EVALUATION OF TYPING KEY LAYOUTS FOR STYLUS INPUT

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We studied initial user performance with and preference for alternative typing-key layouts for typing with a stylus. Previous analyses have indicated that, after asymptotic practice with this kind of typing, users should type fastest with certain nonstandard layouts. Although asymptotic performance is important in selecting a layout, it also is important to evaluate initial performance with and preference for layouts. Twelve participants used paper models of six different layouts to type four sentences. The layouts were the QWERTY, Dvorak, standard alphabetic, square alphabetic, and two digraph-based layouts. Performance and preference favored the QWERTY over the other layouts. The square alphabetic layout took a distant second place. QWERTY should be a product's default layout even if users can type with only a single finger or a stylus. If the QWERTY layout is not feasible, designers should consider using the square alphabetic layout for limited typing or a digraph-based layout for extensive typing.

INTRODUCTION

For hand-held tablets and portable computers (including pen-based systems), it is important to evaluate the best arrangement of keys for typing layouts when users type with one finger or a stylus. Also, improved layouts for one-at-a-time character selection could help the population of computer users whose special needs limit them exclusively to this style of typing. The purpose of this study was to investigate initial user performance with and preference for alternative typing-key layouts when users are restricted to typing with a single finger or a stylus.

Lewis, Kennedy, and LaLomia (1999) developed a computerized human-performance model, based on Fitts' Law and the frequency matrix for English-language digraphs, for evaluating alternative layouts. They used a path-analysis program to help determine which letters should occupy which positions to minimize the distance between commonly occurring pairs of letters in both a conventional (roughly 3 x 10) and a square (roughly 5 x 5) key matrix. Getschow, Rosen, and Goodenough-Trepagnier (1986) also developed a square digraph-based key layout, using a variant of a simple assignment procedure (known as a "greedy" algorithm).

Table 1 shows the results of comparing predicted asymptotic performance (error-free performance after extensive practice) for several layouts to the conventional QWERTY layout using the model developed by Lewis, Kennedy, and LaLomia (1999). The value in the "Prediction" column is the value that the human-performance model returned for the layout, with smaller numbers interpreted as faster throughput. Table 2 shows the six different layouts.

For many handheld products, however, users might perform only casual typing, never achieving asymptotic performance. For this reason, even though asymptotic performance can be important in selecting a typing-key layout, it also is important for designers to evaluate users' initial preference for and performance with the layouts.

The purpose of this study was to obtain preference and performance data for the initial use of these six typing-key layouts to help designers decide which layouts to include in their products.

Table 1. Summary of Predictive Human-Performance Model Analyses (Lewis, Kennedy, and LaLomia, 1999)

Key Layout	Arrangement	Prediction	Percentage Improved/ Degraded Relative to QWERTY
Getschow/ Rosen/ Goodenough-Trepagnier	Square	1594	+31%
Lewis/ Kennedy/ LaLomia	Square	1699	+27
Alphabetic	Square	2006	+13
QWERTY	Conventional	2318	0
Alphabetic	Conventional	2389	- 3
Dvorak	Conventional	2777	-20

Table 2. Six Typing Key Layouts

QWERTY Layout

```
1 2 3 4 5 6 7 8 9 0
 Q W E R T Y U I O P
  A S D F G H J K L !
   Z X C V B N M , . ?
     ---SPACEBAR---
```

Dvorak Layout

```
 1 2 3 4 5 6 7 8 9 0
! ? , . P Y F G C R L
   A O E U I D H T N S
    Z Q J K X B M W V
      ---SPACEBAR---
```

Table 2. Six Typing Key Layouts (cont.)

Square Alphabetic Layout

```
6 7 8 9 0
1 2 3 4 5
A B C D E !
F G H I J ?
K L M N O ,
P Q R S T .
U V W X Y Z
-SPACEBAR-
```

Conventional Alphabetic Layout

```
1 2 3 4 5 6 7 8 9 0
 A B C D E F G H I J
  K L M N O P Q R S !
   T U V W X Y Z , . ?
      ---SPACEBAR---
```

Lewis/Kennedy/LaLomia Digram-Based Layout

```
6 7 8 9 0
1 2 3 4 5
Q R W X Y !
L U A O F ?
T H E N G ,
V D I S P .
B C M J K Z
-SPACEBAR-
```

Modified Getschow/Rosen/Goodenough-Trepagnier Diagraph-Based Layout

```
6 7 8 9 0
1 2 3 4 5
F Q U S P !
C O T H M ?
G I E W X ,
K N A R B .
J D L Y V Z
-SPACEBAR-
```

METHOD

Participants

Twelve people participated in the study. Two were IBM employees, and ten were from a temporary-help agency. Five participants were male, and seven were female. One participant was left-handed. All had experience with QWERTY keyboards, with self-reported typing speeds ranging from 10 to 65 words per minute.

Materials

We made paper models of the six typing-key layouts. The keys were 10 mm horizontally and 13 mm vertically, with 3-mm interkey spacing. We randomly selected 24 sentences from the Brown Corpus (Francis and Kucera, 1964), arranged in six sets of four sentences, to use as stimuli.

Procedure

We used a pair of Latin squares to counterbalance immediate sequential effects for both typing-key layouts and sentence sets, and to counterbalance the pairing of typing-key layouts and sentence sets (Lewis, 1989; Lewis, 1993). Participants typed test sentences on the paper models according to the experimental design, using a stylus that left no mark. Participants were instructed not to worry about capitalization, and to type as fast and accurately as possible. If they thought they made a mistake, they were to type the correct letter and continue. After using each layout, participants completed a rating form for that layout. Finally, they arranged the layouts in order from most to least preferred.

The evaluation procedure used in this experiment did not allow for the estimation of typing errors with the layouts, but any observed differences in typing speeds could be indicative of participant control over tapping rates, presumably to achieve an internal accuracy criterion.

RESULTS

Performance

For each sentence that participants typed, we calculated the typing speed in characters per second (CPS). A two-factor (typing-key layout by sentence trial) analysis of variance indicated significant effects of typing-key layout ($F(5,55)=118.9$, $p<.0001$) and sentence trial ($F(3,33)=29.2$, $p<.0001$), but no significant interaction ($F(15,165)=1.1$, $p=.38$) (see Figure 1). A post-hoc Newman-Keuls test ($\alpha=.10$) showed that typing with the QWERTY layout was faster than with all other layouts, and that typing with the square alphabetic layout was faster than with the remaining four layouts, which were not significantly different from each other.

A planned comparison of the square versus conventional alphabetic layouts showed that the square alphabetic layout was faster ($F(1,11)=10.3$, $p=.008$), with no layout by trial interaction. The square alphabetic layout started faster and stayed faster than the conventional alphabetic layout. A planned comparison of the Lewis et al. digraph-based layout versus the Getschow et al. digraph-based layout showed no significant performance differences. On average, typing with the QWERTY layout was 75% faster than typing with the square alphabetic layout, and was almost twice as fast as typing with the other four layouts.

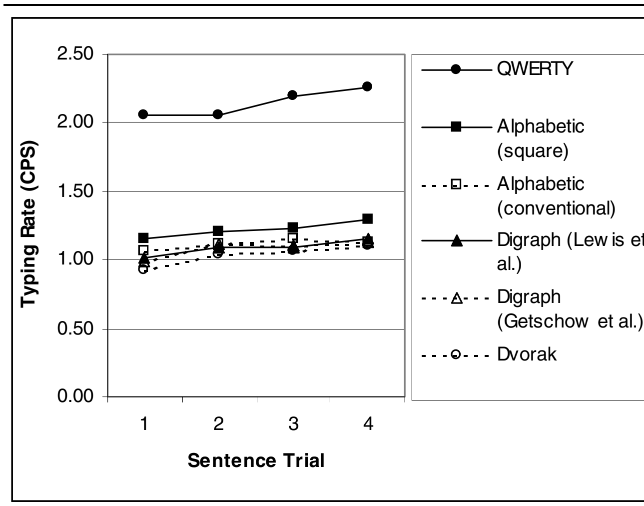

Figure 1. Typing Key Layout by Sentence Trial

Preference: Rating Data

The rating for each layout was the mean of six items on a Key-Layout Rating Form, which participants completed after typing sentences with each layout. An analysis of variance indicated a significant main effect of layout ($F(5,55)=10.4$, $p<.0001$). A Newman-Keuls post-hoc comparison ($\alpha=.05$) showed that participants rated the QWERTY layout as significantly better than all other layouts, and rated the square alphabetic layout as better than the Getschow/Rosen/Goodenough-Trepagnier digraph-based layout. A planned comparison of the digraph-based layouts showed that participants rated the Lewis/Kennedy/LaLomia layout as better than the Getschow/Rosen/Goodenough-Trepagnier layout ($t(11)=2.30$, $p=.04$). As shown by a planned comparison of the alphabetic layouts, participants rated the square layout more favorably than the conventional layout ($t(11)=2.55$, $p=.03$).

Preference: Ranking Data

After participants typed sentences with all the layouts, they ranked them from most-preferred to least-preferred. Analysis with a Friedman test showed a significant effect of layout ($\chi^2(5)=30.1$, $p<.0001$). A post-hoc analysis based on Friedman rank-averages ($\alpha=.10$) indicated that participants significantly preferred the QWERTY layout, and the remaining rank averages were not significantly different. A planned binomial comparison between the digraph-based layouts showed that participants significantly preferred the Lewis/Kennedy/LaLomia layout to the Getschow/Rosen/Goodenough-Trepagnier layout ($p<.05$). A similar comparison between the alphabetic layouts was not significant ($p>.10$).

DISCUSSION AND RECOMMENDATIONS

The strongest finding from this research is the initial superiority of the QWERTY layout to all other layouts, despite the theoretical projection that other layouts should be superior to the QWERTY layout after extensive (asymptotic) practice when users type with one finger or a stylus (Lewis, Kennedy, and LaLomia, 1999). In the initial stages of experience with these layouts, this result is reasonable because the population of computer users (in fact, the population-at-large) has strongly overlearned the QWERTY layout. For example, previous research (Francas, Brown, and Goodman, 1983) showed that participants, regardless of the extent of their keyboard experience during the previous year, typed about 80% faster with a reduced-size QWERTY keyboard than a reduced-size conventional alphabetic keyboard. In the current study, participants typed about twice as fast with the QWERTY layout than with the conventional alphabetic layout, the Dvorak layout, and both digraph-based layouts. The QWERTY layout was about 75% faster than the square alphabetic layout. It is clear from this and other related research (e.g., Soukoreff and MacKenzie, 1995) that the QWERTY layout is the appropriate default for consumer products that require a keyboard, even a reduced-size keyboard. The alternative layouts become reasonable design choices only when a device's form factor cannot support a QWERTY layout.

Participants typed faster with the square alphabetic layout than all other layouts except the QWERTY layout. Participants also rated the square alphabetic layout better than the conventional alphabetic layout. The participants' comments suggested that the basis of this preference was that the square layout made it easier to find and reach consecutive letters than the conventional layout. Therefore, product developers should provide square rather than conventional alphabetic arrangements.

Although performance with the two digraph-based arrangements was about equal, participants significantly preferred the Lewis/Kennedy/LaLomia layout to the Getschow/Rosen/Goodenough-Trepagnier layout. Participants' comments indicated that the basis of this preference was that the Lewis/Kennedy/LaLomia layout more clearly suggested the advantages of a digraph-based layout. According to our human-performance model, the Getschow/Rosen/Goodenough-Trepagnier layout should allow users to type slightly (about 4%) faster than the Lewis/Kennedy/LaLomia layout after practice to asymptote. Balancing the output of our human performance model and user preference in this experiment, it appears that either digraph-based layout would be a reasonable design choice for those situations in which a digraph-based layout is appropriate.

For now, it is not clear how much a user would have to type with the square alphabetic layout or a digraph-based layout to equal initial performance with the QWERTY layout. The extent of additional typing to achieve asymptotic performance with the alternative layouts is also unknown (although it is clear that four sentences is not enough). Knowledge of both of these issues is important for determining the potential usefulness of these alternative layouts. However, until this information is available, product developers should offer both the square alphabetic and digraph-based layouts as alternatives to the default QWERTY layout when a product allows this flexibility, especially when the keyboard is provided on a touch-screen or pen-based system.

The evaluation procedure used in this experiment did not allow for the estimation of typing errors with the layouts, but the typing speed results indicate that participants lowered their typing speed when using unfamiliar layouts, presumably to achieve an internal accuracy criterion when using these unfamiliar layouts. Future work with these layouts should include evaluative procedures that allow estimation of error rates as well as estimates of typing speeds.

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REFERENCES

Francas, M., Brown, S., and Goodman, D. (1983). Alphabetic entry procedure with small keypads: Key layout does matter. In *Proceedings of the Human Factors Society 27th Annual Meeting* (pp. 187-190). Santa Monica, CA: Human Factors Society.

Francis, W. N., and Kucera, H. (1964). Brown corpus manual. Providence, RI: Brown University. (Also, see: http://www.hit.uib.no/icame/brown/bcm.html)

Getschow, C. O., Rosen, M. J., and Goodenough-Trepagnier, C. (1986). A systematic approach to the design of a minimum distance alphabetical keyboard. In *Proceedings of the RESNA 9th Annual Conference* (pp. 396-398). Minneapolis, MN: RESNA.

Lewis, J. R. (1989). Pairs of Latin squares to counterbalance sequential effects and pairing of conditions and stimuli. In *Proceedings of the Human Factors Society 33rd Annual Meeting* (pp. 1223-1227). Santa Monica, CA: Human Factors Society.

Lewis, J. R. (1992). *Typing-key layouts for single-finger or stylus input: Initial user preference and performance* (Tech. Report 54.729). Boca Raton, FL: International Business Machines.

Lewis, J. R. (1993). Pairs of Latin squares that produce digram-balanced Greco-Latin designs: A BASIC program. *Behavior Research Methods, Instruments & Computers*, *25*, 414-415.

Lewis, J. R., Kennedy, P. J., and LaLomia, M. J., (1999). Development of a digram-based typing key layout for single-finger/stylus input. In *Proceedings of the Human Factors and Ergonomics Society 43rd Annual Meeting* (in press). Santa Monica, CA: Human Factors Society.

Soukoreff, W. R., and MacKenzie, I. S. (1995). Theoretical upper and lower bounds on typing speed using a stylus and soft keyboard. *Behaviour and Information Technology*, *14*, 370-379.