Typing on a Touch Surface: Effect of Feedback with Horizontal Touch Keyboard and Vertical Display Setup

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ABSTRACT
Multi-touch touchpads and touchscreens have begun replacing traditional keyboard in certain laptops. Taking advantage of the flexibility of a touchscreen, these designs are expected to enable a more efficient use of the limited real estate of a laptop computer. However, a serious problem remains in that the soft keyboard on a touch screen does not always satisfy users owing to a lack of tactile cues, which is essential for text entry, particularly text entry without looking at the keyboard. We investigated ways to overcome this problem by adding various types of feedback to a touchscreen and evaluated their effectiveness through a controlled user test.

Author Keywords
Touch typing; text entry; feedback; touch surface

ACM Classification Keywords
H5.2. **[Information Interfaces and Presentation (e.g. HCI)]**: User Interfaces - Input devices and strategies (e.g., mouse, touchscreen)

General Terms
Performance; Human Factors

INTRODUCTION
The keyboard has always been at the center of the computing environment, occupying a large area under the display. In laptop computers, the keyboard demands about half the entire horizontal surface, an area much larger than that occupied by a touchpad. It is therefore a good idea to consider a more efficient utilization of the keyboard area by replacing it with a multi-touch touchpad or touchscreen, and indeed, many researchers and manufactures have recently been attempting to do so. For example, dual-screen laptops[1] that include a touch screen instead of a physical keyboard have been introduced. Taking advantage of the flexibility of a touchscreen, such designs are expected to enable a more efficient use of the limited real estate of a laptop computer. A serious problem remains, however, in that soft touchscreen keyboards cannot satisfy users who require the sensation of typing on a physical keyboard.

Although a multi-touch screen is a revolutionary technology, it has a major shortcoming owing to a lack of tactile cues, which are essential for text entry, particularly for text entry without looking at the keyboard. Notwithstanding various supplementary techniques used, such as auto correction, word prediction, and alternative layouts, the text entry speed on a touchscreen is known to be fairly limited compared with that of a physical keyboard [5]. We have speculated that the major reason for this difference is a lack of proper feedback, such as tactile, textural, and auditory feedback. To support this speculation, we conducted a controlled user test to verify the effects of various feedback types on the text-entry performance in a touchscreen environment. The results of this study are valid not only for dual-screen laptops but also for other environments with a vertical display and horizontal touch surface. TactaPad[2], Fingerworks[3], Magic Desk [3], and Visual Touchpad [9] are examples of devices that use a separate display and touch surface. A tabletop environment with a shared vertical display [13] is another example.

RELATED WORKS
Tactile feedback is known to be the key element in touch typing, particularly during eye-free typing situations. Crump et al. [4] sequentially deconstructed a keyboard to observe the feedback effect available on a physical key switch. They found that the removal of tactile perception of a physical key reduces the typing performance. Rabin et al. [12] also studied the role of tactile feedback while typing. They anesthetized the right index fingertip of the participants and observed the difference between anesthetized and normal finger conditions. When anesthetized, typing errors from the right index finger increased sevenfold. This result shows the importance of tactile information for typing tasks. The authors found that the major suspect of typing errors when an anesthetized finger is used is an incorrect initial fingertip position before

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1 http://en.wikipedia.org/wiki/Dual-touchscreen
2 http://www.tactiva.com/tactapad.html
3 http://makezine.com/pub/tool/FingerWorks_TouchStream_LP

a keystroke movement, which is caused by the blocking of tactile information. Tactile information provides the somatosensory sensation of an accurate fingertip location on a keycap and aids in the motor planning for an accurate movement to the next intended key.

Feedback mechanisms available on a physical keyboard (e.g., textural, tactile, and aural feedback) are not available on touch surfaces. Of course, this lack of tactile information reduces the typing performance. Findlater et al. [5] studied the typing behavior of users on a touch surface keyboard. They found that in an *Unrestricted* condition (typing as free as possible without constraint), there is a significant speed reduction compared with a physical keyboard. This result is interesting as the participants were asked to type on an imaginary keyboard, which has no restriction at all. Even under this advantageous configuration, the typing performance was fairly reduced. Although the authors did not investigate the cause of this performance reduction, we believe that the major suspect is the lack of tactile information.

STUDY OF FEEDBACK ON TOUCH SURFACE

Our objective is to replicate the tactile feedback available for a physical keyboard on a touch surface keyboard, and observe its effects on a touch-type performance. We first investigated some of the feedback types available on a physical keyboard: *Force*, *Sound* (auditory) and *Surface texture* feedback. *Force* feedback is a change in the repulsive force applied to each key, enabling the user to feel the actuation of the key switch. *Sound* feedback is the “clicking” sound from the mechanical movement of the switch. These two feedback mechanisms are reactive: they provide a feeling of confirmation of a successful key activation. *Surface texture* is the fine structure of the surface showing the outline of the keys, and enables users to recognize the position of the keys. According to a study by Rabin et al. [12], this information helps users to move their fingers more accurately. We speculate that *Surface texture* is the key element that enables touch typing. We call this feedback proactive or feedback occurring before the actual key activation, unlike reactive feedback that takes place during or after a keystroke.

We then replicated two of the feedback types available for a physical keyboard: *Sound* and *Surface texture*. Because we believe that *Force* and *Sound* feedback have similar roles (reactive feedback), confirming the activation of the key, we chose to replicate *Sound* feedback only. We designed methods to transfer these to a touch surface and examined the typing performance and user satisfaction.

Apparatus

We implemented a touch surface keyboard using an Apple iPad (Figure 1). All events received by the iPad were directly transmitted to a laptop through a serial communication, where they were processed. The iPad

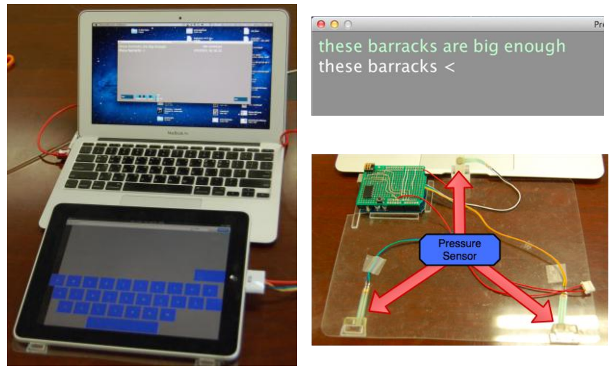


Figure 1: (Left) Placement of each device during the experiment. (Upper right) Task displayed on the vertical screen. (Lower right) Three pressure sensors are placed below the iPad.

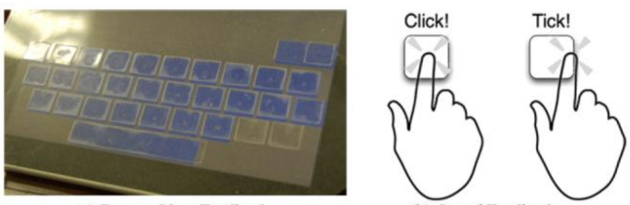
touchscreen displayed nothing but the keyboard layout. We designed a touch surface keyboard layout resembling the physical keyboard on an Apple MacBook Air, with equal key widths (16.00 mm) and key pitches (19.05 mm). The non-key areas between each key were mapped to the closest key, because on a physical keyboard, it is impossible to hit these areas without activating a key switch.

People generally skim through the keyboard surface to find the bumps on the F and J keys. However, on a touch screen keyboard, every touch is committed as a keystroke, and therefore, this skimming action is not available. For this reason, we need a mechanism to allow users to scan through the screen without activating any keys. To permit this action, we utilized the duration of the keystroke and the pressure change. We added three pressure sensors behind the iPad, and checked the frequency of the pressure sensor value stream. We aggregated the sensor values from the three pressure sensors and filtered them through a high-pass filter. If a rapid pressure change is detected, we commit this as a keystroke candidate. The cutout border of each key was carefully adjusted depending on the system installation. During skimming, the pressure change is subtle and is thus filtered out. In addition, the duration of the touch is used to distinguish between skimming and typing. The average touch duration of a typical keystroke is less than 150 ms; however, the touch duration is much longer while skimming. As a result, only a touch with a rapid pressure change and short duration (<300 ms) is recognized as a valid keystroke.

Feedback Design

Our design should convey tactile information resembling a physical keyboard. Adding mechanical actuators [11][10][14] is a simple solution for this problem. Although these approaches are inexpensive and practical, they do not provide any surface textures. Some recent works have used more advanced technologies. TeslaTouch [2] introduced electrovibration to deliver different surface textures to the fingertips. STIMTAC [1] uses a squeeze film effect that gives different feelings of friction. Although these techniques have the ability to convey the textures of a touch surface, such feelings can only be perceived by a moving finger. While typing, the hands generally remain still between keystrokes. During a keystroke, the contact duration is too short and finger displacement barely occurs. In addition, the texture changes throughout the entire surface in these techniques, and multi-touch functionality cannot be supported. During the scanning stage of touch-typing, multiple fingers concurrently slide over the surface. Thus, multi-touch support is a necessary condition. Because of these limitations, we designed a physical key-shaped template. This design can deliver an explicit feeling of the presence of a key without the need for any complicated technologies.

We designed two types of feedback mechanism: *Texture plate* and *Sound* (Figure 2). *Texture plate* and *Sound* are exact replacements of *Surface texture* and *Sound* feedback of a physical keyboard. Our key observation was that proactive tactile information is an important feature for touch typing. As proactive feedback, *Surface texture* was the primary element to be replicated from a physical keyboard.



(a) *Texture Plate* Feedback (b) *Sound* Feedback

Figure 2: Implementations of the feedback used in the experiment.

Texture plate

Texture Plate is a proactive feedback mechanism that provides *Surface texture*. We constructed the *Texture plate* using a transparent OHP film (0.1-mm thick). One piece of the film was cut into the key shapes and glued onto another piece of the film. The film is thin enough, and hence, the two layers of the film did not diminish the capacitive sensing capability of the iPad touchscreen, while still providing the distinction between keys (Figure 2-a).

We provided three types of *Texture plates*: *F-J*, *Home-row*, and *Full*. Because the bumps on the F and J keys, and the home-row keys themselves, are utilized during the initial calibration stage of typing, we incrementally heightened the feedback level from the F and J keys only (*F-J*), the home-row keys only (*Home-row*), and all the keys (*Full*); bumps were added to the F and J keys for each texture plate.

Sound

Sound is a reactive feedback that enables users to confirm input. We simply recorded a clicking sound from the *Cherry Brown Switch*[4] and played it after a keystroke. Because we are aiming to support touch typing, we added additional information: if a touched location is far from the key center (out of the 50 × 50 px box-shaped area, but within the 88 × 80 px key area), we used a higher toned sound (doubling the frequency of the default clicking sound) (Figure 2-b).

[4] http://www.cherrycorp.com/

Experiment

After designing the feedback mechanisms, we conducted a group usability test to study their effects.

Participants

Sixteen participants (9 males, 7 females) ranging in age from 19 to 30 (M = 23.5, SD = 2.66) participated in our study. All participants were touch typists. The participants took a 1-hour test and were paid $9 each. Eight of the participants have experienced using a full-sized touchscreen keyboard such as that found on an iPad.

Conditions

We organized the six feedback conditions listed in Table 1. *Sound*, *F-J*, *Home*, and *Full* are the conditions used for each individual feedback mechanism. *Full+S* examines the combinational effect of *Sound* and *Full*.

Name	Texture Plate	Sound
None	NO	NO
Sound	NO	**YES**
F-J	**F and J**	NO
Home	**Home-row**	NO
Full	**Full**	NO
Full+S	**Full**	**YES**

Table 1: List of feedback conditions

Task

The participants were required to exactly copy an entire string of characters appearing on the vertical screen (Figure 1). A correction was required if any errors occurred (a “correct as you go” approach [7]). The character strings were randomly selected from the MacKenzie phrase set [8]. The string was automatically committed after an exact copy was made, and the participants could request to reset the typed text as desired. The participants were asked to type quickly and accurately.

Procedure

The participants sat in front of the touch surface keyboard (Figure 1) and had a 5-min *initial configuration* session to become comfortable with the device, during which they were allowed to type example strings and adjust the device position, chair height and placement, and screen angle.

The participants were given a 1-min *practice session* and a 3-min *recording session* for each condition. As a comparison group, they first performed the same task using the physical keyboard of a MacBook Air (*Keyboard*). Next, they typed under each condition in random order. The order was counterbalanced across the participants. All six conditions were tested for the touch surface keyboard. After the testing, we asked the users to answer a questionnaire regarding *likeness*, *unintended inputs*, *fatigue*, and the need to *glance* at the keyboard.

RESULTS

We calculated the words per minute (**WPM**) for the typing speed and keystrokes per character (**KSPC**) for the error rates [7]. We also analyzed the user survey.

Typing speed

We calculated the **WPM** as $S/_T \times 60/_5$, where S is the length of the string, and T is the elapsed time in seconds. We considered only successfully committed strings. In addition, T was measured from each string individually. We also measured **Peak WPM** as $60/_{IKSI \times 5}$, where the inter-keystroke interval (**IKSI**) is $SS/_{ST}$, with only successive keystrokes and no backspaces. Additionally, SS is the length of the string, and ST is the elapsed time in seconds. Figure 3 shows the experimental results.

We analyzed the results using a one-sided *paired-sample t-test*.

- *Keyboard* was significantly ($p < 0.0001$) faster than all other conditions.
- *None* was significantly faster than *F-J* ($p = 0.033$) and *Home* ($p = 0.002$).
- *Sound* was significantly faster than *F-J* ($p=0.012$) and *Home* ($p = 0.003$).
- *Full* was significantly faster than *Home* ($p = 0.006$).
- *Full+S* was significantly faster than all other conditions ($p = 0.012$ for *None*, $p = 0.013$ for *Sound*, $p = 0.011$ for *Full*, and $p < 0.01$ for the others) except for the *Keyboard*.
- *Home* condition was significantly slower than all other conditions ($p < 0.01$) except for *F-J*.

A similar **Peak-WPM** was measured for all touch surface keyboard conditions, and thus, we can presume that the feedback conditions did not affect the typing ability of the participants. Therefore, the major disturbance factor is the frequency of errors. Thus, by extracting the error rate, we can clearly observe the difference between each condition.

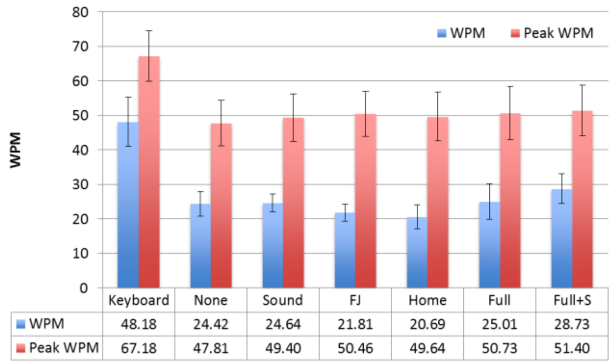


Figure 3: Average **WPM** and **Peak-WPM** for each condition (error bars: SD)

Accuracy

We also calculated **KSPC** as $TS/_S$ for accuracy, where TS is the total number of keystrokes and S is the length of the string. According to [7], **KSPC** is the appropriate measurement for determining accuracy with a "correct as you go" approach. Figure 4 shows the results.

Again, we analyzed these results using a one-sided *paired-sample t-test*.

- *Keyboard* was significantly ($p < 0.0001$) better than all other conditions.
- *None* was significantly better than *F-J* ($p=0.007$) and *Home* ($p = 0.001$).
- *Sound* was significantly better than *F-J* ($p = 0.018$) and *Home* ($p = 0.003$).
- *Full* was significantly better than *Home* ($p = 0.021$).
- *Full+S* was significantly better than all other conditions ($p = 0.012$ for *None*, and $p < 0.01$ for the others), except for the *Keyboard*.
- *Home* was significantly worse than all other conditions ($p = 0.021$ for *Full* and $p < 0.01$ for the others), except for *F-J*.

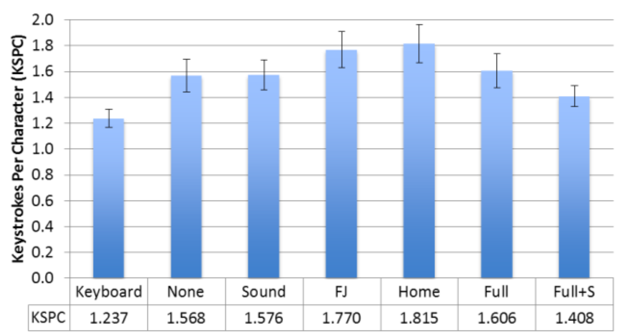
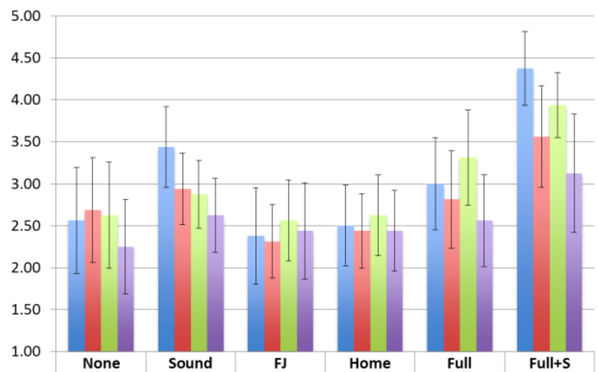


Figure 4: **KSPC** for each feedback condition (error bars: SD)

User Survey

After the test for each condition, we asked the users to answer four questions: (*Q1*) *Did you like the keyboard feedback?* (*Q2*) *Did you feel any unintended behaviors occurred, such as a non-committed keystroke or accidental input?* (*Q3*) *Did you feel fatigue?* (*Q4*) *Did you have to glance at the keyboard screen often?* We used a five-level Likert scale and allowed the users to modify their previous answers during the test. Figure 5 shows the results (higher scores are always better). A one-sided *paired-sample t-test* was used to analyze the results.



	None	Sound	FJ	Home	Full	Full+S
Likeness	2.56	3.44	2.38	2.50	3.00	4.38
Intend	2.69	2.94	2.31	2.44	2.81	3.56
Fatigue	2.63	2.88	2.56	2.63	3.31	3.94
Glance	2.25	2.63	2.44	2.44	2.56	3.13

Figure 5: Result of user survey. Higher scores are better. (error bars: SD)

Likeness

Full+S was significantly better liked than all other conditions ($p < 0.01$). *Sound* was significantly better liked than *None*, *F-J, and Home* ($p<0.01$). *Full* was significantly better liked than *F-J* ($p = 0.028$). The other conditions showed no differences.

Unintended inputs

Full+S was significantly better than all other conditions ($p = 0.045$ for *None*, $p = 0.043$ for *Sound*, and $p < 0.01$ for the others). *Sound* was significantly better than *F-J* ($p = 0.014$) and *Home* ($p = 0.021$). The other conditions showed no differences.

Fatigue

Full+S was significantly better than all other conditions ($p = 0.028$ for *Full* and $p < 0.01$ for the others). *Full* was significantly better than *F-J* ($p < 0.01$) and *Home* ($p = 0.018$). The other conditions showed no differences.

Glance

Full+S was significantly better than *None* ($p = 0.024$), *F-J* ($p = 0.047$), *Home* ($p = 0.047$), and *Full* ($p = 0.035$). *Sound* was significantly better than *None* ($p = 0.014$). The other conditions showed no differences.

DISCUSSION

Overall, there is no doubt that *Full+S* showed the best performance. Only this condition provided both the surface texture and the auditory feedback most similar to a physical keyboard. Although we presumed that a typing condition with one or more feedback type can improve the typing performance, only *Full+S* showed a significantly better performance than *None*, which is the baseline condition. The conditions providing only one type of feedback showed no significance over *None*, which was different from our expectations. Interestingly, *F-J* and *Home* showed the worst performances. These conditions were designed to give the location of the correct home-row position using partial surface textures. However, these textures confused the users instead of helping them, as it seems no information is better than partial information.

Based on the user survey and an informal user interview taken after the test, *Full, Sound*, and *Full+S* were generally preferred. Some users reported that they enjoyed a sense of freedom under these conditions. They felt that they could type sentences with less annoyance. This tendency not only agrees with our background study that tactile feedback enhances typing performance, but also suggests that these feedback mechanisms can provide a sensational enhancement.

The major disturbance factor for WPM was the accuracy, since the **Peak WPM** was not differentiated based on the condition used. In addition, the difference was more saturated in **Peak WPM** than in **WPM** alone. We concluded that the feedback conditions had no effect on the typing speed, but the frequency of errors did affect the typing speed overall. Because our setup demands a separation between the finger and the screen, we can interpret that less erroneous conditions enabled a more stable touch-typing experience.

The fastest typing speed on our touch surface keyboard reached only 67% of that found for a physical keyboard on an average. In a study on mobile touchscreens by E. Hoggan et al. [6], the tactile touchscreen technique used reached almost the same speed as that for a physical keyboard, which may imply that our feedback design is flawed. However, we need to point out the differences in the experiment setups used. In Hoggan's approach, the participants were asked to memorize an entire phase and to type the phrase without a break in their visual focus. The users also typed on the touch surface keyboard while carefully viewing the keyboard area. In our experiment, the participants were asked to type while following a phrase displayed on the screen. In addition, because a 1-min practice session is quite short, the participants may not have adapted well to each configuration.

In our study, the keyboard area was separate from the screen. This is not a common configuration yet. However, several companies are now developing dual-screen laptops, and the separation of the touch surface keyboard and display is garnering attention. Users are sometimes forced to use their visually separated keyboard under this type of situation.

CONCLUSION

Our experimental results showed that *Full+S* dominated the other conditions and that keyboards with partial texture (*F-J* and *Home*) had a negative effect, contrary to our expectations. Our main conclusion is that the combination of full surface texture and sound feedback will be helpful in improving the efficiency of a touch surface keyboard. These findings may be of practical value as the statistically significant improvement found in this study did not require an active tactile feedback mechanism, which is not easy to implement effectively on a touch screen, and only required the addition of a 0.1-mm-thick layer on the screen and a simple sound feedback mechanism.

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