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The results did not support all our hypotheses and demonstrated that our understanding of tangible interactions is still limited.

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TangiSoft: Designing a Tangible Direct-Touch Tabletop Keyboard

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Abstract

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1. Introduction

Despite the important role that the text entry plays in many applications, little research has been conducted on text entry methods for digital tabletops [13]. Many text-entry techniques have been proposed for mobile and pen-based devices, but only BubbleType [14] has targeted the unique affordances of digital tabletops, that is, the large horizontal display, direct-touch input, and multi-user support. The specific requirements of text-entry for digital tabletops were characterized by [13] and include: direct-touch interaction, space, rotatability, mobility, and simultaneous interaction.

We have designed a new input device, the *TangiSoft* keyboard (figure 1) that is a hybrid of a physical and a soft keyboard. The *TangiSoft* keyboards seeks to combine the separate advantages of tangible and direct-touch interaction. The design reflects the special requirements for text-entry techniques for digital tabletops [13], and follows the guidelines set out by Scott et al. [28] relating to interpersonal interaction, fluid transition between activities, use of physical objects, and multi-user concurrent interaction. In simple terms, the device is a trackable piece of paper with a printed keyboard layout. Text is entered by direct-touch on the printed keys. The tangible qualities include the ability to move the keyboard by hand and the presentation of a virtual digital layout physically. The soft (virtual) characteristics include the direct-touch interaction and augmentation of the printed keys by projecting digital information (e.g. highlighting for prediction).

2. Motivation

Hinrichs et al. [13][14], Ryall et al. [27], and Widgor et al. [42] have discussed the issue of text-entry on digital tabletops. Ryall et al. proposed wireless keyboards and PDAs as a preferable alternative to soft keyboards and graffiti-style input methods. By contrast, Widgor et al [42] observed a single tabletop user in conventional office setting and found that the soft keyboard was adequate and maintaining the direct touch interaction was a significant factor in this. Both studies recommended that the requirements for text entry at the tabletop needs further exploration and Hinrichs et al. [13] proposed a set of desirable characteristics for digital tabletops regarding text entry, and corresponding set of evaluation criteria.

Our research into tabletop interaction is conducted in the context of the application of digital tabletops in the education of 12-14 year olds, and the need to investigate new text-entry techniques designed specifically for digital tabletops originated directly from our initial studies working with small groups. The observations of Hinrichs et al. [13] apply

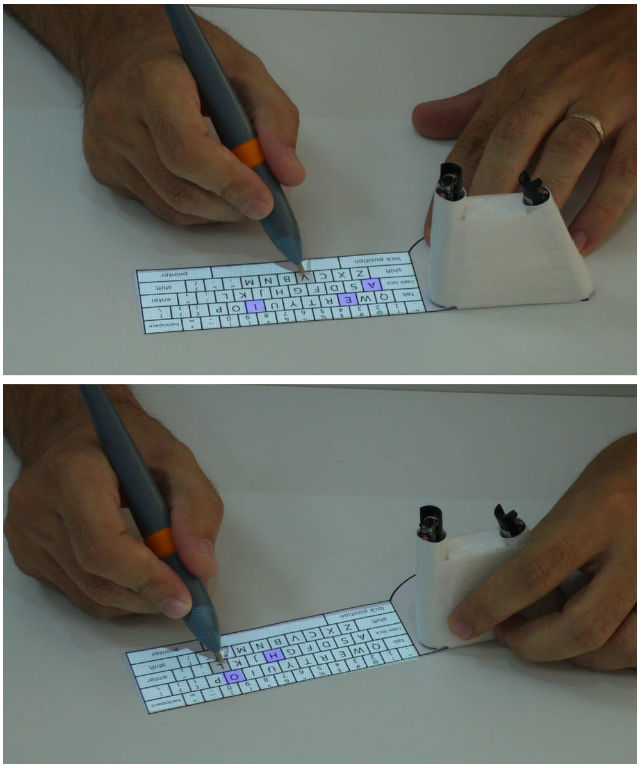

Figure 1. The TangiSoft direct-touch keyboard. Users handled the tangible keyboard in two different ways. The gray projection indicates the position of the pen, and the blue projection indicates the predicted next keys.

well to small group educational settings and include a number of key requirements including ease of learning, maintenance of direct-touch interaction, use of space, rotatability, mobility, and provision for simultaneous interaction.

3. The Design

The principal design choices for our tangible keyboard include: (1) the use of direct-touch input; (2) the design of a keyboard as a tangible tool (allowing for two-handed interaction); (3) the use of a printed, rather than virtual keyboard layout; and (4) the augmentation of the physical paper with projected digital information.

3.1 Direct-touch input

The overhead of switching between tasks, and in this case any task and a writing task, must be kept to a minimum. Observations of users performing tasks on traditional and digital tables have highlighted the fluent mix activities, and regular rapid switching between tasks such as drawing and writing [36, 5, 28]. Such fluid transitions are hindered by the need to change between a direct-touch interaction and the use of a physical keyboard for text entry. Therefore, maintaining the direct-touch input for text entry is an important component for facilitating fluid transitions between activities at the tabletop [13].

3.2 The keyboard as a tangible tool

The use of soft keyboards in digital tabletop systems often requires users to change the location and orientation of the keyboard, in particular, foregrounding and backgrounding (or hiding) it when switching between tasks. Such display, move, and rotation operations, when performed unimanually, are executed sequentially thereby imposing a significant additional load on the user [19]. By contrast, bimanual interaction allows for such task performance at a natural level of chunking realising significant cognitive advantages [6, 11].

However, Terrenghi et al. [37] observed that simply providing users the ability to manipulate digital objects with two-hands did not result in the benefits expected. Unlike the use of physical objects, users used a single dominant hand when interacting with digital objects even in cases where two-handed interaction was possible. Terrenghi et al. suggested that in order to gain the benefits of two-handed interaction, the interface must provide a “ToolGlass-type” interaction [3] or hybrid physical-digital user interfaces.

Fitzmaurice et al. [7] argued that physical affordances are significantly richer than their virtual counterparts. These include the facilitation of two-handed interaction, and parallel position and orientation control, capabilities that are particularly salient in tabletop settings due to the large horizontal space in which users may orient themselves differently at different times during the same session. Fitzmaurice et al. [7] highlight a number of advantages of tangible interface elements that we seek to realise in *TangiSoft* including: (1) encouraging two-handed-interaction; (2) making interface elements more direct and manipulable; (3) exploting our experience in working with physical objects; (4) taking advantage of human spatial reasoning skills; and (5) affording multi-person, collaborative use. *TangiSoft* can be manipulated freely using the non-dominant hand and held in any comfortable angle for the dominant hand to act on the keyboard.

3.3 Printed layout on paper

TangiSoft uses a printed keyboard instead of a projected layout, and users press on the printed keys to input a character. Using the printed layout significantly increases the tangible character of the the device (as compared to simply having a physical handle on a virtual keyboard). The use of print media allows very high resolution display of the characters, which contrasts markedly with the characteristically low resolution of current tabletop projection systems. Using print media also has desirable comfort and safety implications with studies of visual fatigue showing that reading print media is both less fatiguing than a positive display (dark characters on a light background) and leads to less ocular discomfort than reading from a negative display (light characters on a dark background) [10] .

3.4 Paper augmentation

Casting a keyboard as a tangible tool does not preclude the incorporation of additional digital properties. In particular, the flat paper layout allows the projection of digital information over the physical layout. Digital augmentation of the printed keyboard allows us to both highlight the key that the stylus is moving over, and show text-prediction cues, that is, highlighting the keys corresponding to the next most probable letters.

4. Related work

From Wellner's [40] pioneering work on digital tabletops a wide range of issues have been investigated including how to display, organize, browse, and visualize digital data on tabletops [26, 34, 33, 35, 31], specific interaction techniques and interface components such as currents [12], the use of shared versus replicated controls [24], integrating rotation and translation [18], and the use of space and orientation [17, 29, 41, 38, 27]. Although guidelines for designing collaborative systems on digital tabletops [28] only a small number of project have considered the problem of text entry for tabletops [27, 42]. Indeed, Hinrichs et al.'s work [13] is the only systematic account of the problems and requirements of text entry on digital tabletops, and establish desirable criteria with which they unpick the existing candidates such as physical keyboards, mobile physical keyboards, speech recognition, handwriting, gestural alphabets, soft keyboards, and gesture-based keyboards. The only text entry technique designed specifically for digital tabletops is the BubbleType [14]. Text entry, and direct-touch text entry in particular, has been thoroughly studied including the use optimized keyboard layouts [21], improving text entry with prediction [23] gestural alphabets as an alternative to handwriting recognition [8, 4], and gesture based techniques [43, 25, 39].

TangiSoft seeks to exploit the many advantages of tangible interfaces [7, 16, 15] but the principal goal was to design a tool that utlizes two handed interaction and allows parallel movement and rotation operations. Following Guard's work on bi-manual action [9], the benefits of supporting two-handed interaction is well understood [2, 19, 6, 11]. Interestingly, Terrenghi [37] contrasted how people manipulate physical and digital media on digital tabletops, and discovered that even when two-handed interaction is supported for a digital tabletop application, people predominantly used just one hand.

5. Implementation

TangiSoft has been developed for a top-projected (1024×768 resolution) pre-production prototype of the multi-pen horizontal *Promethan Activboard*. One pen is used for the actual direct touch interaction, and the sensors of two other pens are used for tracking. A QWERTY layout is printed on a piece of paper and tracked with the sensors (figure 2).

Figure 2. Two alternative designs for the tangible keyboard. Placing the sensors at either ends of the keyboard reduces alignment errors and sensor-sensor interference.

The *TangiSoft* keyboard needs to be calibrated by first placing it in a vertical position (figure 3, left) to established the width and position of the keyboard with respect to the tracking pens for vertical orientation. In the second step (figure 3, right) the keyboard is placed horizontally and the width and height are calibrated for horizontal orientation.

Figure 2 shows the various configuration of the sensors. Placing these on opposite sides of the keypad reduced both the impact of error inherent in the tracking, and interference between the sensors. We made the final keyboard slightly larger than some of our initial designs (13.6×5cm as compared to 11.8×4cm for the first design) to reduce both interference and sensitivity to small alignment errors. Finally key areas were made smaller than the actual hit area to force users to target the middle area of the key and thus tolerate for small errors in alignment. We also pasted this keyboard on a card and laminated it to improve its physical characteristics.

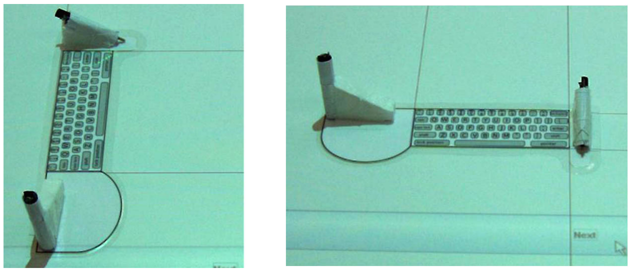

Figure 3. The calibration process. Step 1 (left) reads the vertical values. Step two (right) reads the horizontal values.

Although we considered using Fitts' law to optimize keyboard size, we came to a similar conclusion as that stated by MacKenzie and Zhang [22] that the overall keyboard size depends directly on the individual key size, that is, increasing the hit area has a proportional effect on the distance and thus an index of difficulty that is independent of the keyboard size. MacKenzie and Zhang measured the speed for two keyboard sizes (10cm and 18cm from keys "Q" to "P") and found no significant difference in speed, although the error rate was significantly higher for the smaller keyboard). Accot and Zhai [1] provide a general guideline for steering (and thus pen-based interaction at this scale) that choosing a size that is large enough to utilize finger and wrist movement, but not elbow movement, yields the best performance.

Another factor to consider in determining the size of a keyboard designed for tabletops is the space that the keyboard occupies. Since tabletops provide multi-user environments and it is inappropriate to have the keyboard of one user covering a large area of the tabletop shared space. Although we implemented *TangiSoft* on a top projected pen-based tabletop, the keyboard can still be used with bottom projected and touch-based surfaces (printed on a semi-transparent paper) using the inherent tracking of such systems.

6 Case studies

Implicit in our design are the following hypotheses: (1) tangible characteristics and two handed interaction will promote mobility; (2) that the small keyboard size made possible by the printed layout should improve speed; and (3) that the printed layout should result in less eye strain that for a projected equivalent. We conducted two sets of studies to explore these claims, two behavior studies (in particular mobility), and two performance studies.

6.1 Behavior studies

A small number of subjects (ages ranged between 17 and 25, and all were regular computer users) were observed using *TangiSoft* with two applications . Each study commenced with a supervised training session on both *TangiSoft* and the default standard soft keyboard until they reported felling comfortable with the interaction technique (training sessions ranged from 5 to 10 minutes). The applications logged the location and orientation of the keyboard with each phrase entered and we filmed users to assist the analysis of participants behaviour, in particular, in relation to their use of non-dominant hands and handling style of the keyboard when moving and typing.

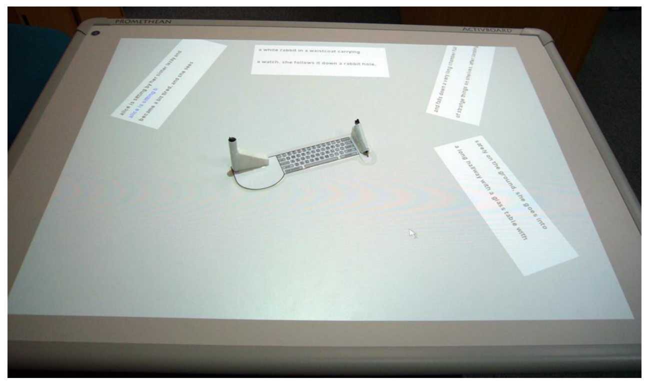

Figure 4. Long text copying application.

6.1.1 Study 1: copying long text phrases

The first application required users to copy two relatively long lines of text in four blocks located at the edges of the table as in figure 4. We assumed that having to copy two lines of small, distant, and rotated text that cannot be moved would encourage users to move the keyboard. Also to make the comparison fair, we did not use the standard Activboard soft keyboard as it cannot be rotated, and we implemented a rotatable soft keyboard. The new soft keyboard uses the same layout that is printed on the paper, but in a projected form, with a thick border around it that allows translation of the keyboard by dragging it from the edges, and rotating by dragging the corners.

Results: Three users took part in the study (1 female and 2 males), and exhibited three distinct behaviors. The first user moved both the tangible and the soft keyboard when working with each text block, and even moved around the table to get into the best position to type the text. She used both hands to work on the tangible keyboard and used the non-dominant hand to move it and set the frame of reference across the entire tabletop surface. The second user also moved and rotated both types of keyboard in a similar

manner but stayed in a single location (in a sitting position) – movement was primarily rotation. This user also used the non-dominant hand to move *TangiSoft*, but while typing he used only his dominant hand and put the non-dominant hand under the table. The third user did not move the soft keyboard at all, but only slightly changed the orientation of *TangiSoft* while typing (up to 10 degrees), and like the second user did not hold the tangible keyboard while typing.
Reflections: Moving the soft keyboard required a sequence of drag and rotate actions compared to one fluent movement for the tangible keyboard. Nevertheless, we concluded from the behavior of the first two users that since the task for each block was rather long, then it made sense to move both keyboards even if moving the soft keyboard required more than one action. However, we could not conclude that the tangible keyboard is more mobile than the soft keyboard, and sought to explore potential difference further with an alternative application.

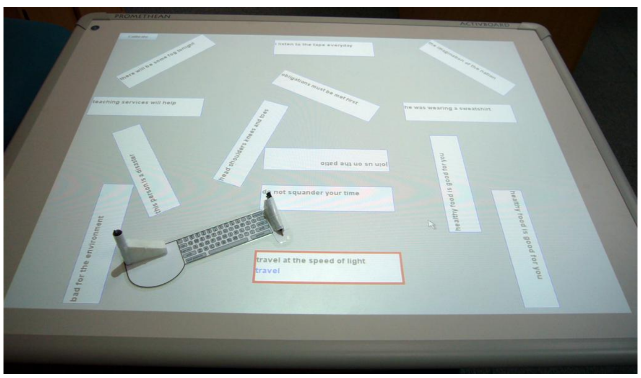

Figure 5. Short text copying application.

6.1.2 Study 2: copying text phrases

Four users (1 female and 3 male) used second application which required them to copy 14 phrases of 3-5 words located across the tabletop. The order of the copying was fixed between phrased located at relatively distant locations. We assumed that when faced with the task of copying only shorter texts users would only move the keyboard if the action was sufficiently lightweight (figure 5).
Results: Three of the four users had taken part in the first text copying study and were only interviewed after this study to ensure no biasing of their behaviour. Two of these participants exhibited similar behavior for both applications. One moved both keyboards alike and moved around the table while entering the text, the other moved both keyboards alike but did not move himself. Although in some cases this stationary user moved the tangible keyboard with his dominant-hand keeping his non-dominant hand under the table. The third user exhibited a different behaviour, changing the position and orientation of the soft keyboard in for half the phrases but neither moving nor changing the rotation of the tangible keyboard. Nevertheless he still used the non-dominant hand to hold the keyboard while typing. The fourth (and new) user did not move either of the keyboards for the whole duration of the task although again he held the tangible keyboard with his non-dominant hand during the whole session.

6.1.3 Reflections on the behaviour studies

Despite the elaborate nature of the applications, there was no case in which the same individual moved the tangible keyboard but not the soft keyboard (for the same task), although we did observe that the tangible keyboard did not hinder mobility. Users who frequently moved the keyboard used their non-dominant hands to do so (in most cases). Users held the tangible keyboard one of the two ways shown in figure 1. Placing the keyboard in the appropriate position was done in one fluid movement that combined translation and rotation, as opposed to a sequence of repetitive move and rotate operations required position and orient the soft keyboard.

Our understanding of how people interact with tangible objects is still somewhat limited. While literature suggest that tangible objects allow for two-handed interaction which in turn brings a number of advantages [2, 19, 6, 11], many of the participants reported a preference for using one hand only. One participant considered having to use the non-dominant hand to move the tangible keyboard, or even moving the keyboard with the dominant hand (which required changing the way the pen is held) to be “extra-effort” and preferred the soft keyboard because he could easily move and rotate it with the pen whilst maintaining the unimanual pen-based interaction style.

Another issue with the tangible keyboard is that those who prefer to use one hand, can do so freely with the soft keyboard without worrying that it will move because of the tapping, while in many cases they felt the need to fix the position of the tangible keyboard to prevent it from shifting while typing. Also some participants commented that they felt more at ease when working with the soft keyboard because it feels as part of the application and they interacted with it the same way they do with normal desktop application. Again this ran counter to our hypothesis that working with tangible objects is easier and would be favoured and quickly appropriated by users.

6.2 Performance study

User performance was assessed through two text entry studies. The first compared the speed and accuracy using *TangiSoft* with Activboard soft keyboard, and the second compared speed and accuracy using *TangiSoft* with and without prediction cues. For both studies we used our initial tangible keyboard design (figure 2-A) and ten experienced computer users (2 females and 8 males with ages ranging from 22-35 years). The dimensions for the *TangiSoft* keyboard was 4×12cm and for the soft keyboard 10.7×26cm.

6.2.1 Study 3: speed and accuracy

The task was to type 20 phrases using each keyboard following a training session of 20 phrases. Users performed the study with both keyboards is a randomly assigned order. The phrases to type were taken randomly from the phrase set provided by MacKenzie and Soukoreff [20] and error rates were calculated using minimum string distance [32]. Users were asked not to correct errors made when typing and the backspace key was disabled.

Results: the soft keyboard gave rise to significantly better performance in terms of both speed and accuracy. The average speed in characters per minute (cpm) for *TangiSoft* was 77.7cpm and for the soft keyboard 116.7cpm. Measuring the significance using ANOVA test with a significance level of 0.05 resulted in $F = 29.13$ and $P = 0.004$. The average error rate for the tangible keyboard was 8.4% and for the soft keyboard was 3.1% with $F = 13.90$ and $P = 0.002$.

Reflections: Although counter to our initial hypotheses we can identify a number factors that explain the difference in performance: (1) the need to make small adjustments to the tangible keyboard to align it with the the projection proved to be a more-significant issue than expected, both increasing the error rate and forcing them to slow down to make sure that they are hitting the right keys; and (2) Nine of the ten users stated a preference for a larger sized tangible keyboard complaining that this initial design was too small (contradicting our hypothesis that a smaller keyboard leads to faster performance). Indeed, despite our lengthy training session the second study (same participants) gave an average speed of use of *TangiSoft* with no prediction of 91.8cpm which is significantly better than the speed observed in this study (F=7.18, P=0.0153) which indicates that there is a substantial learning effect not addressed in the design of our studies.

The limitations of the hardware (tracking inaccuracies and interference) which give rise to small miss-alignment between the keyboard and the projection, appear to be the major factor contributing to the the reduction in both speed and accuracy. Before we can make a definitive judgement as to the benefits (or otherwise) of *TangiSoft* we propose additional studies using more accurate tracking and a range of different sized keyboards with different physical properties. Although we anticipated that for pen-based input a smaller keyboard would lead to better performance, MacKenzie and Zhang [22] observed that size does not affect speed. Sears et al. [30] similarly found little difference when comparing the performance of touch-screen typing for keyboard sizes ranging from 24.6cm to 6.8cm (from keys "Q" to "P") and that smaller keyboards lead to slower performance and increased error rate, though their study allowed two handed finger input which has marked differences from our configuration.

6.2.2 Study 4: text prediction

The second study included an additional training session of that required participants to enter 10 phrases with the text prediction feature activited. The prediction information highlights the most probable next letters for the part of word being typed. The actual task was to type 40 phrases alternating between prediction and no prediction.

Results: no significant difference in terms of speed and accuracy was demonstrated. The average speed with prediction was 87.2cpm and without prediction 91.8cpm ($F = 0.81$ and $P = 0.38$). For accuracy the average error rate for the prediction case was 8.55% and without prediction was 9.05% ($F = 0.06$ and $P = 0.81$). Of the 10 participants, three reported that prediction made typing a little easier, one reported that it made typing more difficult, and six reported that it did not make a difference, although two of these commented that it might help when the person is not sure of the spelling especially for long words. Notably, the *TangiSoft* keyboard was always held at an angle ranging from 24 degrees conter-clockwise to 4 degrees clock wise and was very rarely put in a pure horizontal position. Which is a positive affordance of the tangible keyboard.

Reflections: We can conclude with some confidence that prediction is not useful for adults who are expert computer users as was the case for our 10 participants. The prediction feature may still be useful with people not experienced with the QWERTY layout or when trying a new layout [23], and it also has the potential to help children or non-native speakers who have difficulty spelling. Almost all users preferred the online keyboard over the tangible one but implementation issues (specially alignment and size) played a major factor. The task required the users to type a total of 90 phrases between training and actual testing which caused a degree of fatigue. Furthermore, the *TangiSoft* keyboard required a degree of deliberate control to be exercised by the user to prevent it from moving while typing. The effects of both these factors were observed in the latter stages of each trial during which speed decreased and error rate increased for all users.

7. Discussion

The design of *TangiSoft* aimed fulfil a number of requirements: learnability, the maintenance of direct-touch interaction, use of space, rotatability, mobility, and the provision of simultaneous interaction. As we observed from our as we observed in our four studies *TangiSoft* was easy to learn. Direct-touch is maintained by the hybrid design. The use of a printed layout removes the limitation of the projector resolution and allows the keyboard to be as small as the tracking technique and input sensitivity allows. The case studies showed that *TangiSoft* did not hinder mobility and afforded fluid movement and rotation by the non-dominant and dominant hands alike. Finally, regarding simultaneous interaction, it is possible to have as many tangible keyboards as the tracking technology used allows, and it is also easy to move one tangible keyboard among many users working around the table. For these reasons, we claim that Activboard does satisfy the design criteria, yet the issue of user acceptance of this new technique remains.

The results of the studies show that our understanding of how people interact with tangible objects is still limited. Based on literature we assumed that a tangible version of a soft keyboard would yield better performance and more natural use. Also, based on general guidelines for the size, we assumed that smaller would mean faster and that prediction would aid performance. None of these assumptions turned could be demonstrated. Most of the nineteen users who participated in the studies expressed their preference for the soft keyboard principally because: (1) it could be used with one hand leaving the other free; and (2) it gave users the impression that it was more integrated with the application. Nine of the ten users asked also preferred a larger version of the keyboard. Therefore, even if a smaller keyboard can be implemented without the alignment problems we experienced, users express no preference for a smaller layout. Only one of nineteen users asked commented that looking at the tangible keyboard for long periods was more comfortable to the eye than the soft one. Finally, users did not see the need for the tangible keyboard, reporting that for casual text entry tasks the online keyboard (and specially the rotatable version) was sufficient.

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