# On-screen keyboards: does the presence of feedback or tactile landmarks improve typing performance?

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## ABSTRACT
Physical keyboards provide feedback and tactile landmarks that are not present on on-screen keyboards (OSKs). Similarly, physical keyboards provide faster typing speed than OSKs. The present study was designed to address the lack of research into the direct application of different types of feedback and tactile landmarks to on-screen typing with the intent of improving tablet OSK performance. Fourteen participants performed typing tasks using 6 tablet OSK variants: no feedback (the benchmark), audio feedback, visual feedback, haptic feedback, key-shaped tactile landmarks, and inverse tactile landmarks with ridges over the key gaps. Typing performance was not statistically different across the conditions, except for the key-shaped landmarks, which performed worse. This was largely due to the overlay affecting the sensitivity of the keys. The conclusion is that, without additional changes, feedback and tactile landmarks alone do not offer the opportunity to improve the performance of OSKs.

### Author Keywords
Typing; touchscreens; text input; tablet computers; tablets

### ACM Classification Keywords
H.5.2. User Interfaces: Input devices and Strategies; Evaluation / methodology

### General Terms
Human Factors; Design; Measurement; Performance

## INTRODUCTION
Mobile devices with touch screens are ubiquitous, and the differences between phones, tablets, and computers are blurring. Most of these touch-enabled devices make use of an on-screen keyboard (OSK), yet current OSK designs demonstrate inferior performance when compared with traditional physical keyboards [5, 9, 16]. As we continue developing these devices, we should aspire to reach the point at which our creativity becomes the bottleneck rather than our text entry method [13]. Since current OSK designs are not yet good enough to hit this mark, we can learn from the characteristics of physical keyboards that provide faster typing speeds and attempt to emulate them on OSKs.


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There are several differences between OSKs and physical keyboards that may contribute to the reduced typing performance, including: the inability to rest fingers on the keys without typing, the absence of tactile landmarks that enable users to feel the edges of keys, a lack of tactile feedback when a key is depressed, as well as other general keyboard layout differences (e.g. OSKs tend to be smaller than traditional keyboards to fit on a given screen).

To emulate some of these physical characteristics on OSKs, key press feedback can be provided via visual, audio, or haptic means. Tactile landmarks can also be provided via overlays (e.g. the Touchfire overlay), or optically matched buttons that morph out of the screen (e.g. Tactus). These options are marketed as improvements to OSKs, but they still do not match the feel of physical keyboards.

While related work exists, no quantitative studies have been published that show the effects of tactile landmarks and feedback on tablet OSKs. This information is an important piece of improving tablet OSK performance. The purpose of this study was to address this gap by comparing a tablet OSK with no feedback or tactile landmarks to OSKs with visual, audio, and haptic feedback, as well as OSKs with concave and convex tactile landmarks while keeping all other factors identical (e.g. layout). Outcome measures included typing speed, accuracy, and subjective preference.

### Related work
Previous studies have explored the effects of tactile landmarks and feedback for data entry in non-tablet OSK contexts, but with mixed results. Surprisingly, most papers found no effect for keyboard feedback, especially for expert typists. But the results are often dependent on context - for instance numeric keypad entry as opposed to full keyboards. Most of these studies are quite old.

Several of these studies have explored push button and number entry contexts. One of these papers concluded “visual, auditory, or kinesthetic feedback shows little effect on performance by experienced operators, but visual feedback appears to be important during training” [1]. This finding was reinforced by a study which found that auditory feedback generally had no effect, with the possible exception of no-travel keys for which error rates were worse than traditional keys [17]. The effects of *visual* feedback were explored for another number entry task, which found no effect on speed, although feedback did affect the number of corrections that were made [19].

For typing tasks, one study looked at the effects of tactile key feel and found that experienced typists type with a fixed motor program that doesn't depend on feedback. This study stated that "key travel is unimportant as feedback for experienced operators" and "a flat keyboard is not necessarily worse than a keyboard with key travel" [8].

Contrary to this, another early study found improvement in performance and user preference with the inclusion of audio feedback in keyboard design, although they noted that users wanted the ability to turn the feedback off [15]. A more recent study found benefit by combining audio feedback and a full texture plate for OSKs, but no benefit for audio feedback or tactile landmarks in isolation [11]. This OSK was specialized with pressure sensors to enable fingers to rest on keys without triggering them, and was used in a desktop context (not tablet) with separate keyboard and monitor. No other forms of feedback were explored here.

A conventional keyboard study investigated the effects of incrementally removing the keytops (tactile landmarks) and the rubber dome sheet (tactile feedback) from a physical keyboard. Not surprisingly, they found worse performance for keyboards with reduced tactile landmarks and feedback [3]. This study design isolated confounding variables by running tasks on the same keyboard mechanism, but was not reflective of real-world typing performance as keyboards are never used in these deconstructed states.

Focusing on tablet-sized keyboards, four real-world keyboards with different feedback and tactile landmark characteristics were compared on performance [16]. The traditional physical keyboard showed the best performance, while a flat capacitive off-screen keyboard with no feedback showed the worst performance. There was not a significant difference between the OSK with visual feedback and the flat physical keyboard with tactile landmarks but no feedback.

Another exploration built a tablet OSK that allowed fingers to rest on the keyboard without typing, the TapBoard [12]. But no performance advantage was found when it was compared with a standard OSK. No tactile landmarks were present for this OSK.

Haptic feedback has been integrated into small touchscreens [18], and most touchscreen cell phones today provide audio, visual, and vibrotactile haptic feedback. The effects of vibrotactile and audio feedback have been explored in these small touch screens for a numeric entry task [14]. In this context, both audio and tactile feedback improved performance relative to no feedback.

To conclude, elements of feedback and tactile landmarks have been explored in non-tablet OSK contexts, though with mixed and context-dependent findings. Several external keyboard and key entry studies found no benefit for providing visual, audio, or tactile feedback keyboards in typing or numeric entry tasks, particularly for expert typists. But, the application of feedback and tactile landmarks directly in the context of text entry on a tablet OSK has not been specifically addressed until now.

## METHOD

Six keyboard variants with different feedback and tactile landmark characteristics were created on a 10.1" Samsung Galaxy Tab 2 tablet. The OSKs used the AnySoftKeyboard layout with the 'plain dark' theme (Figure 1), a commonly used, real-world OSK. Like all tablet OSKs, keys triggered on touch-and-lift, meaning that it was not possible to rest fingers on the keyboard without typing. This was most relevant for the tactile overlays, which could only be felt to reposition fingers when typing.

The feedback and tactile landmark variants included:

*No feedback or tactile landmarks* – the benchmark

*Visual feedback* – keys turned red when touched.

*Audio feedback* – keys emitted the Android OS "click" sound when touched. Tablet volume was set at 50%

*Haptic feedback* – keys triggered the tablet's vibromotor when touched. Intensity was set to a 100ms pulse. This was long enough to be felt during a normal screen touch. The haptic feedback was accompanied by an audible buzz.

*"Keys" tactile overlay* – A pattern of .7mm thick acrylic was laser cut to match the layout of the OSK in order to provide the feel of raised keys. These keys were adhered to a standard transparency sheet, and then affixed over the OSK. Gaps between keys matched those of the OSK – 1.7mm. See figure 2.

*"Inverse" tactile overlay* – This overlay was the inverse of the "keys" overlay, with the gaps between keys being raised by .7mm to provide tactile landmarks around the keys.

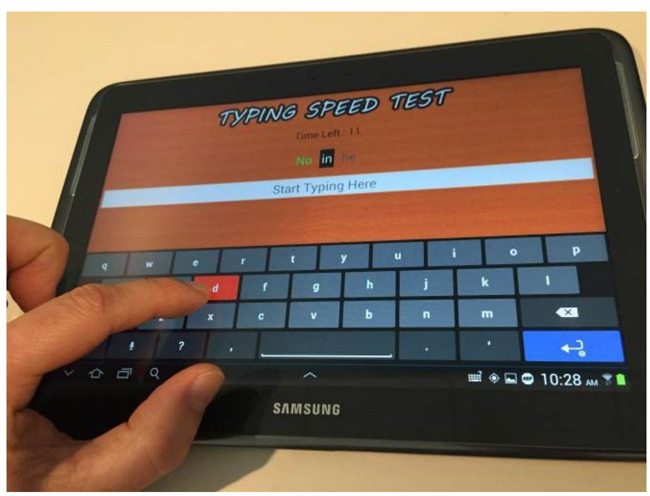


**Figure 1. The "typing speed test" task on the 10.1" Galaxy Tab 2, using the AnySoftKeyboard showing visual feedback on "d."**

**Figure 2. The tactile overlays - "Inverse" overlay, with ridges between keys at left, and .7mm thick "Keys" overlay at right.**

### Task

A typing test ("Typing Speed Test" in Android OS) was used, which presented a series of randomized words in sentence format, including commas, periods, and capitalizations. Participants were asked to type as quickly and accurately as possible, while maintaining their natural OSK typing style. Users could correct errors within the current word if they desired, but not previous words. Previous words were highlighted green or red if typed correctly or incorrectly, respectively. Autocorrect was not enabled. The interface position on the screen was the same for all keyboards. The software automatically calculated net typing speed (the gross typing speed minus the number of words with errors, expressed in words-per-minute (WPM)) and accuracy (the percentage of words typed correctly). The software did not capture the number of typos within a misspelled word, nor any corrections made.

### Participants and Procedure

Fourteen working professionals were included in this study, 7 male and 7 female, with ages ranging from the mid-20s to the early 60s. Hand length trended small, averaging 23rd percentile for males, and 30th percentile for females [7], with one left-handed user. Seven participants identified as touch-typists, 2 as hunt-and-peck typists, and 5 as blended. Three participants had longer fingernails, which can alter OSK typing style by precluding the use of finger tips. Twelve participants owned a tablet, though only 5 of them reported typing on them frequently. The variety of users was selected to ensure that results were generalizable.

A within-subjects study design was used, with each participant typing on all 6 keyboard variants. Participants first adjusted their seat height and tablet position to meet their comfort preferences, then answered background questions. Keyboard presentation order was counter-balanced to mitigate learning or fatigue effects. Participants were given one warm-up session to familiarize them with the task, then given the six keyboards in the pre-set order. Tablets were placed flat on the table in landscape mode and used with two hands to represent standard typing usage. For each keyboard, participants were given a familiarization period, followed by the two minute typing task in which typing performance data was collected. After each keyboard, participants were questioned about their typing experience. Once all of the keyboards had been tested, participants gave a final keyboard preference ranking. The entire test took each person approximately 45 minutes.

## RESULTS

Typing performance results are shown in Figures 3 and 4. Error bars represent the standard error. Differences in net typing speed and accuracy relative to the benchmark condition (no feedback, no tactile landmarks) were evaluated using 2-tailed pairwise t-tests. Significantly inferior typing performance was found for the "Keys tactile landmarks" condition relative to the benchmark for both net typing speed (p=.007), and accuracy (p=.04). A trend for reduced net typing speed was found for the Inverse Tactile Landmark condition, but it wasn't quite significant (p=.10). No other performance differences were found, though even these differences have caveats, as will be discussed.

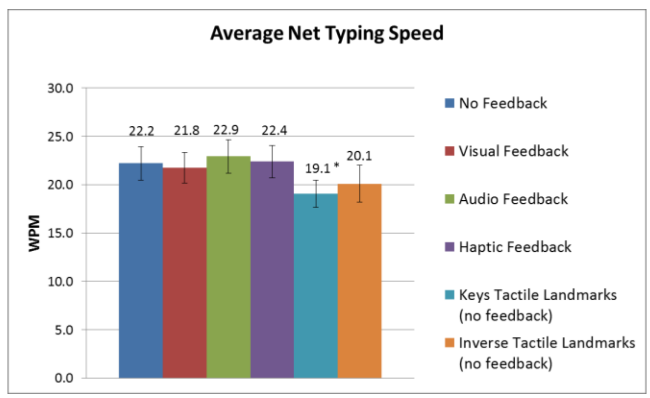


**Figure 3. Average net typing speed. * represents significant difference (p<.05) relative to "no feedback"**

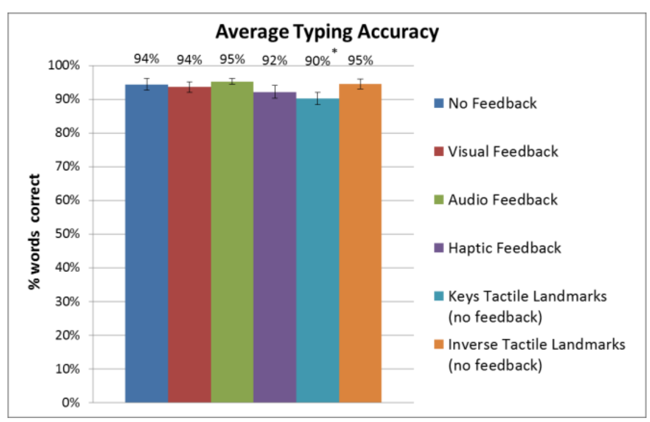


**Figure 4. Average typing accuracy. * represents significant difference (p<.05) relative to "no feedback"**

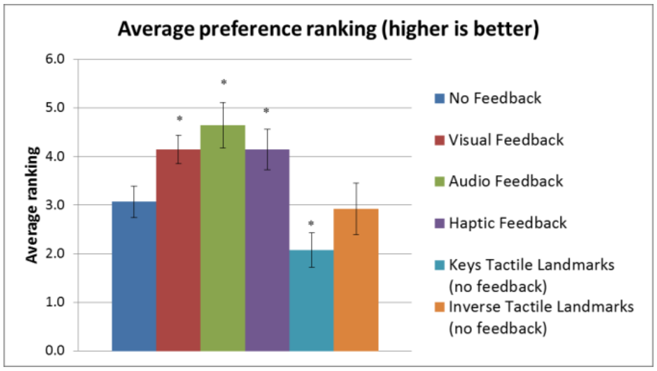


**Figure 5. Average preference ranking. 6="most preferred", 1="least preferred", * represents significant difference (p<.05) relative to "no feedback"**

Subjective rankings are shown in Figure 5. Differences in ranking were evaluated relative to the "no feedback" condition using pairwise Mann-Whitney U tests to account for the non-parametric data. All feedback conditions ranked higher relative to "no feedback", and the "Keys Tactile Landmarks" ranked as less preferred ($p<.05$). There was no difference in rank for the "Inverse Keys" condition.

## DISCUSSION

### OSKs and typing style

Typing on the tablet screen is different than typing on a physical keyboard. One of the few advantages of typing on a tablet is that the visual distance between the input area (the keyboard) and the output area (the screen) is very small. For the Galaxy Tab 2 keyboard used in this study, there was only a 23mm distance between the top of the keyboard and the typing input area. This made it easy to quickly verify that keys were correctly typed when using the more visually intense "hunt-and-peck" typing style, and may have reduced the need for other forms of feedback.

But, there are also differences that slow users down on OSKs relative to physical keyboards. As previously mentioned, fingers cannot be rested on OSKs without entering data, meaning that it is impossible to establish "home position" by feel. Tactile landmarks must be felt without consequence in order to be fully utilized, and current tablet OSKs do not provide that ability.

Another issue with tablet OSKs is that they tend to be smaller than traditional keyboards. Previous research suggests that typing performance drops off when center-to-center key spacing drops below 16mm for square keys [10]. The AnySoftKeyboard keys were rectangular, with key spacings of 21.5mm horizontal, and 12.3mm vertical. This smaller vertical spacing may have affected typing speeds overall. But this spacing was constant for all of the keyboards and therefore should not have affected differences between conditions.

At least two previous studies have indicated that typing is an open-loop activity, especially for expert typists [4, 8] – meaning that feedback is not used while depressing keys. The findings from this study show again that feedback is not necessary. However, the context is also quite different as noted above: nearby visual verification that keys were typed, inability to rest fingers on the glass, small keyboard layout, and reduced capability to touch-type.

Typing on the OSK interfered with normal typing style. Zero participants touch-typed on the OSKs, despite 7 touch-typists present in the study. Of these, 2 were reduced to using just two index fingers on the OSK. Only 5 people used 7 or more fingers to type, and only 4 people out of 14 used their right thumbs to press the spacebar of the OSK, whereas previous work has found that 78% of people normally do so when typing on a physical keyboard [2].

### Feedback

There were no typing performance differences for any of the feedback conditions relative to the no-feedback condition, though there were differences in preference rankings. While this result is not what is intuitively expected (more feedback is better in most contexts), it is consistent with much of the previous research on keyboard entry [1, 8, 11, 17, 19]. In the traditional keyboard context, feedback was not needed by experienced typists to maintain their typing performance. The OSK context is a little different, however, as most of these users were not expert, and many typed with a different style from what they use on a physical keyboard as noted above.

Participants could feel the screen when they struck it and see the characters appear as they were typed, which provided some feedback on key touches, even for the no-feedback condition. The small distance between the keyboard and the text task helped with this. Adding audio, visual, or haptic feedback in addition to these basic types of feedback did not improve typing performance.

Based on rankings, audio feedback was the most preferred. Five participants stated that they liked the sound, while most participants felt that the audio feedback communicated that they could safely move to the next character (though this difference did not show up in terms of improved performance). However, 6 of the participants commented that the sound was annoying or too loud. Most stated that they would need the ability to turn it off, and that it would likely annoy those around them.

Visual feedback was more preferred than no-feedback in the rankings, even though it also did not yield a performance improvement. Two participants (one with red/green color blindness) did not notice the visual feedback at all relative to the no-feedback condition. Most participants had nothing strongly positive nor negative to say, though 3 people commented that they didn't like that the spacebar did not offer visual feedback (which it, in fact, did not), and two more commented that they did not like the choice of red for the highlight color.

Similarly, haptic feedback was more preferred than no-feedback, even though it did not offer a performance improvement either. In general, there were positive comments on the haptic feedback such as "the vibration is neat." The sound of the haptic feedback was heavily commented on, with 6 people saying they did not like the sound, while 4 liked it or preferred it to the sound of the audio feedback condition. Two participants commented that that the haptic feedback was indistinct at high speeds – the pulses blended together and were not crisp enough. The haptic pulse width was set to 100ms to be long enough for people to feel it. However, future haptic feedback for keyboards should likely be set a little shorter to accommodate faster typing styles, perhaps around 75ms or less, to avoid this blending.

The present study measured short-term effects of feedback. However, a previous study looked at the long-term effects of audio feedback on typing force and muscle load, and found that the effects of feedback were negated over time [6]. That study found a short-term reduction in finger muscle load that disappeared after one week and remained no different after two weeks. Though the outcome measures were different, there is no basis to expect typing feedback to have a greater effect with more exposure time.

The conclusion on feedback is that it did not enhance typing performance on tablet-sized on-screen keyboards, though it did affect how much people liked a given keyboard design.

### Tactile landmarks

The Keys tactile landmark overlay degraded typing performance and subjective preference when compared with the "no feedback" condition. This is somewhat surprising because users would have had the opportunity to ignore the landmarks if they didn't like them, in which case the keyboard would function just like the benchmark OSK. However, there are several factors that contributed to both the dislike and performance issues for this condition.

The biggest issue was that the Keys tactile overlay affected the sensitivity of the keys. Prior to the study, no sensitivity differences were found. But, the unexpected performance findings and user feedback (11/14 commented on the lack of responsiveness) prompted a follow-up sensitivity test. For this, each key was struck 20 times using either a hunt-and-peck style, or a touch-typing style. Keys registered 100% with no overlay. With the Keys tactile overlay, key strikes only registered 98% of the time with hunt-and-peck, and 95% of the time with touch-typing. It is possible that the repeated placing and removal of this overlay altered its performance. The finding of reduced performance with the keys tactile overlay is almost certainly due to this issue and therefore no conclusions can be made about this condition.

Beyond key sensitivity, users had other frustrations with this overlay. As the Keys tactile overlay looked more like a traditional keyboard, users expected it to work more like a traditional keyboard. In particular, they expected to be able to rest their fingers on the keytops for comfort and to feel the home position. Instead, they were frustrated because they couldn't touch the keys without generating keystrokes. This mismatch in expectation led to some of the dislike of this tactile overlay. This is a real-world issue as tap-on-lift is standard for tablet typing, and representative of existing hardware-only overlay designs. To be effective and meet user expectations, future designs should combine tactile landmarks with the ability to rest fingers without typing.

Physical implementation issues with the Keys overlay also contributed to its general dislike. The gaps between the keys were small – 1.7mm, matching the OSK. These gaps were too small to be easily felt by the fingers. In this way the design was not very effective in providing tactile landmarks as intended. Future designs ought to consider larger gaps to be more easily felt – perhaps around 3mm. Further, three participants commented that the overlay added parallax, making it harder to see the key legends.

The Inverse tactile overlay avoided many of the issues that plagued the Keys overlay – the keys were thinner so there were no complaints about the sensitivity or parallax, and the tactile landmarks were easy to feel. Also, keys were not likely to trigger if the landmarks were inadvertently touched since the tactile landmarks were over the key gaps and not the keys themselves. Subjectively, the Inverse tactile overlay was the most polarizing: with 3 people ranking it as their most favorite, and 5 people ranking it their least favorite. People who liked it felt that it guided their fingers to the correct spots. People who didn't like it felt that it interfered with their typing style, or that the narrow tactile landmarks were uncomfortable to touch. On average, the Inverse tactile overlay showed similar performance and preference relative to the no feedback condition.

One implementation issue to note on the Inverse tactile overlay is that the overlay shape encircled the spacebar (including the bottom edge) and potentially interfered with thumb strikes. This shape required an unnatural horizontal orientation of the thumb in order to press the spacebar. Several participants commented on this issue. If future versions of this type of overlay are explored, the bottom edge of the spacebar overlay should be left open to allow for better thumb access.

In conclusion, tactile landmarks did not improve typing performance. Previous work suggests that there is some benefit for combining the ability to rest fingers on keys, tactile landmarks, and audio feedback in external touch keyboards [11], though that interaction was not explored in this study.

Overall, this study found no significant performance benefits for either tactile landmarks or for different types of feedback while typing on a tablet OSK. See table 1 for a summary of how these findings compare with the previous key entry and keyboard work as discussed in the introduction.

**Table 1: Summary of previous feedback and landmark studies. - indicates no effect found, + indicates performance benefit**

<table>
<tr><th>Study</th><th>Visual feedback</th><th>Tactile feedback</th><th>Audio feedback</th><th>Tactile Landmarks</th><th>Finger resting</th></tr>
<tr><td>[1]</td><td>-</td><td>-</td><td>-</td><td></td><td></td></tr>
<tr><td>[17]</td><td></td><td></td><td>-</td><td></td><td></td></tr>
<tr><td>[19]</td><td>-</td><td></td><td></td><td></td><td></td></tr>
<tr><td>[8]</td><td></td><td>-</td><td></td><td></td><td></td></tr>
<tr><td>[15]</td><td></td><td></td><td>+</td><td></td><td></td></tr>
<tr><td>[11]</td><td></td><td></td><td colspan="3">+</td></tr>
<tr><td>[11]</td><td></td><td></td><td>-</td><td colspan="2">-</td></tr>
<tr><td>[3]</td><td></td><td>+</td><td></td><td>+</td><td></td></tr>
<tr><td>[16]</td><td></td><td></td><td></td><td>-</td><td></td></tr>
<tr><td>[12]</td><td></td><td></td><td></td><td></td><td>-</td></tr>
<tr><td>This study</td><td>-</td><td>-</td><td>-</td><td>-</td><td></td></tr>
</table>

## LIMITATIONS

The biggest limitation of this study is that the reduced sensitivity of the Keys tactile landmarks limits our ability to make conclusions about that condition. Beyond that, the sample size was fairly small, and exposure times to each of the keyboards were fairly short. These results are representative of initial exposure to feedback and tactile landmarks, for two-handed typing with a flat tablet in landscape mode. Finally, accuracy measures were limited in that the error measure provided by the test software did not detect corrected errors, or track multiple errors made in a single misspelled word.

## CONCLUSION

Typing performance for tablet-sized OSKs was not improved by any of feedback or tactile landmark conditions. While feedback did not enhance typing performance on tablet-sized OSKs, it did have an effect on how much people liked a given keyboard design.

Similarly, tactile landmarks did not improve typing performance on their own. However, conclusions are withheld on the Keys tactile landmarks due to degraded sensitivity associated with this particular implementation. Future explorations should allow fingers to touch OSK tactile landmarks without triggering key presses in order to make appropriate use of them. Landmarks must be touched to be felt, and therefore to provide any utility.

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