The typing performance and preference costs of reducing tactile feedback and tactile landmarks in tablet keyboards

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The purpose of this study was to evaluate the effects of tactile landmarks and tactile feedback on keyboard typing under real-world conditions. Four keyboards were tested, representing a range of tactile landmarks versus no landmarks, tactile feedback versus no tactile feedback, and the ability to rest the fingers on the keys vs. keys that triggered when simply touched. Participants completed a typing task on each of the keyboards while their performance and preference was collected. The conventional keyboard with tactile landmarks, tactile feedback, and the ability to rest the fingers was significantly better than the other options both in terms of performance and preference. The capacitive keyboard, which had tactile landmarks but no tactile feedback, nor the ability to rest fingers on the keys without triggering them performed the worst in terms of accuracy and preference, showing that tactile landmarks alone do not ensure good performance.

INTRODUCTION

As notebook and tablet computers follow the market trend towards increased mobility, there is pressure on input devices to get smaller. This poses a risk of reducing their usability. For instance, previous work showed negative effects on typing performance and comfort for keyboards with smaller key spacing (Pereira et al., 2012) and slower performance and increased ulnar deviation of the wrist for touchpads with reduced size (Camilleri et al., 2012).

One of the most extreme examples of input device size reduction is in tablet computers which have replaced physical keyboards with on-screen keyboards (OSKs). These OSKs offer the advantage of portability, but lose many of the traditional keyboard typing features that have evolved over the long existence of keyboards. The tradeoff for this high portability is that OSKs have been shown to have inferior typing performance, comfort, and preference ratings. For instance, Chaparro et al. (2010) measured a 27% reduction in typing speed on an iPad OSK when compared with a netbook keyboard with physical keys. Similarly, a study with the Acer Iconia tablet's OSK concluded that "participants made more errors with the [OSK] than with the other, physical keyboards. Further, participants typed slower on the [OSK] than on the other three [physical] keyboards." This virtual keyboard was also the least preferred of those tested (Hoyle et al., 2013).

Kim et al. (2012) ran a study where users typed on an OSK in a traditional computer setup where the task monitor was separate from the keyboard. This study found that the OSK reduced typing speed by more than 60%, accuracy by more than 10%, and significantly increased subjective discomfort at the hand/wrist and the neck/shoulder relative to a conventional keyboard. Conversely, this study found that less force was applied to OSKs than to physical keyboards.

Another study compared a conventional keyboard with a FingerWorks touch keyboard (a flat, opaque keyboard surface with no tactile landmarks or feedback). That study found that the conventional keyboard was 40% faster and 16% more accurate than the touch keyboard (Thom-Santelli, 2004).

Some of the measured performance differences can be explained by the fundamental differences between physical keyboards and OSKs. Physical keys offer tactile feedback to give confirmation that they have been successfully depressed. Physical keys also offer valleys and ridges that can be felt to properly position the fingers over the keys, without the need to look at the keyboard. Users can rest their fingers on physical keys, in contrast to OSKs where keys trigger with a finger tap. As a result, users must visually orient their fingers and hold them over the screen, potentially disrupting their typing style on an OSK. Finally, physical keyboards provide the full screen space for the task, whereas OSKs occupy roughly half of the screen real estate.

However, it is not clear how each of these factors affects typing performance. Crump and Logan (2010) investigated the effects of different types of tactile feedback by deconstructing a conventional keyboard, incrementally removing the keytops (tactile landmarks) and then the dome switches (tactile feedback). Not surprisingly, they found increases in typing response time, interkeystroke interval, and error rate for the keyboards with reduced tactile landmarks and feedback. Error rate, for instance, increased 62% when the keycaps were removed and 175% when the tactile domes were also removed - leaving participants to type on a flat sensor. While this study design isolated potential confounding variables by running all tasks on the same deconstructed keyboard, it also is not reflective of real-world typing performance as keyboards are never used in these partially deconstructed states.

The purpose of this study was to evaluate four real-world keyboards that possess different tactile landmarks, tactile feedback, and types of touch versus press activation to give insight into the effects of keyboard feel in typing performance and preference. This information is important to those who must weigh the benefits of providing more portable keyboards with the costs of reducing tactile landmarks and feedback (especially key travel) from keyboards - potentially reducing their performance.

METHOD

The four keyboards included in this study were:

On-screen keyboard (OSK):
The OSK used in this study was the default keyboard for the Microsoft Surface 1 tablet running Windows 8 RT. Visual feedback was present as each key was highlighted when touched – a unique capability of the OSK. Since users typed on a flat glass surface, there were neither tactile landmarks nor tactile or audio feedback when a key was triggered. Keys were triggered when the fingers lifted off the screen. The keyboard was used in Landscape mode. See table 1 for key switch properties.

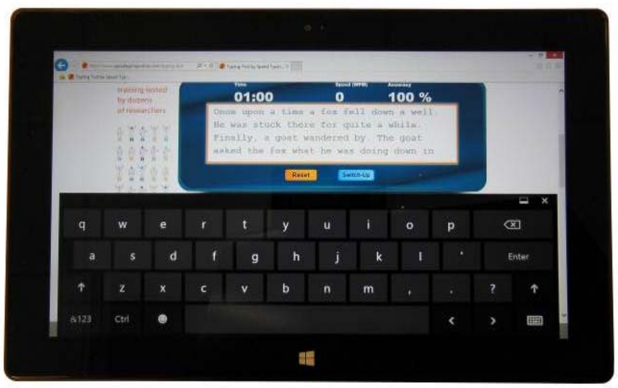

Figure 1 – Microsoft Surface On-Screen Keyboard (OSK)

Capacitive keyboard:
The capacitive keyboard was a very thin (.6mm) concept keyboard. The keyboard provided neither tactile nor audio feedback for key presses. However, it provided limited tactile landmarks via keytop shapes that were raised .2mm over the surface, and .2mm tactile nubs on the ‘f’ and ‘j’ keys. This shallow key height results in generally less distinct tactile landmarks than those on conventional keyboards. Keys were triggered when the fingers touched the surface.

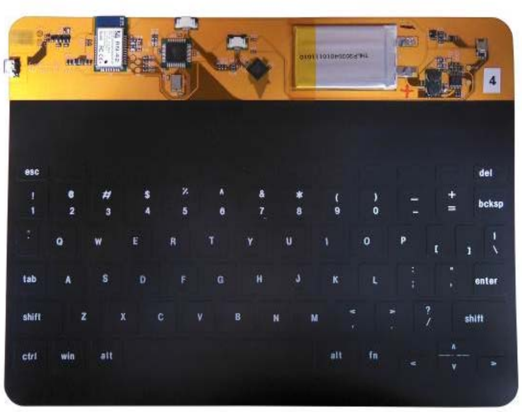

Figure 2 – Capacitive Keyboard

Microsoft Surface Touch Cover:
The Touch Cover used a resistive force sensor to sense key presses. This allowed users to rest their fingers on the keys without triggering them. The force required to activate a key press was measured at 75g with a 5mm diameter circular contact area. The keys do have some shaping and were elevated .2mm over the surface, similar to the capacitive keyboard, as well as tactile nubs on the ‘f’ and ‘j’ keys. The keyboard provided neither tactile nor audio feedback for key presses.

Figure 3 Microsoft Surface Touch Cover

Microsoft Surface Type Cover:
The Type Cover was very similar to the Touch Cover in layout, but featured moving, physical keys that provided tactile feedback and some audio feedback when depressed, and tactile nubs on the ‘f’ and ‘j’ keys.

Figure 4 Microsoft Surface Type Cover

All keyboards were connected to a Microsoft Surface tablet for the typing task. This tablet uses a 10.6” screen with a 16:9 aspect ratio. Screen resolution was set to 1366x768. The OSK was typed directly onto the Surface, while the other keyboards used the Surface tablet as an external monitor. Audio feedback from the computer was turned off for all keyboards, so they could operate in their natural physical state. Differences between the keyboards are summarized in table 1.

Key Characteristics	**On-screen keyboard (landscape)**	**Capacitive keyboard**	**Surface Touch Cover**	**Surface Type Cover**
Tactile / Audible Feedback	No	No	No	Yes
Key Travel	0	0	0	1.5 mm
Activation criteria	Finger Lift	Finger Touch	75g (37.5kPa)	60g
Can rest fingers on keys without typing	No	No	Yes	Yes
Visual feedback on keystrike	Yes	No	No	No
Tactile Landmarks	No	Yes	Yes	Yes
Key gap width	1.8 mm	3 mm	2.5 mm	0.6 mm
Key gap depth	0 mm	0.2 mm	0.2 mm	2.5 mm
Tactile nub height on 'f' and 'j' keys	0	.2 mm	-0.2mm	0.2 mm
Keycap concavity	0	0	0	.1mm
Other Variables				
Centerline key spacing (pitch)	18.7 mm	18 mm	18.6 mm	18.6 mm
External Monitor	No	Yes	Yes	Yes

Table 1: Summary of keyboard characteristics. Emphasized variables are highlighted.

Task

A typing test interface (speedtypingonline.com) was used which presented a series of sentences in the form of Aesop's Fables, which were presented in randomized order. The participants were asked to type the phrases as quickly and accurately as possible, while maintaining their natural typing style. Users were allowed to correct their errors if they desired. Autocorrect was not enabled. The position of the task interface on the screen was the same for all keyboards.

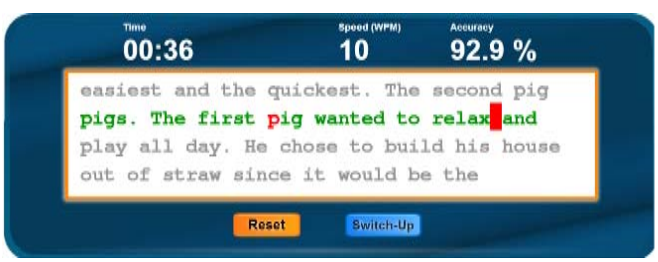

Figure 5: Typing task interface

The software automatically calculated net typing speed (the gross typing speed minus the number of missed words, expressed in words-per-minute (WPM)) and accuracy (the percentage of words typed correctly). Note that the accuracy measured is conservative in that it excludes words typed incorrectly even if they were later corrected.

Participants and Procedure

14 people (7 male and 7 female) participated in this study. Average hand size trended to the smaller side, with hand length averaging 19th percentile for the males, and 18th percentile for the females. When asked how particular they were about their notebook keyboard performance on a five point scale (1 – don't care / 5 - very particular), participants responded with an average of 3.9, indicating that they were particular about their keyboard performance. Eight of the participants self-identified as touch typists, verifying that keyboards were tested with a variety of typing styles. Ten of the participants owned a tablet and used the OSK (i.e. were familiar with typing on this keyboard style). One participant used an external keyboard with their tablet.

The entire test took each subject approximately 50 minutes to complete. The study began by measuring the participant's hand size, and asking a series of general questions on their keyboard usage. Participants were then asked to feel the keyboards and to rank them from best to worst on key feel after trying each for roughly 30 seconds. This was intended to simulate the experience of trying a number of keyboards quickly while shopping to find the one that feels the best. Once the ranking was completed, a series of typing tests was run on each keyboard. Balanced Latin squares were used to determine the order of exposure to the keyboards across participants. Participants were allowed to adjust their seated height and tablet position to meet their comfort preferences before performing the typing tasks. They were given a one minute warm up period on the typing task in which to get comfortable with typing on each keyboard, followed by a short break and a two minute typing task during which typing performance data was collected. For the first keyboard, the participants were given an additional warm up session to familiarize them with the task. After the typing task, participants were questioned about their typing experience, during which they rested from typing. After all of the keyboard typing tasks were completed, participants gave a final key feel ranking based on their extended experience typing on the keyboards.

RESULTS

Typing performance results are shown in Figures 6 and 7.

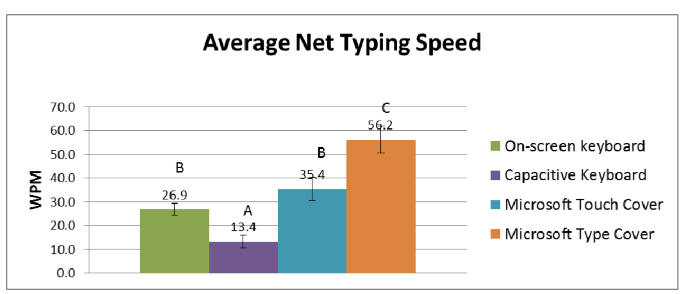

Figure 6: Average net typing speed. Values that do not share a letter are significantly different. Error bars represent the standard error.

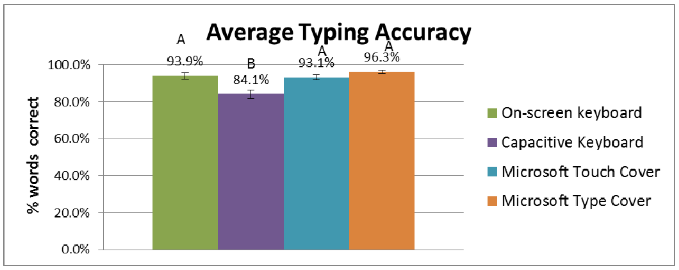

Figure 7: Average typing accuracy. Values that do not share a letter are significantly different. Error bars represent the standard error.

Differences in net typing speed and accuracy were evaluated using a one-way ANOVA with a Tukey follow-up. Significant differences were found between keyboards for net typing speed $F(3,52) = 18.71$, $p < .001$, and for accuracy $F(3,52) = 10.94$, $p < .001$. Blocking for participants, the Tukey minimum significant difference is 12.4 WPM ($p < .05$). Differences in typing performance relative to the OSK are summarized in table 2.

	Net typing % difference	Accuracy Difference
OSK relative to capacitive KB	50%*	9.8%*
OSK relative to Touch Cover	-32%	.8%
OSK relative to Type Cover	-109%*	-2.4%

Table 2: Relative typing performance differences. * denotes significant ($p<.05$)

Table 3 shows the average subjective key feel rankings taken at the beginning of the study (with only short keyboard exposure), and at the end of the study (after the full typing experience). Initial rankings mapped very closely to final rankings, meaning that people did not change their minds much over the course of keyboard use. Keyboards were ranked from 1st (most preferred) to 4th (least preferred), meaning that lower numbers represent higher preference.

Key feel rankings (lower is better)	Initial Ranking	Final Ranking
On-screen Keyboard	2.9	2.6
Capacitive Keyboard	3.4	3.6
Microsoft Touch Cover	2.7	2.8
Microsoft Type Cover	1.0	1.0

Table 3: Average key feel rankings (1 = most preferred, 4 = least preferred)

DISCUSSION

Overall, typing speeds were much higher for the traditional keyboard with tactile feedback - the Type Cover. This is consistent with the previous studies that have shown reduction in typing speed for OSKs (Chaparro et al., 2010, Hoyle et al., 2013). Keyboards with tactile landmarks but no tactile feedback showed mixed effects in typing speed relative to the OSK, depending on whether users could rest their fingers.

Observationally, the OSK disrupted user's typing styles – reducing them from using almost all of their fingers to just one or two per hand and requiring frequent looks at the keyboard to place fingers. This behavior change was caused by the combination of key activation on finger tap (no finger resting) and the dependency on visual feedback for finger alignment. Overall, the OSK offered the advantages of visual feedback upon keystroke, and short viewing distance to the content. This partially compensated for its shortfalls in lack of tactile landmarks and feedback. Still, the OSK provided an inferior typing performance relative to the physical keyboard. From a tablet keyboard standpoint, the OSK was attractive in that it was built into the tablet (i.e. nothing extra to carry), and offered typing performance comparable to the Touch Cover and better than the capacitive keyboard.

The capacitive keyboard showed the worst performance overall. This was somewhat surprising as an external capacitive keyboard would be expected to offer benefits over the OSK. For instance, the capacitive keyboard offered tactile landmarks. Additionally, the full screen was available for display with the capacitive keyboard. This is contrasted with the OSK where half of the screen was obscured by the keyboard itself. Even though the full screen was available, screen space was not a factor in this study as the typing window size was standardized to fit with the OSK in all conditions. The capacitive keyboard also had several disadvantages relative to the OSK. The capacitive keyboard offered no local feedback, whereas the OSK provided visual feedback by highlighting the key when a character was successfully tapped. Users were observed frequently looking between the keyboard, to verify finger placement, and then to the screen, to see whether input was successfully registered. Making this worse, the visual distance between the typing task and the keyboard was greater for the capacitive keyboard than the OSK.

Similar to the OSK, typing styles were disrupted on the capacitive keyboard. On it, users changed to using just a few fingers per hand and relying on visual positioning for finger placement. An analysis of the average gross typing speeds shows that they are very similar for these keyboards: 36.8 WPM for the OSK, 33.8 WPM for the capacitive keyboard. The significant accuracy reduction drove the reduction in net typing speed. The accuracy issues were observed to be caused largely by the lack of feedback on the capacitive keyboard, combined with the fact that it was too easy to trigger keys, including accidentally hitting adjacent keys. So, keys had to be struck accurately and were perceived as being "too sensitive." Like the OSK, users were seen frequently identifying the desired keys visually rather than tactilely and then verifying that the inputs registered properly by looking at the screen. Since the keys triggered on touch, users were not able to make use of the tactile landmarks (touch could only be used for input, not location). This would seem to be a fundamental issue with any external keyboard with keys triggered on a touch. Triggering the keys on finger lift rather than finger touch might help this. But, that approach was not tested in this study. Subjectively, the capacitive keyboard was least preferred, with nine participants rating it a four (least preferred), and the remainder rating it a three (second to last).

There was no statistically significant difference in typing speed or accuracy for the Touch Cover (with tactile landmarks) relative to the OSK (no tactile landmarks). Subjectively, the OSK and the Touch Cover were also ranked almost identically. Despite these performance similarities, a difference in user behavior was observed. Using the tactile landmarks of the Touch Cover and the ability to rest the fingers on the keys, users were able to maintain their normal typing style – indicating that the tactile landmarks were successful. This is in contrast to the OSK, which caused users to change their typing style. However, the lack of feedback on the Touch Cover keys caused users to frequently check that input was properly interpreted by looking at the screen. That tended to slow typing down. The typing speed effects of having no feedback versus having no tactile landmarks appear to be roughly similar in magnitude as there was no significant difference between the Touch Cover and the OSK, despite the observed difference in typing style. Adding feedback (audio, for instance) to the Touch Cover would likely improve its performance.

The direct comparison of allowing fingers to rest on OSK keys without triggering them versus traditional OSK keys that trigger on tap has been explored in previous work. Kim et al. (2013) found that OSKs that allowed finger resting had similar typing performance to OSKs that do not allow finger resting. It is not surprising that the ability to rest the fingers alone did not make a significant difference in typing performance. However, the combination of finger resting and tactile landmarks would be expected to improve typing performance. While that combination was not found to be significant in this study, this is likely due to the fact that the OSK provided visual feedback on keystrike while the Touch Cover offered no feedback.

The Type Cover was the clear winner for net typing speed. It provided the combination of tactile landmarks and tactile feedback which performed significantly better than the other keyboards. This performance advantage was subjectively noted by the users as well. All fourteen participants rated the Type Cover as most preferred for both initial ranking and final ranking. That is the strongest possible subjective preference. Familiarity with a conventional keyboard alone does not explain these findings, as nine out of fourteen participants owned and used a tablet with an OSK. This result underscores the importance of both tactile landmarks as well as tactile feedback for optimal typing performance.

CONCLUSIONS

The capacitive keyboard performed the worst overall both in terms of typing performance and subjective preference. While it provided tactile landmarks, users were unable to make use of them due to their inability to rest their fingers on the keys without triggering them. It provided no key press feedback.

The OSK performed similarly to the Touch Cover, with no significant difference. Even though it lacked tactile landmarks and tactile feedback, the OSK did provide visual feedback, giving participants confidence that keys were properly registering and enabling them to type without explicitly verifying input. In contrast, the Touch Cover provided tactile landmarks with the ability to rest the fingers, but no feedback when keys were pressed. The difference in feedback (visual for OSK, none for the Touch Cover) likely negatively affected performance, confounding the ability to see benefit from the tactile landmarks.

The conventional keyboard with tactile landmarks and tactile feedback provided the best keyboard performance both in terms of typing speed and strong subjective preference. This underscores the importance of the combination of tactile landmarks and tactile feedback in higher performance typing.

LIMITATIONS

The main limitation with this, as any keyboard study, is that other variables besides those being tested exist between keyboards. These other variables were minimized where possible (see table 1), and many of those that remain have been shown to have minimal effects within normal keyboard design ranges. For example, Pereira et al. (2012) found no differences in typing performance for key pitches in the range of 17mm-19mm. Additionally, this is a study with a fairly small sample size and a relatively short exposure to each keyboard. However, as expected, large differences were found which still yielded significant results. Additionally, participants represented a range of user types.

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