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Touchscreen interfaces for flexible alphanumeric data entry

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Abstract:

In cases when only limited alphanumeric data must be entered, or when layout, labeling, or size may be changed, traditional keyboards may not be optimal. A series of experiments has demonstrated the usability of touchscreen keyboards. We give a summary of the existing data concerning the usability of touchscreen keyboards including typing rates for experts and novices on keyboards of various sizes. We also report on a recent study done with representative users. Results indicate that typing rates increase rapidly reaching peak performance after only 25 minutes of use. Practical suggestions for the design of such a keyboard are also presented.

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INTRODUCTION

There are many situations where typing only limited text is required. For example: cashiers at a department store sometimes enter a customer's name and address, managers of fast food franchises occasionally access information easily available from the cash registers, and users of a portable hypertext system primarily follow links but occasionally enter text for a search. Although the traditional keyboard is well known and allows rapid data entry, its physical presence and inability to adapt to special needs may be a problem. Handwriting recognition has been improving [8] but is still slow and constrained, resulting in less satisfactory and natural interfaces than expected.

For several years we have been investigating the use of touchscreens to provide alternative interfaces for traditional problems. A recent series of studies has focused on using touchscreen keyboards for limited data entry. First we present the motivation for this series of studies. Then we review some relevant research and previous studies using touchscreen keyboards. Then we present a study which investigated the effects of limited practice with a touchscreen keyboard. Finally, we discuss our conclusions and the impact these studies may have on researchers and practitioners.

MOTIVATION

Why use touchscreens?

A basic principle when designing interfaces is to use data entry techniques that match the task as closely as possible. For instance, when designing a telephone the keypad should not be organized in any way other than the well known 3x4 layout. Additional examples include using a calendar to select a particular day, or a map to choose geographic area.

Of course, some of these ideas can be applied to an interface regardless of the pointing device being used. However touchscreens provide an unrivaled sense of immediacy and an engaging sense of direct manipulation that make them highly effective for domains such as public-access information systems, museums, libraries, home automation, point of sale terminals, etc.

Why a touchscreen keyboard?

The inadequacies of traditional keyboards and the potential benefits flexible touchscreen interfaces can provide motivated this research.

Traditional keyboards may not be optimal when:

- only limited data needs to be entered,
- the system is accessible to the public (durability),
- the layout must be changed (Dvorak),
- labeling must be changed (internationalization),
- feedback must be altered (users with special needs),
- size is a concern (larger or smaller).

Flexible touchscreen interfaces provide an attractive alternative to a traditional keyboard when these circumstances are considered. Unlike traditional keyboards touchscreens have consistently been shown to be durable enough for public access systems and the layout, labeling, feedback and size can be changed dynamically to fit user demands. In addition, the touchscreen keyboard can be displayed only when needed, increasing the space available for other purposes and possibly decreasing the size of systems.

PREVIOUS RESEARCH

Target Selection

There has been a great deal of research that focused on target selection. Various strategies have been explored with many different target sizes. This research has resulted in a relatively consistent set of recommendations. The two primary selection strategies that are used are *land-on* and *lift-off*. The *land-on* strategy results in a selection at the location where users initially touch the screen if they touch a selectable target [9]. Research indicates that targets that are at least 20-25mm square can be accurately selected using this strategy [3, 6, 14]. The *lift-off* strategy allows users to drag their finger on the screen and lift it when it is correctly placed to make a selection [9, 7]. Sears & Shneiderman [11] reported favorable results using this strategy for selecting targets as small as 1.7x2.2mm. Targets 0.4x0.6mm could be selected by experienced users.

Touchscreen keyboards in a hospital

Weisner [14] conducted a study evaluating a touchscreen keyboard for use in a hospital setting which included 75 hours of mockup review by clinical and administrative staff and 680 hours of field trial testing by hospital staff. The results indicated that a QWERTY touchscreen keyboard was acceptable in this environment for entering limited quantities of alphanumeric data (names or patient IDs).

Touchscreen keyboard vs. Traditional keyboard

Sears [13] conducted a study that investigated many factors that influence the efficiency of touchscreen keyboards, and compared them with the traditional keyboard and a mouse activated keyboard. The factors investigated include the selection strategy to use (land-on vs. lift-off), size of the keys, type of feedback to provide (visual and/or audible), the angle at which to mount the touchscreen (30, 45, 70 degrees from horizontal), and the correction of biases introduced by the angle of the screen. The first phase of this study demonstrated that the standard monitor position is sub-optimal, at least when using a touchscreen. Subjects preferred the 30 or 45 degree angles, with the majority preferring 30 degrees. The second phase of this study demonstrated that biases do exist when touchscreens are mounted at an angle other than orthogonal to the users line of sight (also see [2, 4, 6]). By correcting for these biases, targets could be reduced in size without increasing errors. The final phase of this study compared a touchscreen keyboard to a standard QWERTY keyboard and a keyboard activated using a mouse. Nine computer science students typed six strings 3 to 5 five times over several days. The keyboard was mounted at a 30 degree angle and each key was 2.27cm square for a total size of 24cm between P and Q. A speed of 25 words per minute (wpm) placed the touchscreen keyboard between the standard keyboard (58wpm) and the mouse (17wpm). Although the touchscreen was not as fast as the standard keyboard it was demonstrated as a usable input device.

Effect of keyboard size on speed and errors

Another study investigated the effect of keyboard size on typing rates for touchscreen keyboards [12]. This study experimented with four touchscreen keyboards which varied from 6.8 to 24.5 cm wide (from Q to P keys). This study demonstrated the potential speed of touchscreen keyboards which varied from 9wpm (for the smallest one) to 20wpm (for the largest one) for novices and from 21 to 32 wpm for experienced users. There were no significant differences in error rates between keyboard sizes. These results indicate that although significantly slower, even the smallest keyboard (6.8cm wide, Figure 1) was usable for limited data entry, especially when space is limited. However, it is recommended that a larger keyboard be used if space is available. Once the keyboard is positioned on the screen users could be allowed to resize the keyboard if desired.

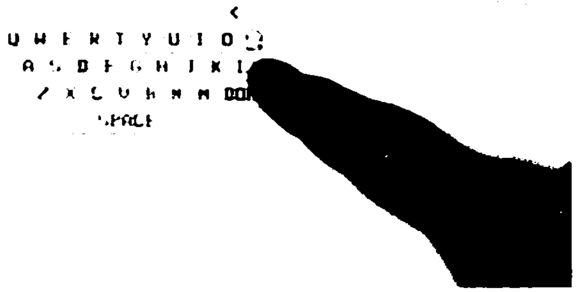

Figure 1: The smallest keyboard used in a previous study measured 6.8cm from Q to P key.

EXPERIMENT: MEASURING USER PERFORMANCE WITH LIMITED PRACTICE

The study presented in this paper attempts to measure the typing speed of representative users after limited practice. There were several goals for this study. First, subjects were selected to provide a representative sample of one set of potential users. Second, we wanted to estimate the typing speed reached after limited practice and also how long users must work with touchscreen keyboards before they achieve a significant improvement in typing rates. Third we intended to explore the use of a complete QWERTY keyboard (Figure 2) since previous studies had used an abbreviated keyboard.

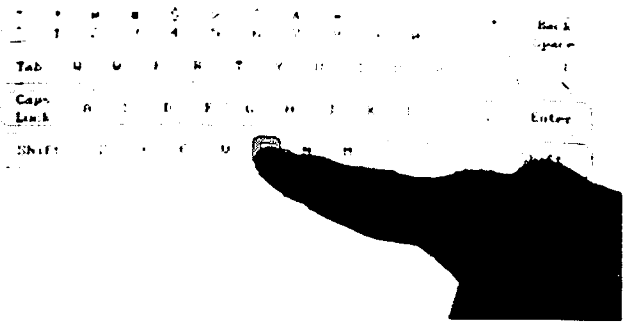

Figure 2: Complete QWERTY keyboard used in this study.

Apparatus

An NEC PowerMate 386/25 PC with a Sony Multi-scan HG monitor and Microtouch capacitive touchscreen was used. A special desk allowed the monitor to be mounted below the desk surface at 30 degrees from horizontal (Figure 3). The keyboard slid into the desk when not in use. The position of the monitor allowed subjects to rest their forearms on the desk.

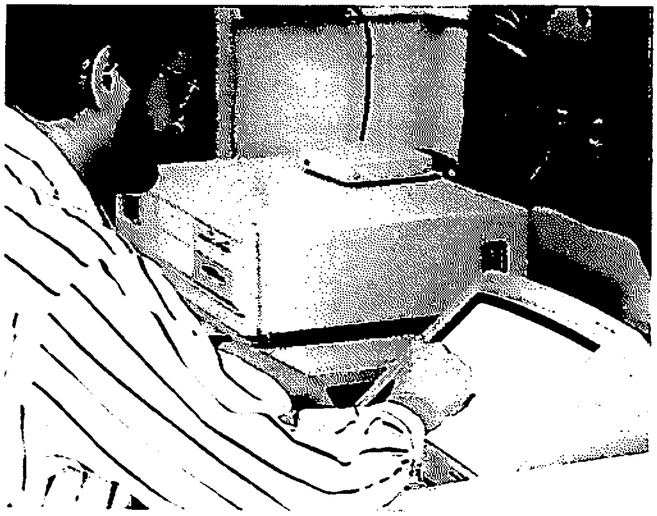

Figure 3: Desk used in this study.

The touchscreen keyboard was a complete QWERTY keyboard. Alphabetic keys measured 1.15cm per side and other keys were proportional in size. The keyboard measured approximately 22cm from one side to the other (this was chosen to be equal to the size of the medium keyboard of a previous study [12]). To shift a key (to get a capital letter or symbol above a number) users touched the shift key first, lifted their finger, and typed the key to be entered. A shift-lock key was also available for longer strings of capital letters. The lift-off selection strategy was used since keys were too small to reliably select using land-on. When a key was touched it highlighted and users could then drag their finger to a different key if needed, when the user lifted their finger the key returned to it's normal colors and soft clicking noise was heard. The shift key remained highlighted after it was touched until the next key was touched. When the shift-lock key was touched it remained highlighted until it was selected again (deactivated). The space bar was activated by touches that fell anywhere on or below it to allow for easier selection.

Subjects

Thirteen cashiers were recruited for this study. Cashiers were chosen since they represent typical potential users of systems where typing speed is an issue. They were recruited from personnel offices from several stores in the area of the University of Maryland, College Park. All subjects were familiar with, but not necessarily experienced using, the standard QWERTY keyboard. Subjects were paid for participating in the experiment which lasted approximately two hours. Subjects were instructed that speed and accuracy were both important. Bonuses were given to the two subjects with the best performances.

Design and Procedure

A single trial consisted of typing ten names followed by typing two names with addresses including numbers and punctuation (see Table 1 for a sample trial). Every trial contained exactly the same number of characters and was controlled to eliminate any extremely difficult names or addresses.

Sue Shapiro	Nadine Jacobs
Rebecca Lee	Yonina Slavin
Marica Smith	Martine Ferret
Doron Stadlan	Sophie Atwood
David Griver	Joe Cob
Joseph Garvy 586 Burton Rd. Rockville, MD 20873	Ronit Romero 603 Hyde St. Silverville, MO 69043

Table 1: A sample list of names and names with addresses users typed for a single trial.

Subjects began by typing a single trial using the standard keyboard. Data was collected to allow a comparison between the keyboard and touchscreen. Subjects were instructed in the use of the touchscreen shift key then typed a practice string followed by a set of three reference strings using the touchscreen keyboard. These strings were the same as those used in a previous study [12] in order to allow a comparison between this study and the previous study (Table 2). Next users typed ten trials of names and names with addresses using the touchscreen keyboard. There was a pause of 3 to 4 minutes between each trial. When the ten trials were completed users then retyped the practice string and the set of three reference strings typed earlier to allow a comparison of their initial performance with their performance after limited practice.

MONDAY
FIRST WE MUST START
THE QUICK BROWN FOX JUMPED OVER THE LAZY DOG

Table 2 - The three reference strings typed at the beginning and end of the touchscreen portion of this study

These tasks were calibrated in a pilot test to provide enough practice to allow an increase of the typing speed while keeping each trial reasonably short. We wanted to avoid simulating extended and strenuous use of the touchscreen keyboard since in a such cases the standard keyboard would probably be preferred.

Subjects answered several questions concerning fatigue between each trial. The time to enter each string was automatically recorded. Two types of errors were also recorded. A corrected error was any contiguous string of backspaces, and an uncorrected error was any letter (or sequence of letters) in the final string which was incorrect.

Results and discussion for 10 trials of names and names with addresses

Time. Mean times and standard deviations for users to type each of the lists using the touchscreen appear in Table 3 and Figure 4. The standard keyboard trial had a mean of 173 seconds and standard deviation of 114.4. An ANOVA with repeated measures for trial showed a significant effect F(10,120)=11.0 ($p < .001$). Tukey's post hoc HSD showed that trials four through ten were faster than trial one, and that trials seven through ten were faster than trials one through three ($p < .05$). These results indicate that subjects improved steadily, reaching their fastest performance at trial seven and then maintained that speed. Tukey's post hoc HSD also showed that there was no significant difference between the subjects performance with the touchscreen keyboard after the fourth trial and the single reference trial with the standard keyboard.

Trial	1	2	3	4	5	6	7	8	9	10
Time	287	252	253	231*	217*	217*	198**	201**	204**	196**
SD	59.4	69.5	61.0	75.3	43.8	98.9	44.7	49.3	42.5	37

Table 3 - Mean and standard deviation for time in seconds to complete a single trial using the touchscreen.

* Significantly faster than trial 1

** Significantly faster than trials 1 through 3

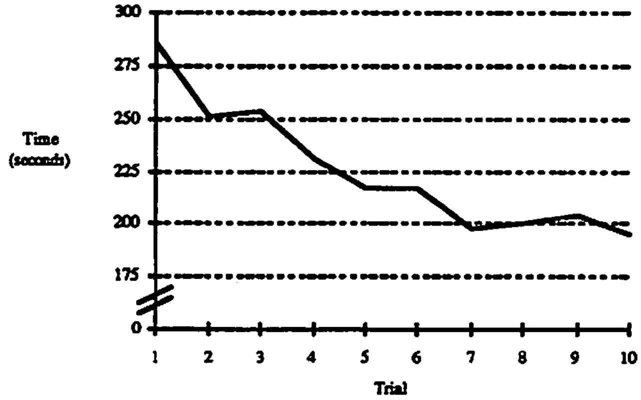

Figure 4 - Graph of mean time to complete each trial (1-10)

Errors. Means and standard deviations for corrected and uncorrected errors for trials using the touchscreen appear in Tables 4 and 5 respectively. The standard keyboard trial had means and standard deviations of 4.3 and 3.4 for corrected errors and 5.8 and 5.8 for uncorrected errors respectively. An ANOVA with repeated measures for trial was performed for both corrected and uncorrected errors. The results showed a significant effect for corrected errors F(10,120)=2.0 ($p < .05$). However, Tukey's post hoc HSD found no significant differences (for $p < .05$). The results showed no significant effect for uncorrected errors.

Trial	1	2	3	4	5	6	7	8	9	10
Errors	8.7	7.0	7.8	5.8	5.9	4.7	5.3	5.9	7.2	6.7
SD	4.9	2.9	5.4	3.7	2.4	3.6	3.8	3.6	4.2	4.8

Table 4 - Mean and standard deviation for corrected errors in a single trial using the touchscreen

Trial	1	2	3	4	5	6	7	8	9	10
Errors	5.4	4.2	6.1	3.4	4.0	3.6	3.2	3.1	2.6	4.0
SD	6.5	4.9	10.0	4.4	3.6	4.8	4.3	4.0	4.0	4.5

Table 5 - Mean and standard deviation for uncorrected errors in a single trial using the touchscreen

Discussion. The results for the 10 typing trials with the touchscreen keyboard show that subjects steadily increased in speed. After trial six, subjects reached their peak speed and maintained that speed for the remainder of the experiment. Overall, these results indicate that subjects reached their peak performance after an average of approximately 25 minutes of touchscreen keyboard use and maintained that performance throughout the experiment. Subjects quickly learned that it was not possible to "touch-type" on the touchscreen as they did on the traditional keyboard. Even with this limitation subjects quickly learned to use several fingers when using the touchscreen.

For comparison purpose we calculated the typing speed in word per minute using the same technique as the previous study [12]. On average subjects improved from 9.5wpm in the first trial to 13.8wpm in the last trial (with an average of 15.8wpm for the standard keyboard). The previous study [12] found speeds of 15.7wpm for novices with the same size keyboard. It is likely that the presence of uppercase characters, numbers and punctuation resulted in these differences.

Since subjects only performed the task with a traditional keyboard one time it is not completely fair to compare the keyboard with any touchscreen trials after the first. However, these comparisons will provide some indication of how fast touchscreen performance improves. Comparing the single standard keyboard trial and the first touchscreen trial shows a clear advantage for the standard keyboard, except for uncorrected errors where performance was similar. After approximately 18 minutes of practice subjects improved their touchscreen performance to equal their initial performance with a traditional keyboard.

Between each trial the subjects rated the fatigue they felt in their eyes, arm, fingers and overall on a scale from 1 to 10. The results show that the ratings grew slowly but never came close to the maximum value (Figure 5) which seems to indicate that fatigue was not an issue. Several subjects stated that a touchscreen keyboard would be fine to use.

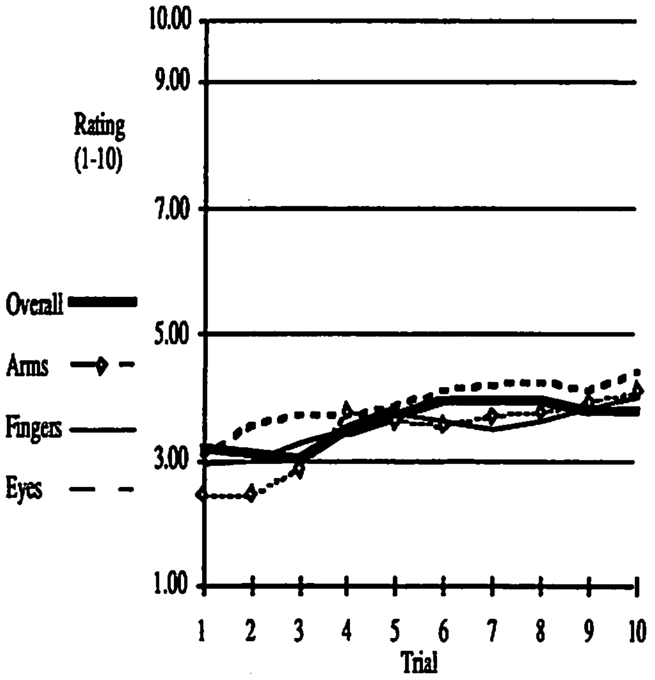

Figure 5 - Mean ratings for four fatigue questions after each of 10 trials.

Results and discussion for the reference strings

Time and Errors. The three reference strings were used to provide a supplementary measure of speed variation during the test and to compare the results of this experiment with the previous experiment. Means and standard deviations for time, corrected, and uncorrected errors for this study appear in Table 6. A t-test was performed for time, corrected, and uncorrected errors comparing the first and last touchscreen tasks. Results indicate that subject performance improved significantly in both time and corrected errors between the first and last time subjects used the touchscreen keyboard (T=5.4, p < .001 and T=3.3, p < .01 respectively). There was no significant difference for uncorrected errors.

Attempt	Time	Corrected	Uncorrected
First	65.8 (22.9)	3.0 (2.5)	0.3 (0.6)
Last	42.8 (11.2)	1.2 (1.0)	0.2 (0.4)

Table 6 - Mean time in seconds, corrected errors, and uncorrected errors to enter the two sets of three strings (standard deviations in parentheses).

Discussion. These results also show that users improve significantly given limited practice with a touchscreen keyboard. A comparison of the results with those of Sears et al. [12] indicates that the subjects in the current study performed slightly worse at the beginning of the experiment than the psychology undergraduates defined as novices in the previous study (Tables 6 and 7). The subjects in the current study improved by the end of the experiment to perform better than novices, but not as well as experienced subjects of the previous experiment (Tables 6 and 7).

Users	Time	Corrected	Uncorrected
Novice	55.2 (15.0)	3.4 (2.8)	0.4 (0.6)
Experienced	32.3 (1.4)	1.3 (1.0)	0.0 (0.0)

Table 7 - Mean time in seconds, corrected errors, and uncorrected errors for novices and experienced users to enter the set of three strings (standard deviations in parentheses) from Sears, et al. [12].

PRACTICAL CONSIDERATIONS

Smaller keyboards could not be used without the lift-off strategy which allows selection of a key only when the finger is removed from the screen. There are also some clear benefits in filtering the few last touch coordinates received before the lift-off, to avoid the inevitable small movements accompanying the lift-off.

An additional consideration is how fast the touchscreen technology is capable of responding to touches and lift-offs. Capacitive touchscreens, like the one used in this study, have been reported to have the slowest response times [5]. However, the amount of pressure necessary, amount of light transmitted through the touchscreen, and many other factors are also important [10].

The general workstation design must also be considered. Sears demonstrated that mounting the monitor at 30 degrees from horizontal was preferred by users and caused less fatigue [13]. These results were supported by Ahlström and Lenman who reported less fatigue and errors for a monitor mounted at 30 degrees from horizontal [1]. Ahlström and Lenman also demonstrated that providing an elbow rest is beneficial.

The ability to recognize multiple touches simultaneously, which is not possible yet with commercially available touchscreens, may also improve performance. Multi-touch touchscreens would allow more natural use of a shift key as well as faster typing.

CONCLUSION

The standard mechanical keyboard remains the input device of choice when large quantities of alphanumeric data needs to be entered. However, when data entry is limited, a keyboard is not practical, or flexibility is a requirement (alternative layouts or languages), a touchscreen or stylus keyboard may prove useful.

We have provided a benchmark for typing speed that may help designers decide how appropriate this technology is for their application. We have also shown that typing speed increases rapidly reaching peak speeds after only 25 minutes of practice. A flexible touchscreen interface provides easy solutions to many problems. Although custom interfaces will be preferred for special types of data (e.g. telephone numbers, times, dates, compass directions, colors) there will always be situations when limited quantities of free form text must be entered. In these situations a touchscreen keyboard can be used.

In addition, touchscreen interfaces are compatible with many of the emerging pen-based systems. Using an appropriate touchscreen technology allows any stylus to be used. This allows users to take advantage of the additional familiarity of pen-based interfaces, but does not require them to have a stylus to work. Proponents of both technologies should take advantage of the research in these closely related areas. In conclusion, we encourage designers to consider the flexibility of touchscreens when designing interfaces.

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NOTE

A video demonstrating the use of touchscreen keyboards of various sizes as well several other touchscreen interfaces is available from the Human-Computer Interaction Lab.

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