Text Entry on Interactive Tabletops Using Transparent Physical Keyboards

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Abstract
A key obstacle to interactive tabletops becoming as useful as traditional desktop computers is the lack of efficient text entry methods. We report a quantitative study comparing four different haptic keyboards for interactive tabletops and draw conclusions for future iterations.

Author Keywords
Interactive tabletop, text entry, passive tangible keyboard, SLAP Widgets

Text Entry on Tabletops
Although interactive surfaces have gained much interest over the last two decades, the tabletop community is still searching for a representative application, or "killer app", that justifies the move from traditional desktop computers to interactive surfaces for certain tasks. Despite the inherent affordance for collaborative work, there are currently no established productivity applications on tabletops that outperform their desktop counterparts in terms of efficiency. We believe that a main reason for this is the lack of an efficient text entry method.

Many operations on tabletops can be triggered by touching on-screen icons or using gestures. This makes tabletops suitable for all kinds of kiosk systems, games,

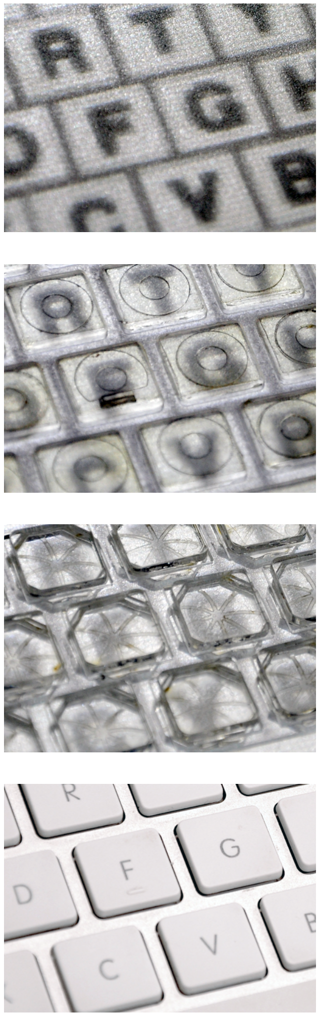

Fig. 1: Keyboards in our user study. From top to down: On-screen, Flexible SLAP, Rigid SLAP, Conventional.

and musical applications. However, productivity tasks often require extensive text input, and writing long texts demands an efficient and ergonomic input method. Finding an appropriate text input method that takes the nature of interactive tabletops into account is still an open research question.

A common solution, which is often employed for public touch screens, are on-screen keyboards. While easy to implement, they provide only limited haptic feedback. They require visual attention, and typing errors are frequent when users' hands drift. Findlater et al. [1] give evidence that modifying the key layout and involving a per-user model for keystroke detection can improve such keyboards. Yet, typing on a flat surface is still significantly slower than on conventional keyboards. Also, the *intangibility* of on-screen keyboards implies that modes are required to show, hide, move, and rotate them in a tabletop context.

Hinrichs et al. [2] analyze several input methods and determine requirements for input devices on tabletops. These include performance factors such as efficiency and learnability, as well as environmental factors like real estate and mobility. Factors relevant for collaborative work, such as the ability to share input devices, are also considered. In tabletops applications, it is important that typing devices are accessible on demand, can be easily aligned and passed on to other users, and removed if they are not needed anymore.

Despite the numerous different text input methods like gestures or speech recognition, the most efficient way of entering text on tabletops seems to be wireless physical keyboards (e.g., [5]). Additional top-projection gives them the capability of dynamic relabeling [6]. However, they are relatively large, bulky, and inflexible. Top-projection also leads to occlusion issues and may change the user experience. This potentially increases the learning effort when transitioning from desktop to tabletop systems.

Passive Tangibles

In 2009, we demonstrated SLAP Widgets [3], tangible general-purpose controls for interactive tabletops. They are passive haptic tangibles that are tracked visually; a camera beneath the table surface detects the arrangement of visual markers and spots inside the controls' areas. Made of transparent material such as acrylic or silicone, they can change their visual appearance on the fly using rear-projection.

Our basic widget set includes the SLAP Keyboard. It combines the benefits of a physical keyboard with the flexibility of dynamic rear-projection. It is also lightweight, robust, and *collapsible* (cf. [2]), and inherently supports social protocols, like the hand-over of controls. Unlike on-screen keyboards, no modes are required; the keyboard is ready to use when it is put on the table, and can be quickly removed after typing. It is also low-cost and robust; the absence of electronic parts simplifies maintenance. Finally, we can dynamically change the keyboard layout.

Most users appreciated the idea of a flexible keyboard. However, we have not reported a quantitative evaluation of this concept yet. In the following, we present a recent study that compares four different keyboards, ranging from pure virtual ones to conventional physical keyboards (Fig. 1):

Fig. 2: Experimental setup.

Keyboard	M	SD
Conventional	59.2	18.6
On-screen	37.8	15.7
Flexible SLAP	33.4	12.3
Rigid SLAP	32.1	13.5

Table 1: Word per minute depending on condition.

Keyboard	M	SD
Conventional	7.1	7.5
On-screen	10.7	9.4
Flexible SLAP	12.6	9.0
Rigid SLAP	12.8	8.3

Table 2: Total error rate in percent depending on condition.

1. **On-screen keyboard**: The keyboard layout is projected on the tabletop surface. No further haptic feedback is given.

2. **Flexible SLAP keyboard** as presented in [3]: It consists of an off-the-shelf silicone keyboard protection skin mounted on acrylic bars. Thin acrylic plates and rings on each key improve haptic feedback.

3. **Rigid SLAP keyboard** is entirely made of acrylic: Each key is spring-loaded with a bent acrylic foil. If a key is pushed down, a small knob touches the surface and triggers a keystroke. The user also hears a click sound when hitting a key. We developed this keyboard in response to a preceding qualitative user study whose participants demanded a clearer pressure point.

4. **Conventional keyboard**.

For the rear-projected keyboards (1-3), we employ a visual approach to detect keystrokes: Pushing a key creates an IR spot that is seen by a camera beneath the surface.

Quantitative User Study

In our user study, we asked participants to type strings on each of the four keyboards *as fast and as accurate* as possible. We hypothesized that the conventional keyboard would outperform all other keyboards in terms of words per minute (WPM) and total error rate (TER) and that the haptic feedback of the SLAP keyboards would beat the virtual on-screen version.

Experimental Setup

Participants were sitting at a curve multi-touch system, BendDesk [4]. The keyboard of each respective condition was placed and/or projected in front of the user on the horizontal surface. Position and size of each key was constant across conditions. During the test, the table showed strings at the vertical surface that users had to copy. An input field below displayed the current user input (Fig. 2). We intentionally chose this two-focus setup as it suggests eyes-free typing.

Test Procedure

A participant subsequently conducted all keyboard conditions in randomized order. A condition consisted of 2 training trials and 15 trials in which we measured the performance. In each trial, the table presented a random sentence from the phrase set by MacKenzie and Soukoreff [7]. The participant entered each string in lower-case and confirmed with the *Enter* key.

Participants

We tested 10 participants between 23 and 31 years old (M = 26.0, SD = 2.4). All subjects were skilled writers using a keyboard "multiple times a day".

Results

Our results are shown in Table 1-2 and Fig. 3. A mixed-effects model analysis of the variance showed a significant main effect of the keyboard condition in terms of words per minute ($F_{3,531}$ = 150.6495, $p <$ .0001) and total error rate ($F_{3,531}$ = 15.4131, $p <$ .0001). There was no significant interaction between trial and condition and no main effect in trial. The user was modeled as a nominal random effect in the test. A pairwise comparison using Tukey-Kramer HSD test showed significant differences between the

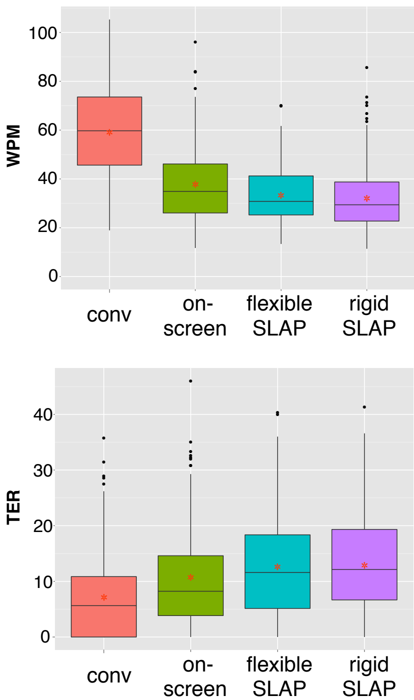

Fig. 3: Words per minute (WPM) and total error rate in percent (TER) depending on condition. Red asterisks denote mean values.

conventional and all other keyboards in terms of WPM and TER (p < .01). Differences between on-screen and SLAP keyboards where not significant, with the exception of the pair on-screen versus rigid SLAP keyboard in terms of TER (p = .0067).

Discussion

It is no surprise that the conventional keyboard outperformed all the others. Pressing on one of its keys means pressing on over 60 years of research and optimization. Also, all participants were highly familiar with it. However, in contrast to our hypothesis, the SLAP Keyboards did not outperform the on-screen version. From the quantitative findings, the differences among the non-conventional keyboards are small and only partially significant. Given the benefits of dynamic relabeling and the convenience to reposition or hand-over, SLAP Keyboards still represent a useful alternative to on-screen keyboards.

However, many participants commented that they perceived typing on the SLAP keyboards as more error prone. The main reasons where visual detection errors, bad readability of key labels due to the glue used for the key assembly, and a too strong pressure point in the rigid keyboard. These are engineering issues that have to be solved in future iterations.

Developing a transparent keyboard is tricky. Even after 150 hours of design iterations and hand-made prototypes, the SLAP Keyboards still do not reach the efficiency a conventional keyboard. An important lesson learned is the fact that the pure addition of haptic feedback does not yield a more efficient typing. We consider this as an “uncanny valley of haptics”. As long as the haptic feedback of our SLAP keyboard does not at least nearly match the conventional keyboard, it will *impair* the users’ ability to type text. Accordingly, a deeper investigation of haptic perception and an industrial manufacturing process are necessary. This requires an interdisciplinary team including experts in mechanical engineering and product design. This also means that further engineering iterations are necessary that are difficult to publish at CHI. However, for the ultimate goal to produce a lightweight, translucent, tangible keyboard for interactive tabletops that enables fluent text input, this would be clearly worth the effort.

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