Interlaced QWERTY – Accommodating Ease of Visual Search and Input Flexibility in Shape Writing

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ABSTRACT
Shape writing is an input technology for touch-screen mobile phones and pen-tablets. To shape write text, the user spells out word patterns by sliding a finger or stylus over a graphical keyboard. The user's trace is then recognized by a pattern recognizer. In this paper we analyze and evaluate various keyboard layouts, including alphabetic, optimized (ATOMIK), QWERTY, and interlaced QWERTY for shape writing. The goodness of a layout for shape writing has two aspects. For users' initial ease of use the letters should be easy to visually locate. For long term use, however, the layout should maximize the imprecision tolerance and writing flexibility for all words. We present empirical studies for the former and mathematical analyses for the latter. Our results led to a new layout, interlaced QWERTY, which offers excellent separation of word shapes, while still maintaining a low visual search time. Many of the findings in our study also apply to traditional soft keyboards tapped with a stylus or one finger.

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Keyboard, text input, visual search, shape writing, mobile

ACM Classification Keywords
H5.2. Information interfaces and presentation: input devices and strategies; I5.5. Pattern recognition: interactive systems

INTRODUCTION

Shape writing is a text entry method for touch-screen enabled devices. To shape write text the user slides a stylus (or finger) over a graphical keyboard. ShapeWriter recognizes the user's trace on the keyboard and pattern matches it against a set of word shapes that are created from a lexicon. Figure 1 shows an ideal trace on the keyboard (left) and a user's input trace that will be recognized as the word *the* (right) [3].

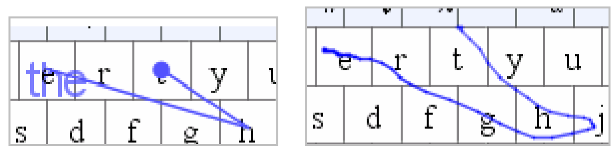

Figure 1. The ideal word shape for *the* (left) and a user's trace for the word *the* (right). Adapted from [2].

Since shape writing is symbiotic with a graphical keyboard, the choice of layout of the keys is likely to significantly influence its quality. For example, QWERTY, ATOMIK, and an alphabetic layout are all compelling possibilities, but for very different reasons. QWERTY is familiar to most computer users and hence should be the easiest in the beginning stage of shape writing. ATOMIK (Figure 2) is optimized for movement efficiency and is also tuned with an A to Z tendency to improve visual search [9]. An alphabetic layout has a familiar order to go by hence might be subjectively more acceptable to many users. More generally, the goodness of a layout for shape writing has two aspects. For users' initial ease of use it has to be very easy for the user to locate individual letters. For optimal long term use, however, the layout should maximize the imprecision tolerance for all words and enable "sloppy" writing. The current work is divided accordingly. We first empirically investigate the ease of initial visual search with various layouts. We then use computational methods to study the error tolerance of each layout. Combining the two we introduce a new layout – interlaced QWERTY.

INITIAL VISUAL SEARCH PERFORMANCE

Two factors may influence the ease of visual search on a layout; familiarity based on previous experience (which means QWERTY to most people) and a strong clue to where each letter is likely to be at. The latter factor naturally leads to exploration of alphabetic layouts. The best known study on alphabetic layout (of a physical keyboard) is probably [6]. Norman and Fisher expected, but did not find, that novice users typed faster on such a keyboard than on a standard QWERTY keyboard. The key problem with an alphabetic keyboard, they concluded, was that the keys were laid out sequentially in multiple rows. The location of a key depended on the length of each row – the break point from which the next letter had to start at the left end of the keyboard again.

More recent studies have focused on stylus keyboard layouts tapped with one finger or a pen. In Lewis and colleagues' study [4], novice users typed random test sentences on "paper models" of QWERTY, Dvorak Simplified Keyboard (DSK), a 3 row alphabetic layout, a 5 × 5 square alphabetic layout (with 6 characters in the last row), and two layouts optimized for movement reduction including a layout modified from one of the earliest optimized stylus keyboards [1]. They found that on average, in comparison to QWERTY novice users took about 75% longer on the 5 × 5 alphabetic layout, and almost 100% longer on any of the other four layouts.

In Mackenzie and colleague's study [5], novice users tapped the pangram "The quick brown fox jumped over the lazy dog" on paper images of, among others, QWERTY, DSK, a 13 (row) × 2 (column) vertical alphabetic layout, and an layout optimized for movement distance (FITALY). Their results show that in comparison to QWERTY, novice users took 137% longer on DSK, 90.6% longer on the vertical alphabetic layout, and 146% longer on FITALY.

The previous studies do not offer a comparison between QWERTY and ATOMIK. Unlike the previous optimized layouts that were exclusively focused on movement reduction, ATOMIK was also tuned towards an A to Z tendency from upper left to lower right corner (Figure 2). Smith and Zhai [7] reported that the alphabetical tuning helped novice performance. We are interested in how such an ATOMIK layout compares with QWERTY or an alphabetic layout in relative visual search performance.

Study 1: Initial Visual Search Performance

Method

Three layouts were printed on paper, together with a list of words to be found. The participants were asked to visually (or with the assistance of a pen) locate the letters in the listed words one letter after another. When all the letters in a word were found, the word was crossed out and the participant moved to the next letter. The completion duration of finding all the words with each layout was timed. 12 participants, all daily users of physical QWERTY keyboard users but none familiar with other keyboard layout tested, were asked to complete the task with each layout as fast as possible, but no incentive was given to particularly fast performance or cheating. Participation was voluntary with no compensation. The participants were told to give their preference and comments based on the task after completing all the tests.

The three layouts tested were QWERTY, a version of ATOMIK, and a version of a multi-row alphabetic layout (see Figure 2). The vowels were highlighted in the alphabetic and ATOMIK layout. The key size in all layouts was kept at 8.5 mm × 8.5 mm. The order of the layout tested was balanced across participants in a Latin square pattern.

A total of 19 words were printed in the list on the same page as the layout. The list of words were "*the and you that is in of know not they get have were are bit quick fox jumps lazy*". This list was selected according to three factors that had not been considered together in the previous literature. First, all letters from A to Z were covered in the list. Second, the number of occurrence of each letter should be approximately proportional to the letters' frequencies in common English. Third, the letter transitions should be representative of natural English. Obviously it is impossible to meet all three criteria accurately in a short list of words.

Figure 2. Top-left: alphabetic layout, top-right: ATOMIK, bottom: QWERTY.

The selection of the final words in the test was based on two sources. To reflect the most common letter transitions the first source was the top 20 most frequent words on the Zips' law curve in the spoken English corpus of the American National Corpus. In order to cover all letters in English, the second source was words in the pangram "The quick brown fox jumps over the lazy dog". The list was then manually adjusted to be as short as possible while meeting the three criteria as closely as possible. The resulting 19 words cover all letters in English and have a quite high correlation in letter frequency with the spoken ANC corpus ($R^2 = 0.88$).

Results

On average, the ATOMIK layout optimized for movement efficiency took the longest average time at this very initial stage of exposure (mean 83 s). The alphabetic layout took less time (mean 70 s) and the QWERTY layout took the least time (mean 47 s). The mean difference across the layouts was statistically significant: $F_{2, 22} = 31.1$, p <0001. All pair-wise comparisons were also significant by Fisher's PLSD tests; p <0.001.

Percentage wise, the alphabetic layout took 48.9% longer than the QWERTY layout, and the optimized layout took 76.6% longer than QWERTY, both magnitudes were smaller than what were reported in the previous studies of alphabetic layouts and optimized layouts relative to QWERTY.

The participants did not find the task very hard overall, but the relative ratings on difficulty of locating letters on the three layouts were significantly different $F_{2, 22} = 24$, $p < 0.0001$. On the scale of 1 (Easy) to 7 (Hard) participants rated QWERTY 1.9 (.67), ATOMIK 4.8 (1.66) and Alphabetic 4.1(1.02) respectively. Pair-wise, both the alphabetic and the ATOMIK layout was rated more difficult than the QWERTY layout (Fisher's PLSD, $p < 0.0001$) but the difference between the alphabetical and ATOMIK was not significant ($p = 0.1$).

Discussion

As expected locating letters on an ATOMIK layout took longer time (about 77%) and was viewed as more difficult on average than on the well learned QWERTY, although the difference was smaller than other optimized layouts to QWERTY as reported in the literature [4][5]. The alphabetic layout took less time than ATOMIK but still much more time (about 50%) than QWERTY. It was also rated significantly more difficult than QWERTY. There are many reasons for this, such as the breaking rows argument [6]. Furthermore, the alphabet is not necessarily a rapid and strong clue to locating letters. An informal quick test with a few people showed that even a one line A to Z layout was not as fast as QWERTY.

It appears that for initial ease of use QWERTY is a strong candidate as a graphical keyboard, at least in countries where QWERTY is the standard physical keyboard. This would be, however, an unfortunate default because for single finger and stylus use, either in tapping or in shape writing, QWERTY is rather poor in the long run due to its left and right alternation design [8]. Further, in shape writing QWERTY introduces many conflicting word shapes (see the Computational Study section later in this paper). This brings us to our design phase – can a new layout be derived from QWERTY that mitigates these problems?

Study 2: Visual Search on Interlaced QWERTY

We asked whether it was possible to change a QWERTY layout and still maintain the relative positions of the keys so there will be a sufficient carry-over effect from the standard QWERTY layout in terms of users' ability to search for the keys. The simplest way of doing this is to lay each row of the keys in an arc (up or downward). The problem with an arced layout is that it leaves unusable blank spaces.

We experimented with a novel approach that broke each row of QWERTY and then interlaced them. The result is a keyboard layout we called interlaced QWERTY, or iQwerty for short. Figure 3 shows our final iQwerty design.

It was a design challenge to graphically design iQwerty to look similar to QWERTY. We tackled the issue with a design that has a thin outline around the keys and a light gradient on the interlaced keys (e.g. the w, r, y, i, p keys in the top QWERTY-row in Figure 3). The goal was to make each row in QWERTY still visually appear as one row, but spatially separated into two.

We hypothesized that iQwerty leverages users' QWERTY experience due to local topology similarity. To find out to what extent visual search time from QWERTY could be preserved with the new iQwerty layout we conducted a second user study.

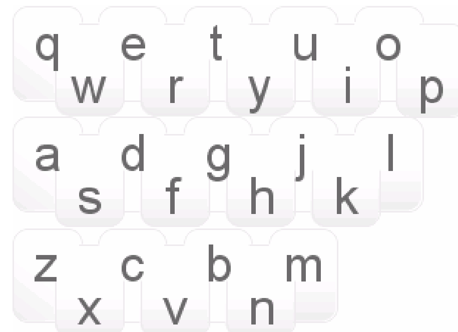

Figure 3. The interlaced QWERTY layout (iQwerty).

Method

The setup of this study was identical to Study 1. We recruited 12 new unpaid volunteers. The layouts tested were the alphabetic layout, QWERTY and iQwerty. The keys in each layout had a diameter of 8.5 mm (similar to Study 1). In iQwerty the width and height of the keys are no longer the same. In that layout, the key widths were set to 8.5 mm.

Results

On average, the alphabetic layout had the slowest mean visual search time in this study (mean = 80.5 s, sd = 14.5 s), the iQwerty took less (mean = 68.3 s, sd = 17.3) and the QWERTY layout took the least time (mean = 60.6 s, sd = 19.4). The mean difference across the layouts was statistically significant: $F_{2, 22} = 11.7$, $p = 0003$. Fisher's PLSD tests showed that the alphabetic layout was slower than QWERTY ($p < 0.0001$) and iQwerty ($p = 0.007$) receptively, but the difference between QWERTY ($p < 0.0001$) and iQwerty was hardly significant ($p = 0.075$).

Percentage wise, the alphabetical layout took 32.8% longer than the QWERTY layout and 17.8% longer than the iQwerty layout. The iQwerty had 12.7% longer search time than QWERTY. To our knowledge this is the smallest difference of any layout relative to QWERTY.

Same as in Study 1, the participants did not find the task very hard overall, but the perceived difficulty difference was significant ($F_{2, 22} = 6.8$, $p = 0.005$). Pair-wise, both the alphabetical and the iQwerty were rated more difficult than the QWERTY layout (Fisher's PLSD, $p = 0.003$, $p = 0.006$ respectively) but the difference between the alphabetical and iQwerty layouts was not significant ($p = 0.8$).

COMPUTATIONAL STUDIES

Study 2 showed that visual search time is an advantage of the iQwerty in comparison to any other known layout except QWERTY. To verify that iQwerty also reduces recognition errors in comparison to QWERTY, we carried out two computational studies.

Computational Study 1: Identical Word Traces

Method

For each word in a lexicon we constructed its word trace by mapping each letter in the word to its corresponding letter key's center position (see Figure 1 (left) for an example of a word trace). Thereafter this geometric pattern (sequence of points) was resampled to a fixed number of equidistant points. We then computed the distance between any two word traces using the (unweighted) location channel algorithm described in [3].

For varying lexicon sizes, we computed the distance between all pairs of patterns for four different layouts: QWERTY, iQwerty, ATOMIK and the alphabetic layout in Figure 2. As a baseline comparison of the different layouts we counted the number of word trace pairs with zero distance in each layout. Since words that have identical word traces because of double-letters (*e.g.* "the" and "thee") are always in collision regardless of layout, such conflicting word trace pairs were excluded from our analysis.

Results

Table 1 lists the number of identical word traces in each layout. As expected QWERTY had the most identical word traces and iQwerty the least. In fact, iQwerty was more than an order of magnitude better than QWERTY in minimizing the number of identical word traces.

Layout	10K	20K	30K	40K	50K
QWERTY	14	38	67	102	135
iQwerty	0	1	6	8	14
ATOMIK	8	20	34	53	77
Alphabetic	3	6	11	17	25

Table 1. Number of identical word traces in each layout for 10K, 20K, 30K, 40K and 50K lexicons.

Computational Study 2: Recognition Tolerance

In the second computational study we estimated the number of word trace pairs with a distance below a large set threshold on iQwerty and QWERTY respectively. We used the same method as in the first computational study, except the threshold was set to 0.5 key radiuses in location distance instead of zero. Note that such a threshold is 1) Rather liberal. For a four letter word within the threshold *any* one of the keys can be missed. 2) Only meant as an intuitive baseline in order to compare the merits between the two layouts. Actual shape writing recognition uses more sophisticated algorithms and more information (such as location and scale impendent shape) that are less intuitive, but more discriminating, hence much more tolerant to errors [3]. 3). Beyond the scope of this note, a complete analysis of tolerance involves more than simple thresholds.

Using this criterion, iQwerty reduced conflicting word pairs by 16% for the largest lexicon size (50K, see Table 2).

Layout	10K	20K	30K	40K	50K
QWERTY	1869	5028	9213	14034	18881
iQwerty	1707	4586	8377	12901	17704
Reduction (%)	**9.3**	**11.4**	**11**	**12.4**	**16**

Table 2. Number of word trace pairs with an average inter trace distance below 0.5 key radius for 10K-50K lexicons.

CONCLUSIONS

The empirical visual search studies suggest that to ease the user's initial visual search experience we have to leverage computer users' existing familiarity with QWERTY. Our computational studies show that QWERTY suffers the greatest number of word trace collisions for shape writing. This dilemma led us to design a transformed QWERTY layout, iQwerty. iQwerty's initial visual search time was more close (about 12.7%) to QWERTY's than any other layout that had been studied in the literature (including all variants of alphabetic layouts). At the same time, iQwerty reduces identical word trace collisions by an order of magnitude in comparison to QWERTY. Further, iQwerty also seems to increase overall recognition tolerance. These results suggest that the new iQwerty layout can aid users who do not want to learn a new keyboard layout in order to shape write quickly. Planned future work includes further investigation of the relationship between keyboard layout and shape writing recognition performance.

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