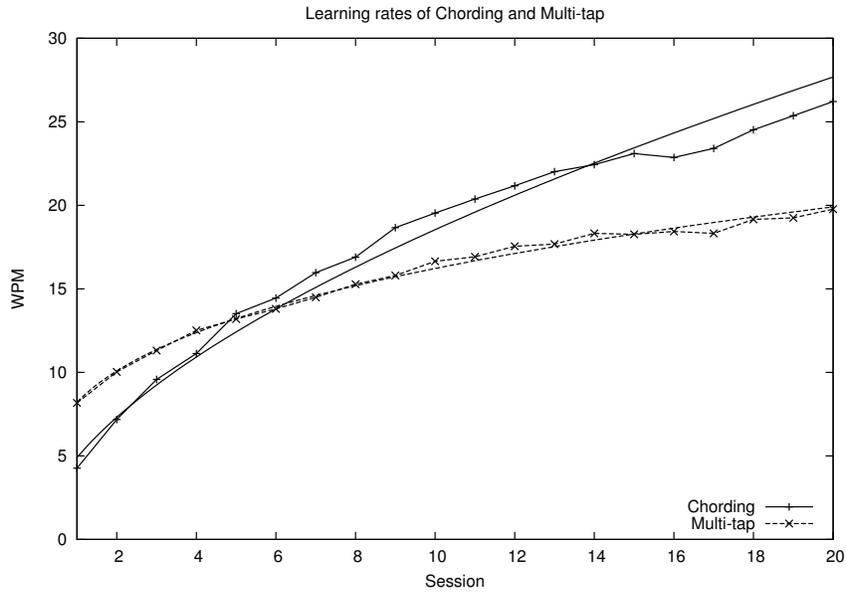


Figure 4: Learning rates and exponential regression curves for multi-tap and chording.

The crossover point in the curves indicates where one condition's typing rate surpasses the other. In our study, the chording method began with slower speeds but quickly overcame multi-tap. The crossover occurred after the fifth session or after 1 hour 40 minutes of practice.

Per Participant Text Entry Rates

Because learning rates are exponential, we graphed the text entry rates per participant as a log-log plot. Both graphs in Figure 5 show data for all ten subjects on a per session basis. The left side of Figure 5 shows the chording data and the right is for multi-tap. The steep slope of chording indicates rapid learning. The slopes of the multi-tap sessions are much more shallow. The curves also show the large variances in the multi-tap entry rates.

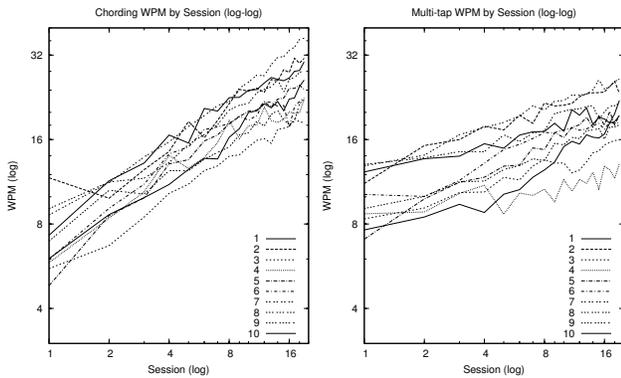


Figure 5: Log-log plots of learning rates for chording (left) and multi-tap (right) for each participant.

Figure 6 illustrates per user regression lines that model per

phrase typing rates for the chording condition. In our 20 sessions, each participant typed approximately 1050 phrases for each condition. We have extended the regression lines to predict what expert rates might be achieved. The chording regressions are particularly interesting because of the clusters that appear. It suggests that the faster typists would reach 60 wpm, the rate of our expert, after 10,000 phrases (approximately 80 sessions or 27 hours) while the slower typists could achieve 45 wpm.

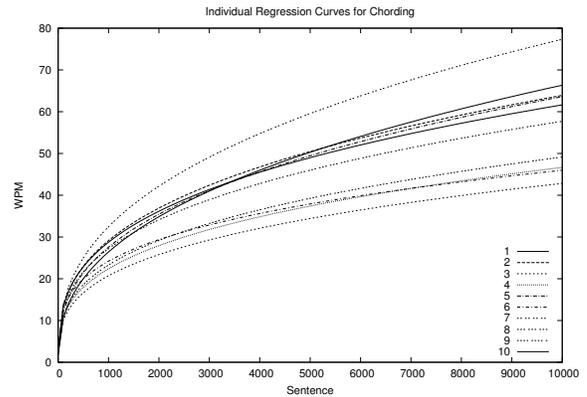


Figure 6: Per participant regressions for chording

Error Rates

We used Soukoreff's and Mackenzie's total error rate metric [16] which combines corrected and uncorrected errors. Our participants tended not to correct their mistakes, so most of the errors in this study were left uncorrected.

Figure 7 shows the average total error rates per session for both conditions. Our error rates are comparable to other studies [9], and all of the error rates are less than 5% after the

second session. The chording method error rates started at 10.4% but quickly decreased. We believe the high initial rate is due to the fact that the participants had no experience with chording on the Twiddler.

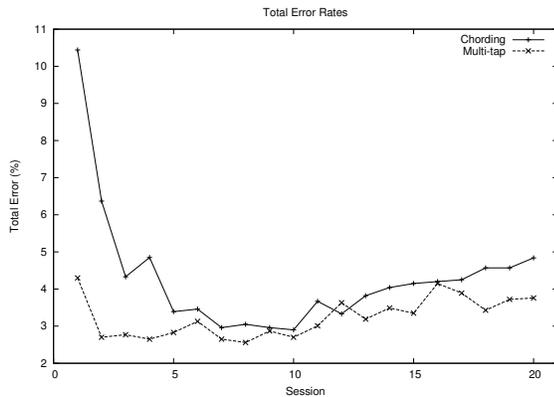


Figure 7: Total error rates for chording and multi-tap.

Expert Chording Rates and Errors

To compare our novice participants' final entry rates with an expert we tested the second author, an expert of 10 years in chording text entry. He utilizes his non-dominant hand in contrast to our study and normally uses multi-character chording shortcuts for increased speed (i.e. 1 chord to type 'the'). We tested him without this feature forcing him to type one character at a time. We conducted three practice sessions to allow him to adjust to the letter-by-letter typing. By session four his average typing rate for chording stabilized and was found to be 59.72 wpm. His total error rates were 4.44%. We also tested the expert with MCCs enabled, resulting in a rate of 65.25 wpm and a total error rate of 6.3%. Some errors were intentional as it was often more efficient to type a chord and correct the last character than to type each letter one-by-one. For example, to type the word "their" the chord "the" may be followed by backspace to remove the trailing space character, resulting in two chords to type three characters.

DISCUSSION

Multi-tap Typing Rates

Our study data for multi-tap reveals a wide range of values for typing rates across users (Figure 5). One explanation for this is prior knowledge and experience with multi-tap. All subjects reported owning mobile phones except for two. Multi-tap is a common technology, and it is hypothesized that participants are familiar with how it works even if they do not use it often. At the very least, the mapping of letters to numbers on a phone is familiar. This might also be a reason for multi-tap rates starting higher than chording. Another factor in multi-tap's initial advantage is the participants' lack of experience with chording. All reported never using chording or the Twiddler before.

Another issue with our multi-tap study data are the values themselves. Our study shows higher typing rates for our

participants than previous studies. The James and Reischel study found multi-tap typing rates of 8 wpm; our participants started close to this rate (8.2 wpm) but quickly surpassed it. One possible explanation for this increase is that while James and Reischel's subjects may have been experienced with sending text messages, they may not have had as much practice as ours. Another possible explanation is the keypad itself. They used a phone keypad while we used a Twiddler which has larger buttons spaced farther apart. MacKenzie et. al also did not use a mobile phone keypad. Their starting rates were comparable to ours, but our participants' final rates were higher. Perhaps an explanation for this is that we allowed 2 finger/thumb entry. Another factor could be that our participants had a rapid base typing rate on standard QWERTY keyboards (Table 3).

It was also observed that all of our participants touch typed for both methods, looking only at the screen not the keypad. Silfverberg examined the ability to type on keypad with different haptics and found significant effects with varying visual attention [13]. Perhaps the Twiddler has better tactile feedback than the mobile phone used in the James and Reischel study.

Chording versus Multi-tap

As we have shown, novices initially have faster typing speeds using multi-tap compared to chording. However, after practice, chording becomes the faster typing method and greatly exceeds the multi-tap rates. Furthermore, our regression lines suggest that the chording method has a greater potential typing rate. With only a little more practice, our participants have the ability to achieve typing rates comparable to our expert.

Keystrokes per character (KSPC) is a metric of how many keys need to be pressed for a particular typing method to generate a character [8]. The KSPC for multi-tap is 2.0432 [9]. For chording, only one or two simultaneous key presses are needed to generate a character. Given Soukoreff's diagrams [15], this equates to a KSPC value of 1.4764. Fewer key presses are required in chording to generate the same text as compared to multi-tap, thus allowing for faster rates using the chording typing method.

Chording on the Twiddler offers even faster potential typing rates due to MCCs. One chord (1 or more simultaneous key presses) can generate multiple characters. For example, the word 'and' can be typed letter-by letter with 4 key presses (1 for 'a', 2 for 'n', 1 for 'd') or 1 chord of 2 simultaneous key presses with the default multi-character chord ('a' and 'h' keys). Key strokes per character changes from 4/3 to 2/3 for this example. Extensive use of the default MCCs available with the Twiddler could offer even faster typing rates than those observed in our study.

As we have shown, the same 3X4 keypad can produce vastly different typing rates. This might be due to a tradeoff in the

use of space versus time. In the standard QWERTY design, all lowercase characters are devoted to a separate key (dedicated space). The opposite extreme would be to use one key to cycle through all characters one at a time. The Twiddler chording method and multi-tap are two distinct points in this design domain. Multi-tap spreads 3 or 4 letters across the keys. The user selects a letter by pressing a particular key several times. Chording does not utilize a temporal approach. The user presses multiple keys at approximately the same time to generate characters. So even if chording and multi-tap had the same keystrokes per character values, chording would be faster since it is not dependent on time.

QWERTY as a Baseline Predictor

We utilized the data collected from a full sized desktop QWERTY keyboard to normalize each participant's entry rate. Table 3 shows each participant's QWERTY average wpm, the ratio of his or her chording and multi-tap rates during the last session to his or her QWERTY rate. This table shows remarkable consistency across participants despite the large range in QWERTY speeds. After twenty sessions, the average ratio for chording is 32.5% (s.d. 3.9), while the average ratio for multi-tap is 24.7% (s.d. 4.5).

QWERTY wpm	Chording (%)	Multi-tap (%)
113.9	32.3	23.0
111.1	28.0	21.0
94.8	31.9	23.3
86.8	30.0	22.4
83.5	33.8	25.8
82.3	29.3	23.8
74.5	29.9	17.6
61.5	36.6	29.9
58.5	31.4	27.2
54.1	41.3	33.3

Table 3: Typing rates as a function of QWERTY speed.

The consistency between participants suggests that QWERTY rates might predict chording and multi-tap rates. Using our table, if someone types 90 WPM on a standard QWERTY keyboard, our data suggests that after 20 20-minute sessions she would type approximately 29 wpm chording, while only 22 wpm with multi-tap. More data needs to be collected to confirm this hypothesis.

Chording as Alternative for Text Entry on Mobile Phones

Both multi-tap and the Twiddler chording method utilize a 12 button 3X4 keypad in a size appropriate for mobile phones. As we have demonstrated through the data collected in this study, even novice chording users quickly outperform multi-tap typing speeds. Furthermore, data suggests that the Twiddler has greater potential expert typing rates. Anecdotally, these typing rates are sufficient for composing email.

One can imagine a mobile phone design based on the current Twiddler keyboard. A speaker can be placed in the position of the "Twiddler" logo in Figure 1, and a microphone

at the base of the keyboard under the "h" key. Furthermore, a high resolution touch screen can be placed on the reverse side of the Twiddler where the thumb buttons currently reside. The thumb buttons (Control, Shift, NUM, ALT, etc.) can be emulated with the touch screen and could be reprogrammed as needed. For messaging or learning to type, the high resolution screen could be used to display a graphical interface similar to that in Figure 3, which would encourage good touch typing and good posture. This screen could also serve for more advanced features. For example, a camera could be mounted in the flat base of the Twiddler (where the velcro strap attaches), and the screen could act as a camcorder viewfinder.

Besides increased text entry speed, this design may have other benefits. For example, the user could type notes without needing to look at his phone. In our experience, this ability is key while engaged in conversation [7]. In a presentation at Mobile HCI 2003, Silfverberg [13] observed that such "blind" typing might be a market differentiator for the teenage population for exchanging notes in class. Finally, the ability for the user to type with his hand at the side with the wrist straight and relaxed may help alleviate the stress of some repetitive strain injuries.

FUTURE WORK

One potential area of future work is to continue the study to find the session number in which participants' chording typing rates begin to level off. Given our regression curves, we expect to reach the rate of our expert after approximately 10,000 phrases. More data would be needed to confirm this.

Another possible point to explore is to include more participants. This study, with only ten participants, showed large variances between participants in the multi-tap typing rates. Perhaps a larger subject pool might reduce the variance observed. It would also be interesting to look at left versus right-handed issues with chording as the layout is not symmetrical. Furthermore, we could explore the effects of gender and different hand sizes. More participants would also allow us to explore if the typing rates normalized by QWERTY speeds are a valid predictor of performance.

We would also like to explore more realistic usage settings of mobile phones. These devices are utilized while people are moving around in their environment; however, participants remained stationary during the trials. By the end of this study, almost all of our participants were touch typing with both methods and only monitored their progress by looking at the screen. A study exploring blind typing, where subjects have limited or no visual feedback, might more realistically simulate mobile use due to limited visual attention [13]. Another study might be to evaluate participants' performance while in motion. Examining performance of the Twiddler chording condition while subjects are moving through their environment would provide more practical typing rates.

The simple highlighting used during our warm-up phase could be extended to create a tutorial for typing. For this study, we allowed only letter-by-letter chords. The Twiddler also provides several default multi-character chords. Examining how to teach novices to use these MCCs and studying their effect on typing performance would be interesting. Likewise, creating a tutorial designed to improve an expert's rates is another interesting project. This would require examining potential inefficiencies in the expert's current typing and creating software to optimize the user's performance.

Finally, we are interested in creating a predictive model of typing rates for the Twiddler chording method and comparing the prediction to actual data. This could be useful for key layout optimization and chord creation.

CONCLUSION

In this paper, we presented a longitudinal study comparing multi-tap and chording methods on a HandyKey Twiddler, a mobile one-handed keyboard with a keypad layout similar to a mobile phone. Chording outperforms multi-tap typing speeds, is learned quickly, and appears to have a higher attainable maximum rate. In addition, the chording rates reported here are faster than those reported in studies on T9 and LetterWise for similar levels of expertise. With the numerous wireless messages sent currently and the predicted increase in wireless email usage, the Twiddler's one-handed chording text entry method should be seriously considered for future mobile phone designs.

ACKNOWLEDGEMENTS

Thanks to DARPA for partial support under the "Augmenting a Program Manager" seedling. Thanks also to Scott MacKenzie for his phrase set and Scott MacKenzie, William Soukoreff, Miika Silfverberg, and Shumin Zhai for their suggestions.

REFERENCES

1. L. Butts and A. Cockburn. An evaluation of mobile phone text input methods. In *Proceedings of the Australian User Interfaces Conference*, 2002.
2. S. Card, T. P. Moran, and A. Newell. *The Psychology of Human-Computer Interaction*. Lawrence Erlbaum, 1983.
3. CellularOnline. Women embracing SMS - study. http://www.mobileoffice.co.za/news_2002/100202-women_embracing_sms.htm, October 2002.
4. CellularOnline. Stats snapshot and analysis. <http://www.cellular.co.za>, 2003.
5. 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.
6. M. Lindstom. Message madness our big chance. SMH <http://www.smh.com.au>, February 2002.
7. K. Lyons. Everyday wearable computer use: A case study of an expert user. In *Proceedings of Mobile HCI 2003*, pages 61–75, 2003.
8. I. S. MacKenzie. KSPC (keystrokes per character) as a characteristic of text entry techniques. In *Proceedings of Mobile HCI 2002*, pages 195–210, 2002.
9. 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.
10. 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.
11. I. S. MacKenzie and S. X. Zhang. The design and evaluation of a high-performance soft keyboard. In *Proceedings of the SIGCHI conference on Human factors in computing systems*, pages 25–31. ACM Press, 1999.
12. Mobile CommerceNet <http://www.mobile.seitti.com>, January 2002.
13. 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.
14. M. Silfverberg, I. S. MacKenzie, and P. Korhonen. Predicting text entry speed on mobile phones. In *Proceedings of the SIGCHI conference on Human factors in computing systems*, pages 9–16. ACM Press, 2000.
15. R. W. Soukoreff. Text entry for mobile systems: Models, measures, and analyses for text entry research. Master's thesis, York University, 2002.
16. 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.
17. T. Starner. *Wearable Computing and Context Awareness*. PhD thesis, MIT Media Laboratory, Cambridge, MA, May 1999.
18. D. Wigdor and R. Balakrishnan. TiltText: Using tilt for text input to mobile phones. In *Proceedings of UIST 2003*. ACM Press, 2003.