INTRODUCTION

There are many situations where typing limited quantities of 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 improved (Pittman, 1991) but is still slow and constrained, resulting in less satisfactory and less natural interfaces than expected. For several years we have been investigating the use of touchscreens to provide alternative interfaces for traditional tasks (Sears, Plaisant, and Shneiderman, 1992). A recent series of studies has focused on using touchscreen keyboards for limited data entry.

In most situations, the traditional mechanical keyboard remains the alphanumeric data entry device of choice. However, when users only occasionally enter limited quantities of alphanumeric data, a traditional mechanical keyboard may not be optimal if one of the following is true:

- the system is accessible to the public (durability),
- the layout must be changed (QWERTY vs. Dvorak),
- the character set must be changed (internationalization),
- feedback must be altered (users with special needs), or
- size is a concern (notebook or palmtop computers).

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, character set, 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 Studies

There has been a great deal of research that focused on target selection. Various strategies have been explored with targets as small as 0.4x0.6 mm (Sears and Shneiderman, 1991). This research has resulted in a relatively consistent set of recommendations. The *land-on* strategy only allows users to make selections where their fingers first touch the screen. Research indicates that targets 20 mm square or larger can be accurately selected using this strategy (Beringer, 1989; Hall et al., 1988; Weisner, 1988). The *lift-off* strategy allows users to touch the screen, drag their finger to adjust the selection, and lift it once it is in the correct location to make the selection (Murphy, 1987; Potter et al., 1989). This strategy allows the selection of targets as small as 1.7x2.2 mm (Sears and Shneiderman, 1991).

Summary of First Keyboard Study: Touchscreen keyboard design and comparisons with a mouse and traditional keyboard

This study investigated many factors that influence the efficiency of touchscreen keyboards, and compared them with the traditional keyboard and a mouse activated keyboard (Sears, 1991). Ten subjects participated in the first phase of the study which demonstrated that the standard monitor position (approximately 75 degrees from horizontal) is sub-optimal, at least when using a touchscreen.

Subjects preferred using touchscreens mounted at 30 or 45 degrees from horizontal, with the majority preferring 30 degrees. These results were supported by Ahlström, Lenman and Marmolin (1991) who reported less fatigue and errors for a touchscreen mounted at 30 degrees from horizontal. They also demonstrated that providing an elbow rest is beneficial.

The second phase of this study demonstrated that biases exist when touchscreens are mounted at an angle other than perpendicular to the users line of sight (also see Beringer and Peterson, 1985; Beringer and Bowman, 1989; Hall et al., 1988). Using a monitor mounted at 30 degrees from horizontal, fourteen subjects consistently touched below targets regardless of the location on the screen. This bias can be explained by the small amount of parallax introduced by the touchscreen. Subjects also consistently touched to the left of targets that were on either side of the screen.

The final phase of this study compared a touchscreen keyboard to a standard QWERTY keyboard and a keyboard activated using a mouse with novice users and no practice. The touchscreen and mouse used an abbreviated QWERTY keyboard (alphabetic, done, backspace, and space keys). The touchscreen was mounted at 30 degrees from horizontal and software was written to correct for all biases discovered in the second phase of the study. Nine subjects typed six short strings with a total of 138 characters. A speed of 25 words per minute (wpm) placed the touchscreen keyboard between the standard keyboard (58 wpm) and the mouse (17 wpm). Although the touchscreen was not as fast as the standard keyboard it was demonstrated as a usable input device.

Summary of Second Keyboard Study: Effect of keyboard size on performance

This study investigated the effect of keyboard size on typing rates for touchscreen keyboards (Sears, Revis, et al., 1992). This study explored four touchscreen keyboard sizes which varied from 6.8 to 24.6 cm wide (from Q to P keys) (Figure 1).

Figure 1: The smallest keyboard used in a previous

study measured 6.8 cm from Q to P key.

Once again, abbreviated QWERTY keyboards were used. Twenty-four novice and four experienced users typed a series of three strings with a total of sixty-nine letters. This study demonstrated the potential speed of touchscreen keyboards which varied from 10 wpm (for the smallest keyboard) to 20 wpm (for the largest keyboard) for novices and from 21 to 32 wpm for experienced users. There were no significant differences in the number of errors in the final strings users typed. A comparison of the results of the novices and experienced users illustrates the benefits of experience. While experienced users were 60% faster than novices on the largest keyboard, they were 113% faster than novices on the smallest keyboard indicating the increased importance of practice for smaller keyboards.

MEASURING USER PERFORMANCE WITH LIMITED PRACTICE

The study presented in this paper attempts to measure the typing speed of more 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 determine 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 abbreviated keyboards.

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. The keyboard slid into the desk when not in use (Figure 3).

Figure 3: Desk used in this study showing the touchscreen mounted at a 30 degree angle with an arm rest.

The touchscreen keyboard was a complete QWERTY keyboard. Alphabetic keys measured 1.14 cm per side for a total keyboard size of 13.2 cm between the P and Q keys (this was chosen to be equal to the size of the medium keyboard of the previous study by Sears, Revis, et al., (1992)). Other keys were proportional in size. To shift a key (to get a capital letter or number) users touched the shift key first, lifted their finger, and then typed the key to be shifted. 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 be reliably selected using land-on strategy. When a key was touched it highlighted, users could then drag their finger to a different key if desired, 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.

<u>Subjects</u>

Thirteen cashiers were recruited for this study. Cashiers were chosen since they represent one set of potential users of systems where touchscreen keyboards may be useful and speed remains important. They were recruited from personnel offices from several stores in the College Park Maryland area. All subjects were familiar with, but not necessarily experienced using, the standard QWERTY keyboard. Subjects were paid $20 for participating in the experiment which lasted approximately 2 hours. Subjects were instructed that speed and accuracy were both important and that bonuses of $20 and $15 would be given to the two best performances.

<u>Design and Procedure</u>

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

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Sue Shapiro              Nadine Jacobs
Rebecca Lee              Yonina Slavin
Marica Smith             Martine Ferret
Doron Stadlan            Sophie Atwood
David Griver             Joe Cob

Joseph Garvy             Ronit Romero
586 Burton Rd.           603 Hyde St.
Rockville, MD  20873     Silverville, MO  69043
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Table 1: A sample list of names and names with addresses users typed for a single trial.

Subjects were instructed in the use of the 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 (Sears, Revis, et al., 1992) and were used 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 break of about 3 to 4 minutes between each trial. When all ten trials were completed users then retyped the practice string and set of three strings typed earlier to allow a comparison of their initial performance with 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 the study.

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

Ten trials of names and addresses

Time. Mean times, mean+standard deviation, and mean-standard deviation for users to type each of the lists appear in Figure 4. An ANOVA with repeated measures for trial showed a significant effect $F(9,108)=13.2$ ($p < .001$). 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 ($p < .005$). These results indicate that subjects improved steadily, reaching their fastest performance at trial seven and then maintained that speed.

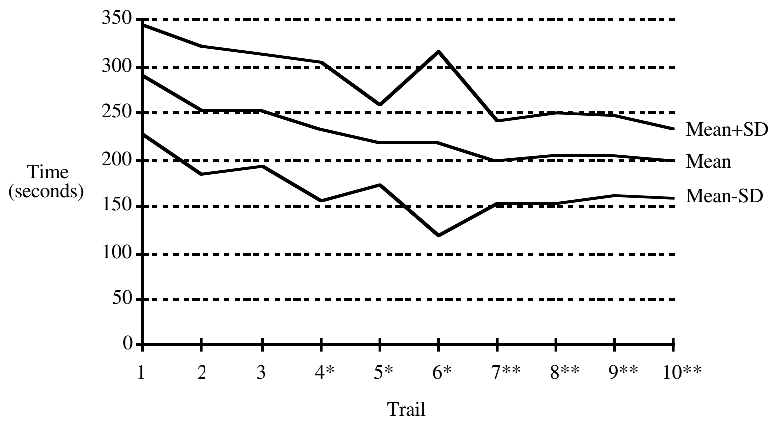

Figure 4 - Graph of mean time to complete each trial. Mean+SD and Mean-SD are also plotted.
* Significantly faster than trial 1
** Significantly faster than trials 1 through 3

Errors. Means and standard deviations for the number of corrected and uncorrected errors appear in Table 3. Any sequence of consecutive backspaces is considered one corrected error. Any incorrect letters (or sequence of letters) in the final string is considered one uncorrected error. Two ANOVAs with repeated measures for trial were performed, one for corrected errors and one for uncorrected errors. The results showed no significant effects of trail on either type of error.

Trial	**1**	**2**	**3**	**4**	**5**
Corrected Errors	8.7	7.0	7.8	5.8	5.9
SD	4.9	2.9	5.4	3.7	2.4
Uncorrected Errors	5.4	4.2	6.1	3.4	4.0
SD	6.5	4.9	10.0	4.4	3.6

Trial	**6**	**7**	**8**	**9**	**10**
Corrected Errors	4.7	5.3	5.9	7.2	6.7
SD	3.6	3.8	3.6	4.2	4.8
Uncorrected Errors	3.6	3.2	3.1	2.6	4.0
SD	4.8	4.3	4.0	4.0	4.5

Table 3 - Mean and standard deviation for corrected and uncorrected errors for each trial.

Discussion. The results for the ten trials show that subjects steadily increased in speed. On trial seven, subjects reached their peak speed, 30% faster than their first trial, 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. Subjects quickly learned that it was not possible to "touch-type" on the touchscreen as they might on a traditional keyboard and adopted various strategies using several fingers.

On average subjects improved from 9.5 wpm (assuming 5 characters per word) in the first trial to 13.8 wpm in the last trial. The previous study (Sears, Revis, et al., 1992) found speeds of 16.5 wpm for novice college students with the same size abbreviated keyboard. It is likely that the presence of uppercase characters, numbers, and punctuation resulted in these differences.

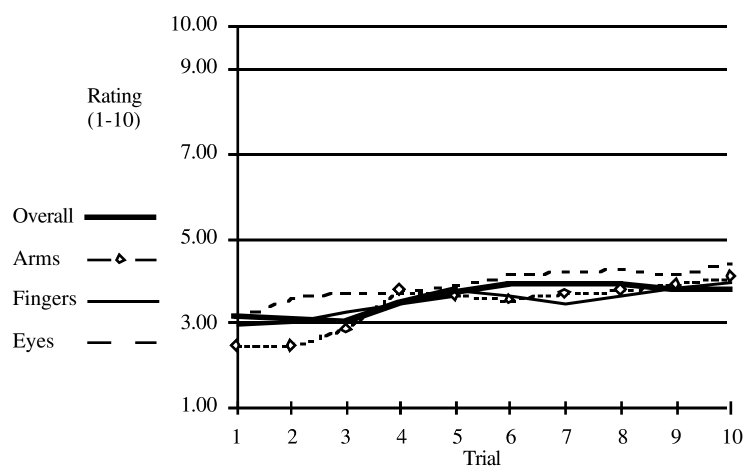

Figure 5 - Mean ratings for four fatigue questions after each of 10 trials.

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, which seems to indicate that fatigue was not a factor in this study (Figure 5). Several subjects stated that a touchscreen keyboard would be fine to use.

<u>Reference Strings</u>

<u>Time and Errors</u>. The three reference strings were used to provide a supplementary measure of speed increase during the test and also 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 4. A t-test was performed for time, corrected, and uncorrected errors. Results indicate that performance improved significantly in both time and corrected errors between the first and last time subjects used the touchscreen keyboard ($T=5.374$, $p < .001$ and $T=3.247$, $p < .01$ 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 4 - Mean time, corrected errors, and uncorrected errors to enter the two sets of three strings (standard deviations in parentheses).

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 5 - Mean time, corrected errors, and uncorrected errors for novices and experienced users to enter the set of three strings (standard deviations in parentheses) from Sears, Revis, et al. (1992).

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, Revis, et al. (1992) indicates that at the beginning of the experiment subjects in the current study performed slightly worse than the novices in the previous study (Tables 4 and 5). By the end of the current study subjects improved to perform better than the novices, but not as well as the experienced subjects in the previous experiment (Tables 4 and 5).

CONCLUSIONS

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 users reached their fastest performance during this experiment after only 25 minutes of practice. Although performance did not improve between the seventh and tenth trials, additional practice may result in even faster performance. A 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) (Sears, Plaisant, and Shneiderman, 1992) there will always be situations when limited quantities of free form text must be entered. In these situations a touchscreen keyboard can be used.

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NOTE: A video showing the touchscreen keyboards, “Open House ‘91”, is available from the Human-Computer Interaction Lab, A.V. Williams Building, University of Maryland, College Park, MD 20742.