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# Top-down Learning Strategies: Can They Facilitate Stylus Keyboard Learning?

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## ABSTRACT

Learning a new stylus keyboard layout is time-consuming yet potentially rewarding, as optimized virtual keyboards can substantially increase performance for expert users. This paper explores whether the learning curve can be accelerated using top-down learning strategies. In an experiment, one group of participants learned a stylus keyboard layout with top-down methods, such as visuo-spatial grouping of letters and mnemonic techniques, to build familiarity with a stylus keyboard. The other (control) group learned the keyboard by typing sentences. The top-down learning group liked the stylus keyboard better and perceived it to be more effective than the control group. They also had better memory recall performance. Typing performance after the top-down learning process was faster than the initial performance of the control group, but not different from the performance of the control group after they had spent an equivalent amount of time typing. Therefore, top-down learning strategies improved the explicit recall as expected, but the improved memory of the keyboard did not result in quicker typing speeds. These results suggest that quicker acquisition of declarative knowledge does not improve the acquisition speed of procedural knowledge, even during the initial cognitive stage of the virtual keyboard learning. They also suggest that top-down learning strategies can motivate users to learn a new keyboard more than repetitive rehearsal, without any loss in typing performance.

### Keywords

Graphical keyboard, stylus keyboard, text input, mobile device, memory, learning, skill acquisition.

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# 1. INTRODUCTION

Motivated by the expected importance of handheld devices, stylus and touch sensitive screen based stylus keyboard has recently received increasing attention in the research literature (e.g. Getschow, Rosen, and Goodenough-Treganier, 1986; Lewis, Kennedy, and LaLomia, 1999; MacKenzie and Zhang, 1999; Zhai, Hunter, and Smith, 2002). A central issue in stylus keyboard research is the layout of letter keys. In order to optimize the stylus movement efficiency, various new layouts have been developed. Some of them, such as OPTI (MacKenzie and Zhang, 1999), Metropolis (Zhai, Hunter, and Smith, 2000), and ATOMIK (Zhai, Hunter, and Smith, 2002), are 30% to 50% more efficient than the standard QWERTY layout in terms of average movement time based on Fitts' law and English digraph frequency distribution calculation (Soukoreff and MacKenzie, 1995).

A serious challenge to the adoption of optimized stylus keyboards is novice users' lack of familiarity with the layout. Before users can take advantage of the optimized movement efficiency, they have to go through a period of learning during which most of their time is spent on visual search of the target keys (Zhai et al., 2000) rather than stylus movement to select the keys.

Designing and optimizing stylus keyboard layout has only reached half way toward a widely adopted user interface. Equal, if not greater, research effort is needed in studying user learning behavior and developing means to accelerate the learning process. Although very few, this line of research in fact has begun. For example, MacKenzie and Zhang (1999) reported the learning curve of an optimized stylus keyboard from an experiment in which participants practiced text entry on the OPTI and QWERTY layouts for many 45-minute sessions. Users could type an average of 44.3 words-per-minute at the end of 20 sessions. For another example, Smith and Zhai (2001) studied the effect of "alphabetical tuning" of an optimized stylus keyboard. They introduced a keyboard layout with an alphabetical bias from upper left to lower right corner of the keyboard while maintaining an optimal layout for the stylus movement efficiency. They found that novice users could perform 10% faster on a stylus keyboard with alphabetical tuning than without.

The current study focuses on whether we can accelerate stylus keyboard learning by providing novice users with top-down learning strategies (i.e. turning declarative knowledge into procedural knowledge) to memorize the keyboard layout. Researchers over the years have developed various techniques to improve recall memory of visual and verbal information (e.g. Atkinson and Raugh, 1975; Bobrow and Bower, 1969; McNamara, Hardy, and Hirtle, 1989). It is unclear, however, that improved recall memory will transfer to quicker typing speeds. Recall and typing rely on two separate memory systems, i.e. explicit vs. implicit. Explicit memories is the terms for things which we can consciously recall and implicit memories is the term for things for which we show knowledge only by our improved performance on some task. Explicit and implicit memory systems seem to function quite independently from each other. For example, a patient with hippocampal damage cannot consciously recall some events but can learn perceptual-motor tasks (Milner, 1965). Similarly, normal people can improve on certain problem-solving tasks without developing any ability to explain what they are doing (Berry and Broadbent, 1984).

Conversely, people can also improve recall memory without affecting implicit memory (Jacoby, 1983).

Although typing can be performed without involving explicit declarative knowledge once it is well-learned, declarative knowledge plays a significant role during the early stages of skill acquisition. Early in the learning process, conscious cognitive processes are heavily involved to understand the nature of the task and how it should be performed. With much rehearsal, the task procedure becomes more automated and requires less attention. According to this well accepted theory, a novice user of a stylus keyboard may type with a disproportionate amount cognitive effort compared to an expert user who may type autonomously. Therefore at the initial learning stage, users may benefit from better cognitive strategies.

Visual search is a good candidate for applying cognitive strategies during an initial learning stage of a new stylus keyboard. If novice users spend a great portion of their time searching for the target keys, then better search and memory strategies for the layout may reduce search time and therefore overall typing speed.

## 2. TOP-DOWN LEARNING STRATEGIES

Three top down learning methods - alphabetical grouping, word based-grouping, and word generation - were designed to provide users with constructive visual search strategies and improve their memory of the keyboard layout during learning sessions. Detail and rationale of these methods are as follows.

### 2.1. Alphabetical Groupings

The ATOMIK (Alphabetically Tuned and Optimized Mobile Interface Keyboard) layout (Zhai, Hunter, and Smith, 2002) was used in this experiment (Figure 1). One of the key features of the ATOMIK keyboard is alphabetical tuning, which has shown faster performance than an unordered keyboard (Smith and Zhai, 2001). In order to enhance the benefits of this feature, the alphabetical grouping method visually groups and highlights the salient visual imagery associated with the underlying alphabetical structure.

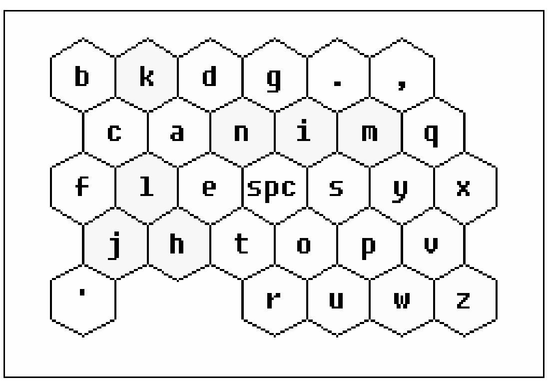


Figure 1: ATOMIK Keyboard

The letters were grouped according to gestalt principles of perceptual organization, namely the principle of proximity, similarity, good continuation, and closure (Palmer, 1977). These principles guide how we segment visual scenes into objects, and therefore they were exploited to create "visual chunks" that corresponded to the cognitive organization that we wanted to create. Based on the ATOMIK layout, visual chunks that preserved continuation and closure (i.e. maintenance of visual contiguity) were the four alphabetic groups shown in Figure 2. Alphabetic ordering of the ATOMIK keyboard assured that keys in adjacent orders maintained proximity between letters within an alphabetic group. This method assigned subtle color differences to each group to highlight similarities for items within a particular group.

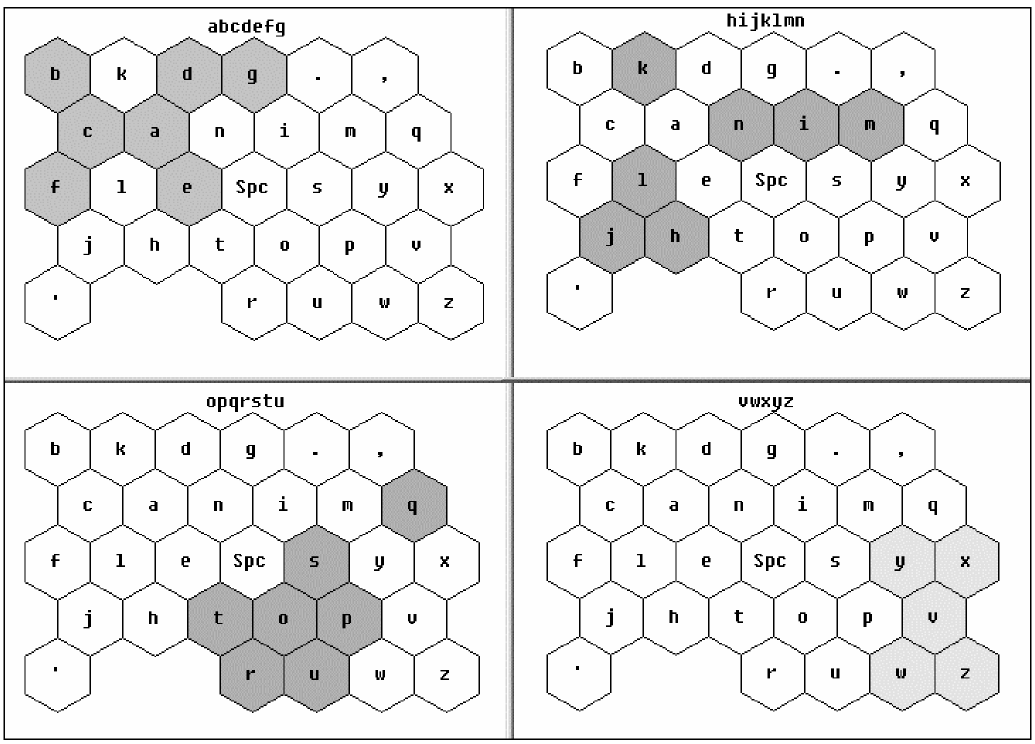


Figure 2: Four Visual Groupings of ATOMIK Keyboard based on Alphabetical Order

With such groupings, the alphabetical bias of the keyboard was highlighted to users and they were given a visual search strategy to reduce their search space during typing. They were told to determine if the target letter is roughly near the beginning, middle, or end of the alphabet, and search sub-areas on the keyboard (e.g. upper-left corner, lower-right, etc.) that corresponded to those divisions to reduce search time.

## 2.2. Word-based Spatial Groupings

To improve users' memory of the keyboard layout, a word-based spatial grouping strategy was used. It aimed to exploit both visuo-spatial and linguistic aspects of typing. Linguistically, the letters were learned by forming words, which are more meaningful than random set of letters. In general, it is easier to remember information without much inherent meanings by associating it with other known objects. One such technique is the mnemonic that converts a group of letters into more meaningful words (Atkinson and Raugh, 1975). Past research suggests that typing is faster when the text is composed of words rather than random letters, and identification accuracy for a single letter is higher when the letter is presented in a word than when it is presented singly (Reicher, 1969).

Using this strategy, we partitioned the keyboard into a collection of mnemonic words. The users were instructed that the keyboard was designed to put the most frequently used letters near the center, and that we will teach them how to remember these letters within the next ten minutes. They were given an illustration of word-based spatial groupings (Figure 3), along with following instructions:

"The *space* key is in the center of the keyboard and is most often used. Around the *space* key is a circle of frequent letters. These letters form words '*net is tops*'. Above and below this circle, you have letters *g* and *r*. These letters also form words '*gin*' and '*rot*'. To the left of these words, you have most commonly used words '*and*' and '*the*'. To the right of '*gin*' and '*rot*', you have words '*my up*'. To the far left, words '*black jack flea*' covers the rest of the keyboard, and to the far right, you have the left-over letters near the end of the alphabet, '*qvwxyz*'."

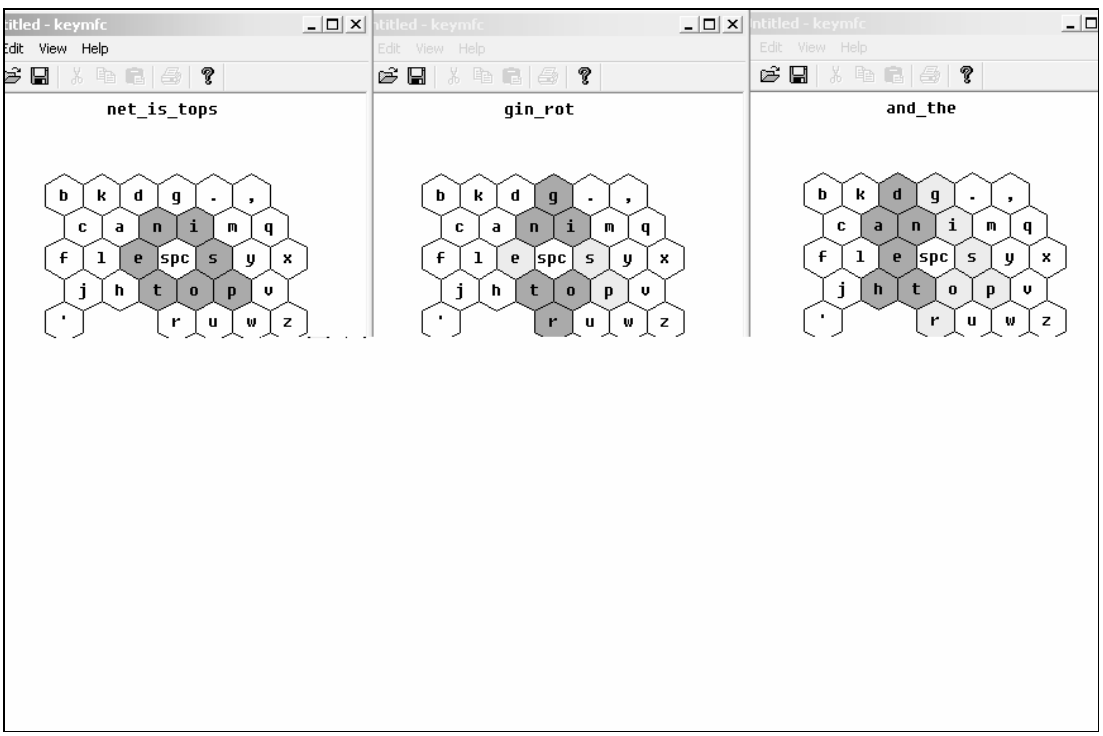


Figure 3: Word-based Spatial Groupings

In a pilot study, users were able to recall the keyboard layout within ten minutes using this mnemonic technique. The words were chosen to be contiguous and they were highlighted during learning to make the groupings visually salient according to gestalt principles. Contiguity was easy to obtain using ATOMIK keyboard because a key feature of the keyboard was maximal connectivity of letters in common words (Zhai et al., 2002). The mnemonic words

various newspaper sections on the web and altered to have consistent sentence lengths. These sentences were randomly selected during test. Although sentences could repeat more than once during an experiment, repetitions were uncommon.

#### 3.1.3. *Design and Procedure*

Participants were told that they would be testing a new keyboard layout for PDA devices that will allow them to improve their text entry speed. They were divided into two groups: top-down learning group and control group. For the top-down learning group, during the first half-hour, they went through four sessions, each for 4.5 minutes. In the first session they familiarized themselves with the alphabetical tuning of the keyboard by the alphabetical groupings method described in the last section. They were asked to tap the keys that corresponded to the letters in alphabetical sequence.

In the second session, participants learned the layout using word-based spatial groupings. The mnemonic words appeared on the screen and the corresponding letters were highlighted on the keyboard. In the third session, they continued learning the word-based spatial groupings, but without highlighted letters, which forced them to search more actively for the letters. In the fourth and final session, they typed words that were self-generated. They were told to type any words or letter combinations that they thought would help them remember the layout better. For the control group, participants were asked to type the random sentences that appeared on the screen. During the first half-hour, four equal sessions were conducted, each for 4.5 minutes.

After the first half of learning the layout or typing, participants were given a questionnaire, asking for their attitude towards the new keyboard layout and their judgment on its effectiveness. The learning group was also asked to rate the effectiveness of the training regimen. Both groups were given a free recall test of the keyboard layout. They had three minutes to fill out as many keys as they remembered on a blank keyboard.

During the second half-hour, both groups were tested on their typing speed and accuracy by typing full randomly selected sentences. The procedure for the test phase was identical to the first half-hour of the control group – i.e. four sessions of typing sentences. After the second half-hour, they were given another questionnaire that included both the old questions from the first half and new questions. Finally, they were given another recall test by filling out stylus keyboard layout with keys blanked out.

# 4. RESULTS AND DISCUSSION

## 4.1. Subjective Ratings

#### 4.1.1. *Training Regimen*

The fifteen participants in the learning group went through the training regimen and gave their ratings. One participant's rating score was more than 2.5 standard deviations away from the mean and therefore subsequently excluded from the following analyses.

In general, they found the training fun (ratings = 5.1 out of 7) and enjoyable (ratings = 5.5). They also found it useful and would recommend it to their friends (5.1), but they did not feel that the regimen was rigorous enough (3.64).

#### 4.1.2. *Keyboard Usability Ratings*

Participants' ratings on the usability of the new layout and their perception of its effectiveness were taken after the first half session and again at the end of the experiment. Table 1 illustrates the average rating scores for each question, collapsed across the first and the second session. As predicted, The top down learning group showed greater preference for the keyboard (Table 1: Q1, $F_{1, 28} = 9.90$, $p<0.004$) and felt that it will be more effective once it is mastered (Table 1: Q2, $F_{1, 28} = 7.33$, $p<0.011$) when compared to the control group.

| No | Description | Scale Range (1-7) | Learning | Control |
|---|---|---|---|---|
| **Q1** | How much do you like this new keyboard? | (1=not at all; 7=very much) | **5.33** | **4.20** |
| **Q2** | Do you believe this keyboard would be efficient once you master it? | (1=not at all; 7=absolutely) | **6.10** | **5.23** |
| **Q3** | How easy is it to learn this new keyboard?. | (1=very easy; 7=very difficult) | **2.77** | **3.67** |
| **Q4** | How well do you remember the keyboard layout? | (1=not well at all; 7= very well) | **4.97** | **4.00** |
| **Q5** | Do you think you will make a lot of errors if you used this keyboard? | (1=very few errors; 7=lots of errors) | **3.10** | **3.47** |
| **Q6** | To what extent do you feel you could type fluently on this keyboard without having to pause to search for particular letters? | (1=not fluent at all; 7=very fluent) | **4.64** | **4.10** |

Table 1: Ratings on the Keyboard Usability for Learning and Control Conditions

They also found it easier to learn (Table 1: Q3, $F_{1, 28} = 7.16$, $p<0.012$) and they recalled the layout significantly better (Table 1: Q4, $F_{1, 28} = 16.04$, $p<0.001$). For both groups, participants' ratings on their memory of the layout increased at the end of the experiment compared to their ratings after the first half session (3.99 after the 1st half vs. 4.98 after the 2nd half, $F_{1, 28} = 23.68$, $p<0.001$).

Interestingly, although participants in the learning group liked the keyboard better, their perception of their own performance was not significantly better relative to the control group (Table 1: Q5, $F_{1, 28} = 0.66$, $p>0.4$; Q6, $F_{1, 28} = 1.85$, $p>0.18$). This result seems opposite of what one might expect -- one might predict that after training with the top down learning strategies, users will show greater bias of their own performance but not necessarily improve their opinion of the keyboard.

Some of the ratings had significant interactions between the learning conditions and the sessions (see Table 2). The participants' ratings increased slightly from 1st half to 2nd half in the control group while the ratings decreased slightly in the learning group. This pattern emerged for their attitude towards the keyboard (Table 2: Q1, $F_{1, 28}$ = 7.26, p<0.012) and its efficacy (Table 2: Q2, $F_{1, 28}$ = 12.25, p<0.002).

| No | Description | Learning | | Control | |
|---|---|---|---|---|---|
| | | 1st Half | 2nd Half | 1st Half | 2nd Half |
| **Q1** | How much do you like this new keyboard? | **5.53** | **5.13** | **3.87** | **4.53** |
| **Q2** | Do you believe this keyboard would be efficient once you master it? | **6.27** | **5.93** | **4.93** | **5.53** |

Table 2: Ratings on the Keyboard during 1st and 2nd half sessions

Finally at the end of the experiment, they were asked again if they liked the keyboard and if they would recommend it to others. The results showed that participants in the learning group were much more likely to recommend the new keyboard to others (ratings = 5.27 vs. 4.07, in learning vs. control; $F_{1, 28}$ = 7.59, p<0.01).

Overall, the positive experience of the keyboard in the learning condition can be a useful catalyst to motivate users to use the new keyboard. This point was evident when we conducted the experiment. The participants in the learning condition liked the keyboard and were motivated to do the tasks. They seemed less tired and bored during the experiment than those in the control condition, and therefore required less prodding and motivation to do their tasks diligently.

## 4.2. Recall

The recall of the key locations was categorized into three groups: correct keys, keys placed one space adjacent to the correct location in any direction, and keys placed more than one space off. The recall score was calculated by giving one point for the correct answer and 1/3 for the keys that are off by one space. A perfect score was 26.

Partial points were given for keys placed one space adjacent to the correct location because participants often switched the locations of two adjacent keys or they would correctly remember a group of keys but misplace the group slightly on the keyboard. Overall pattern of results below remained the same when partial points were not assigned. For example, the overall recall rate of the keyboard layout in the learning condition was 23/26 letters with and 22/26 letters without the partial points. Similarly, the recall rate of the control condition was 15/26 letters with and 14/26 letters without.

As we expected, the recall data showed a large improvement under learning condition compared to the control group (Figure 4). Participants in the learning group recalled the keyboard layout (23/26 letters) much better than the control condition (15/26 letters; $F_{1, 28}$ = 26.01, p<0.001). Both groups has significant improvement from the 1st half (17/26 letters) to the 2nd half hour (21/26 letters; $F_{1, 28}$ = 32.11, p<0.001).

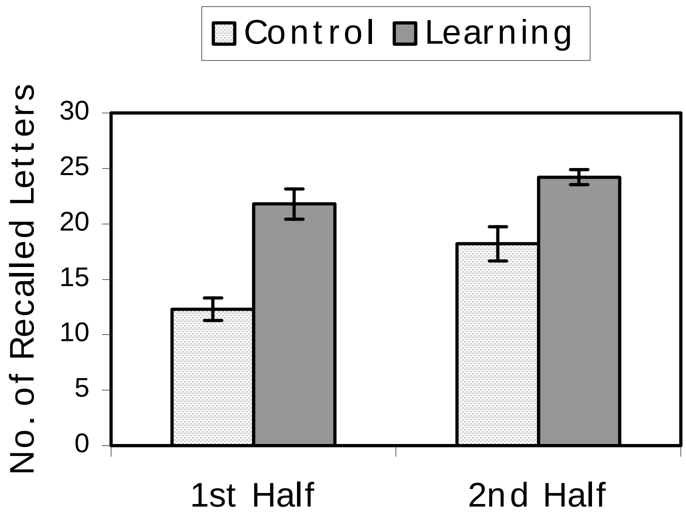


Figure 4: Recall of Keyboard Layout

The control group improved significantly more from 1st to 2nd half (12 to 18 letters) than the learning group (22 to 24 letters; $F_{1,28} = 5.69$, $p<0.024$), but this interaction is likely due to the fact that the learning group already achieved a high level of recall after the first half session. The recall data confirmed that the top down learning strategies were indeed effective in having users memorize the layout.

## 4.3. Typing Speed

During the test phase, participants had high level of accuracy, regardless of the experimental condition. There were no significant difference in error rate between the learning group (1.54% error), the first half of the control group (1.64%), and the second half of the control group (1.75%).

After a half hour of top-down learning, participants in the learning group typed significantly faster (14.9 Words Per Minute or WPM) than the control group who were exposed to the keyboard for the first time (12.0 WPM; $t(26) = 7.15$, $p<3.7e-7$) (see Figure 5). However, when they were compared to 2nd half performance of the control group, they showed no significant difference (14.8 WPM; $t(26) = 0.17$, $p>0.8$).

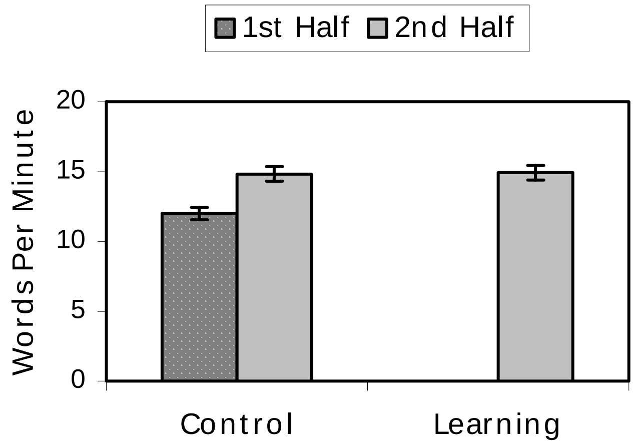


Figure 5: Typing Speed (WPM) during 1st /2nd Half Sessions for Control and Learning Conditions

Closer look at the individual trials during the test phase indicates a steady increase in typing speed throughout the experiment (Figure 6). The four test sessions after the learning strategies were typed faster than the first four sessions in the control condition. When we match the four test sessions in the learning condition with the second four sessions of the control condition, however, we can see strikingly similar patterns between them. This result suggests that when we match for the "exposure" to the new keyboard (i.e. 18 minutes of learning strategies vs. 18 minutes of typing), the typing speed seems follow the same learning curve. In other words, no matter which training method was used, the learning curve appeared to be dictated by the amount of time spent on the keyboard.

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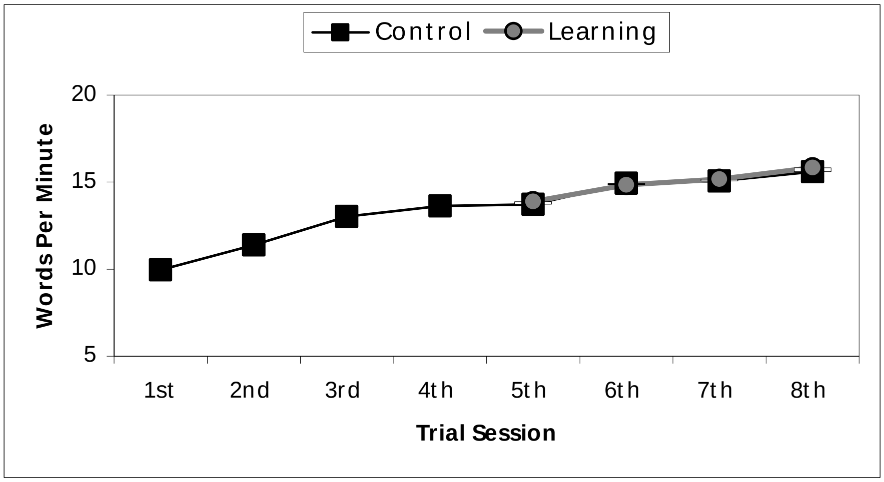


Figure 6: Typing Speed during Individual Test Sessions

The dissociation between recall accuracy and typing speed may be due to two separate quantities associated with a memory trace: *activation* and *strength*. The activation level of memory is related to the number of connections that the trace has with other memory traces, and it determines how accessible the memory is. Our learning strategies helped to recall the layout because it used elaborate processing to access the key locations using visual imagery and mnemonic words. Typing speed, however, may be more related to automaticity of visual search, which in turn is related to the strength of the memory trace of the key locations. Since visual search time improves as a power function of practice (Shiffrin and Schneider, 1977), the time that the users spent rehearsing the learning strategies might have improved the typing speed as a function of practice but the elaboration itself might have only helped the recall memory. These results suggest that quicker acquisition of declarative knowledge does not improve the acquisition speed of procedural knowledge, even during the initial cognitive stage of the stylus keyboard learning.

The performance result of the experiment is interesting both theoretically and practically. Theoretically, the result is informative to future research in understanding stylus keyboarding mechanisms and behavior. One theoretical implication is a "time exposure hypothesis". That is, as long as users spend time with the keyboard, regardless of the methods, they learn to type faster. It is possible that users do not necessarily build layout and letter or word specific memories through learning, but rather simply reduces their visual search time with longer time exposure to the keyboard.

However our data also suggest that individual's recall and typing performance are correlated, although not necessarily causally (see Figure 7). With both groups of participants, we used a median split on the recall score to divide the participants into low and high recall groups. Under both conditions, the high recall group typed significantly faster (15.2 WPM) than the low recall group (12.7 WPM). $F_{1, 26} = 26.6$; $p < 0.001$. There was no significant interaction between learning condition and high/low recall groups. $F_{1, 26} = 1.1$; $p < 0.297$.

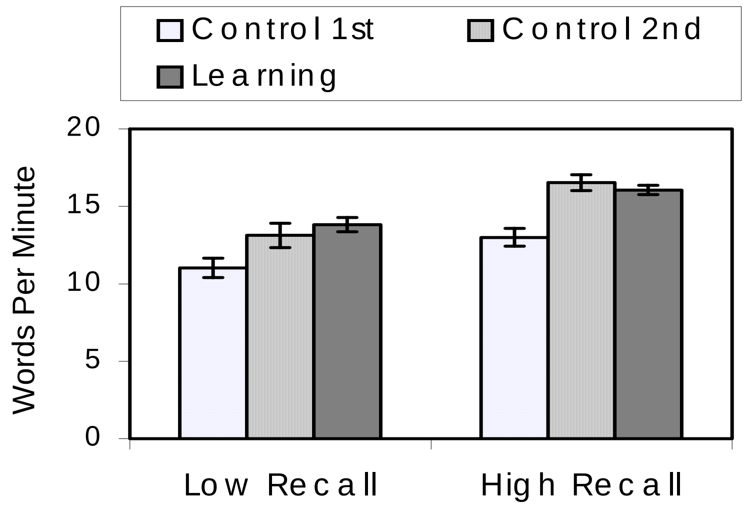


Figure 7: Typing Speed (WPM) for Low and High Recall Participants

Practically, since the learning group's typing speed was faster than that of the first half and equal to the second half of the control group, time spent on top-down learning at least did not go wasted toward improving typing speed. Furthermore, users through the top-down learning group had better recall and better subjective impressions, which may motivate them to continue to use the stylus keyboard so they can eventually gain more from the optimized efficiency. Finally, it is highly encouraging that within 36 minutes of actual rehearsal time, users were able to type around 15 WPM, with many of them typing around 20 WPM by the end of the experiment.

# 5. CONCLUSIONS

Learning a stylus keyboard presents many interesting cognitive psychology challenges. What do users learn and remember when they learn to use a keyboard layout? Do they learn the paths of words or do they learn the positions of the individual keys? What type of memory is involved in learning a stylus keyboard (e.g. spatial, motor, schemata, etc)? There is a body of literature on learning typing on a physical keyboard (e.g. Cooper, 1983; Dvorak, 1936; Ono and Yamada, 1990), but there is no reason to believe the mechanism involved in tapping on a stylus keyboard is the same as ten finger typing on a physical keyboard. We have explored various top-down learning strategies to improve novice users' memory and visual search capabilities of an optimized stylus keyboard (See Zhai, Sue, and Accot 2002 for a different training strategy). Results showed that these learning strategies created more conscious awareness of the key locations. Users briefly going through these top-down learning strategies also typed faster than the users who have no exposure to the keyboard, but equal to those who has spent the same amount of time typing random sentences. A "total time exposure hypothesis" of typing speed is suggested in the data and other implications informative for future research are produced. Users of these strategies also preferred the keyboard more. Importantly, they were more willing to use it in the future, which may be just as reliable an indicator for the eventual adoption of a new layout as the performance advantage that it brings.

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