Improving text-entry experience for older adults on tablets

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Abstract. Touchscreen interfaces are increasingly more popular. However, they lack haptic feedback, making it harder to perform certain tasks. This is the case of text-entry, where users have to constantly select one of many small targets. This problem particularly affects older users, whose deteriorating physical and cognitive conditions, combined with the unfamiliarity with technology, can discourage them from using touch devices. In this study, we analyze the performance and behavior of 20 older adults when inputting text on a tablet. We tested a baseline QWERTY keyboard, as well as 2 variants that use text prediction in order to aid seniors typing. From our results, we derive a set of design implications that aim to improve the performance and usability of virtual touch keyboards, specifically for the older users.

Keywords: Older adults; Text-Entry; Tablet; Pre-Attentive Interfaces.

1 Introduction

In our daily life, we find ourselves surrounded by multi-touch technology, which gained popularity in the past few years through mobile devices such as tablets and smartphones. This enables new opportunities and forms of social interaction, instant information access, constant availability and higher control of the surrounding environment. Since touch screens allow users to directly interact and manipulate the information displayed on the screen by touching it, they are considered to be one of the most natural interaction technologies [7].

This is an opportunity for user groups that, until now, have shown some resistance in adopting technology. The fact that this technology interface relies more on software than hardware makes it highly flexible, and thus easy to adapt to users' needs. This offers the opportunity to design more accessible systems [4]. However, it has the disadvantage of lacking the haptic feedback of physical buttons, making it harder to accurately select targets. This characteristic hampers certain tasks, such as text-entry, where the user has to constantly select one of many small targets. Moreover, since text-entry is a task transversal to many applications, it particularly affects users that have difficulties in aiming and performing movements that require precision.

That is the case of older adults, whose deteriorating physical and cognitive conditions combined with the unfamiliarity with technology, deprives them from the innumerous opportunities created by touch devices. Furthermore, the lack of experience

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with the QWERTY layout can discourage them from using this technology. Although there is a large body of work that tries to understand the touch behavior and improve the typing experience on touchscreens, studies that target older adults are few. Since the requirements for senior users are different due to the declining of their motor and cognitive abilities, the solutions found for young adults may not be suited for seniors.

Therefore, we performed a study to better understand how we can improve the typing speed and/or reduce the error rate of older adults on tablets. Also, we take into account that older people may have little or no experience with the QWERTY layout, and thus developed 2 QWERTY keyboard variants that aim to aid older adults typing. We performed a user study with 20 senior participants. Then, we systematically analyzed the performance of each variant, thoroughly discussing the touch patterns found and the errors committed by the older adults.

Our main contribution is a thorough understanding of text-entry performance on tablets by senior users. We found that visual changes on the keyboard decrease the typing speed, without improving error rate; older adults systematically hit targets to the bottom and to the side of the hand used to type; single touch and a threshold between key taps can be used to reduce accidental insertions; and when a vertical slide occurs between rows, 96.4% of the times users want the character in the above row.

2 Related Work

Generally, older users easily adapt to touch technology. Loureiro et al. [10] analyzed different aspects of 8 touch based tabletop interfaces for the seniors. In all surveyed works, they concluded that touch yields a natural, direct and intuitive way of interaction with a device, allowing easier human-computer interaction for older people.

Stone [15] argue that, considering older people degraded physical capabilities, this kind of interfaces should have multiple sizes for fonts, buttons and icons. To solve the problem of text-entry, authors propose a gesture that allows switching from the traditional QWERTY keyboard (26 buttons), to a 12 button mobile phone interface (0-9*# layout), or even a binary interface. However, no implementation or experimental evaluation was performed.

Other researches have focused on optimal target size, spacing and positioning to improve the usability of touch interfaces for older users [9]. Indeed, Hwangbo et al. found that the target size is an important factor in pointing performance [8]. They recommend square targets with a side of at least 12mm. They also found that when target size reaches this level, the spacing between targets looses importance. However, these studies neglect the particular case of text-entry, which can be considered one of the most difficult tasks to perform on touch devices, due to the large number of targets and small key size and spacing.

Nicolau et al. [13] focused on the particular problem of text-entry. They performed a user study with 15 seniors, measuring the speed and accuracy of participants while performing text-entry tasks, both on a smartphone and a tablet. They also analyze users hand tremor profile and its relationship to typing behavior. Authors derive a set of guidelines for accessible virtual keyboards for seniors. However, the user study was performed using only the QWERTY keyboard, no alternatives were tested.

Although the body of work regarding older adults is relatively small, there is a extensive body of work focusing on average adults. Henze et al. [6] argue that shifting touch events can improve the typing error rate. Authors found that touch events are systematically skewed towards the lower-right corner of keys. Findlater et al. [4] opted for an adaptive keyboard. He evaluated two personalized keyboard interfaces specifically for ten-finger typing, both of which adapt their underlying key-press classification models. One of the keyboards also visually adapts the location of keys. Results have shown that only the non-visual keyboard improved typing speed and error rate.

As noted by Cheng et al. [3], people use different hand postures to type on tablets depending on how they were holding these devices. The authors developed iGrasp, a keyboard that automatically adapts its layout and position based on how the device is held. Another way to reduce the error rate of soft keyboard usage is through language models. Several approaches to highlight keys have been studied which involve making the rendered keys larger or smaller, depending on their likelihood [1]. The authors reported that users were faster and more accurate with this variant than with the regular QWERTY keyboard. Gunawardana et al. [5] developed a method that expands or contracts the keys' underlying area, keeping the visual feedback intact, based on a language model. A simulation suggests that it reduces the error rate.

As we have seen, previous studies are mainly focused on finding solutions for able-bodied adults. Although some studies have already analyzed the touch patterns and the optimal target size and spacing for senior users, none have presented and tested different alternatives to improve the typing experience for older people.

3 Developed QWERTY Variants

Due to the lack of haptic feedback, text-entry remains slower and more error-prone on touch devices than on traditional computer keyboards. Since one of our goals is to aid new users to input text, without hindering older users who are already experienced with QWERTY keyboards, we developed alternative keyboards based on the QWERTY keyboard layout. After developing the regular QWERTY keyboard to serve as a baseline, we developed 2 variants, which are described in the following subsections. These were the variants that achieved the best results in our previous study [14]. These variants use *letter* or *word prediction* to anticipate what the user is going to write. Detailed information about the text prediction algorithm is not the focus of this paper and has been previously published in [14]. The keyboards were implemented as a Windows Modern UI application for Windows 8.

3.1 Color Variant

The Color variant uses the developed letter prediction algorithm to highlight the next most likely letters for the current word (Figure 1a). We expect this variant to perform better than the regular QWERTY keyboard, especially if the user is not acquainted with the QWERTY layout, which might be the case of older adults. By highlighting the most likely letters, senior users may find the desired letter quicker. We also expect that users make fewer errors by noticing they are about to press a key that is not highlighted, or by acknowledging they missed or omitted a key press.

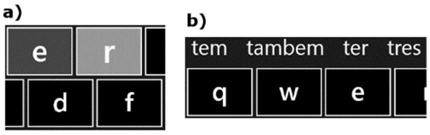

Fig. 1. (a) Color variant; (b) Predicted words variant.

We decided to highlight 4 keys, since a previous study [1] concluded that it was the optimum number between 1, 2 and 4 keys. The highlighted key changes its color from black to gray to avoid the cultural connotations associated with particular colors (e.g.: the green and red colors may have positive and negative connotations, respectively). We also increase the size of the key's label. The highlight is continuous: the more probable the letter, the brighter the color and bigger the label on the key.

3.2 Predict words variant

This variant is an alternative already used in some touch devices. While the user is typing, a list of the most likely words is shown in a horizontal ribbon above the keyboard (Figure 1b). If the word the user wants to write is on the suggested list, he can save some key touches by tapping it so the full word, along with a space character, will be inserted. While this solution is fairly popular among younger users, it may be inadequate for older users. Since there is a cognitive effort required to process the list of suggested words, it might be harder for this group of users to divide their attention between the actual typing and the scanning of the suggestions' list. We opted to suggest 4 words to achieve a balance between the success rate of the prediction and the cognitive effort required to process the suggestions list.

4 User Study

In this user study we evaluate the typing performance of older adults using the developed variants in comparison with the traditional QWERTY keyboard.

4.1 Participants

Twenty participants, 15 females and 5 males, took part in the user study. Their age ranged from 61 to 92 years old, but the most prevalent age group was from 71 to 90 years old (75% of participants). Two participants used only the left hand to type, 5 used both hands, and the rest used only their right hand to type.

No participant had severe visual impairments. We also assessed users' capabilities regarding task-specific tremor, by asking them to draw an Archimedes spiral with each hand without leaning the hand or arm on the table [2]. None of the participants presented accentuated hand tremor. No participant had used a touchscreen device before. Although 17 participants had used the QWERTY keyboard whether in typewriters and/or personal computers (17 participants), most of them (12) reported to have little or no experience with QWERTY keyboards.

4.2 Procedure

The user study had two main phases: training and evaluation. At the beginning of the first phase, we explained how to use the virtual keyboard. Users were asked to type on the developed traditional QWERTY keyboard and the 2 variants. Participants were free to type in the position they found more comfortable. During the training phase, participants were allowed to type 2 sentences per keyboard variant.

In both phases, the task consisted in copying a sentence that was displayed at the top of the screen. After typing the sentence, the user could proceed to the next sentence by pressing a button. Copy typing was used to reduce the opportunity for spelling and language errors. Both required and transcribed sentences were always visible. The sentences were chosen randomly from a set of 88 sentences, such that no sentence was written twice per participant. Each sentence had five words with an average size of 4.48 characters and a minimum correlation with the language of 0.97. These sentences were extracted from a Portuguese language corpus of another study [12]. In order to avoid different correction strategies by the users, the delete key was removed. Participants were instructed to continue typing if an error occurred.

On the evaluation phase, participants were instructed to type the sentences as quickly and accurately as possible. Each user was asked to type 5 sentences for each variant, being the first one still trial (it did not account for the results). The order of tested variants was random to avoid bias associated with experience. In the end, users were asked to answer a survey with some demographic data, as well as satisfaction regarding each variant. The whole process took approximately 1 hour per participant.

4.3 Apparatus

A Samsung ATIV Smart Pc Pro 11.6" was used in the study. Each key has 20mm of width and 15mm of height. Visually, there is a space of 2mm between keys, horizontally and vertically. However, our implementation does not allow pressing between keys: each touch is always assigned to a key. This makes the keyboard more responsive, thus avoiding the frustration of performing a touch that does not produce a character. All participants' actions were logged through our evaluation application, so posterior analysis could be performed.

5 Results

By analyzing the log data produced by our application, we are able to draw conclusions on input speed and accuracy for each keyboard variant. We also focus on types of errors and their main causes. We performed Shapiro-Wilkinson tests of the observed values for Words Per Minute (WPM), Minimum String Distance (MSD) and types of errors to access if dependent variables were normally distributed. If they were, we applied parametric statistical tests, such as repeated measures ANOVA, t-test, and Pearson correlations. If measures were not normally distributed, we used nonparametric tests: Friedman, Wilcoxon, and Spearman correlations. Bonferroni corrections were used for post-hoc tests.

5.1 Input speed

To assess typing speed, we used the WPM [11] text input measure calculated as:

(transcribed text - 1) x (60 seconds / time in seconds) / 5 characters per word

Figure 2a illustrates WPM by variant (without outliers). As expected, we found a correlation between input rate, QWERTY experience and number of hands used to type. A repeated measures ANOVA revealed significant differences between keyboard variants on text-entry speed ($F(2,30)=3.84$, $p<0.033$). Bonferroni post-hoc tests showed significant differences between QWERTY and Color variant, meaning that users type significantly slower with the latter. This result contradicted our hypothesis that inexperienced users, who are not acquainted with the QWERTY layout, would benefit from the Color variant. We believe that the main reason for the lower input rate in the Color variant is that the highlighting of the keys was distracting. However, no user reported this. We also noted that, in some cases, despite the correct letter was the only one highlighted by the Color variant, some participants took a long time to find that letter on the keyboard. This means that some seniors were not paying enough attention to the highlighted keys, excluding them from the benefits of the suggestion.

Regarding the *Predict Words* variant there was no significant difference when compared with the QWERTY keyboard. However, only 7 of the 20 participants accepted at least one suggested word from the list during evaluation; the remaining 13 participants used the *Predict Words* variant as a normal QWERTY keyboard. Still, we did not find a correlation between text-entry speed on *Predict Words* variant and interaction methodology, i.e., if the participant accepted suggested words or typed as a normal QWERTY keyboard.

5.2 Quality of transcribed sentences

To measure the quality of typed sentences we used the MSD error rate, calculated as:

MSD(required text, transcribed text) / Max(required text, transcribed text) x 100

Figure 2b illustrates the MSD error rate by variant. A repeated measures ANOVA did not reveal significant differences between keyboard variants ($F(2,32)=1.044$, $p=0.364$). Opposed to the results obtained on input speed, no correlation was found between quality of transcribed sentences and previous experience with QWERTY keyboards and number of hands used.

We expected both *Color* and *Predict Words* variants to outperform the QWERTY keyboard regarding MSD. Although we are not sure why the *Color* variant did not outperform the QWERTY keyboard, several situations occurred that are important to report. For instance, one participant ended up typing a word similar to the expected one because the *Color* variant suggested it, and he tapped the suggested letters without thinking too much. This is an issue related with the prediction algorithm. Since the system does not always suggest the right letter, the user still has to pay attention to the suggested letters. Sometimes it seemed that participants were afraid of tapping a certain key if the system was not suggesting it, especially after tapping a sequence of keys correctly suggested. The performance of the *Color* variant was also affected by the fact that older users made many errors. This means that the *Color* variant cannot make good suggestions, because once there is an error in the current word, the system is not able to correctly predict the sequence of letters intended by the user.

The *Predict Words* variant also had a MSD similar to QWERTY, mainly because most participants (13) did not accept any suggestion. From the remaining 7, only 3 accepted a high number of suggested words (between 9 and 11 suggestions). From these, 2 participants had worst results in the *Predict Words* variant when compared with QWERTY. This happened because sometimes, when accepting a suggested word (located at the top of the keyboard), users tapped below the intended area, selecting a key from the top row of the keyboard instead. Another common error is to tap the space bar after accepting a suggested word. This counts as an insertion error because after accepting the suggested word a space is automatically inserted. Therefore, the use of the *Predict Words* backfired because participants ended up making mistakes they would not make in other situations.

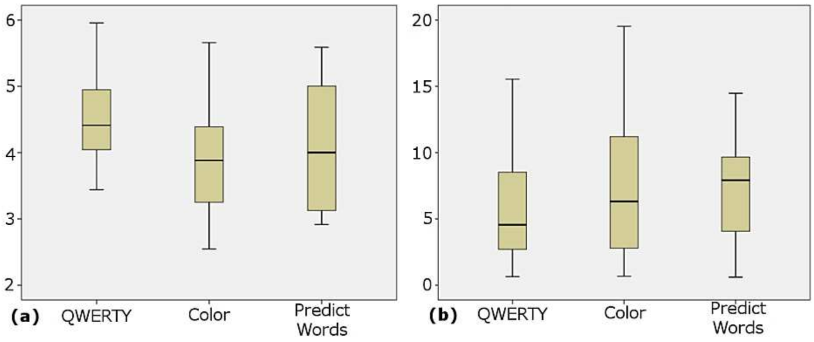

Fig. 2. (a) Participants' WPM by variant; (b) Participants' MSD by variant.

5.3 Typing errors

We classified the types of input errors using MacKenzie's et al. categorization [11] (substitutions – incorrect characters, insertions – added characters, and omissions – omitted characters). In some cases, we assign a more specific categorization to errors, but when we do, we explain the differentiation.

In Figure 3, we can verify that insertion errors are the most common type of error committed by senior participants. This type of error is unevenly distributed through all the participants: participants #2 and #17 are responsible for 62% of all insertion errors. Omissions were the second most common error type, followed by substitutions. The *Predict Words* variant was not analyzed thoroughly regarding typing errors, because most of the participants used it as a QWERTY keyboard.

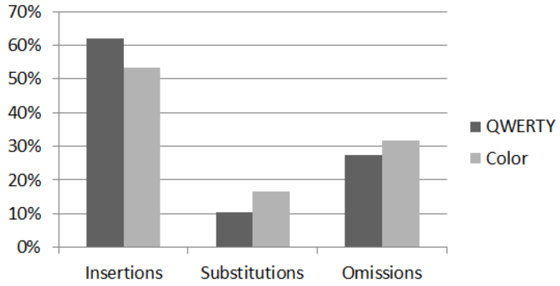

Fig. 3. Contribution of each type of error for the total amount of errors.

Insertion errors.

We found that most of insertions (more than 60% of all insertions) occurred due to multiple interleaved points of contact, i.e., the second point of contact occurs before the first one is released. Since this insertion error exists because the keyboard is multi-touch, it is relevant to assess if this kind of error is mostly committed by participants who used both hands to interact with the keyboard. However, no correlation was found between number of hands used and multiple points of contact insertions.

We found that this type of accidental insertion was committed mostly by participants #2 and #17, which interacted with just one hand. We noted that participant #2 interacted with the index finger of her left hand (intentionally), and sometimes she would touch the screen with the thumb of the same hand (unintentionally), thus generating insertions. Despite participant #17 interacting with just one finger, logs showed that at least two interleaved contact points were recognized. Although we are not sure why this happened (maybe a cut or a dirt in her finger), the only way to correct this kind of error is to disable interleaved touches, i.e., transforming the multi-touch keyboard into a single touch keyboard.

We divided insertion errors into accidental (when users unintentionally add a character) and cognitive (when users intentionally add a character other than the expected). The proportion of each type of insertion error is similar across variants: 81.6% of accidental vs. 18.4% of cognitive insertions. This was expected since, in general, the *Color* variant does not aim to correct insertion errors.

Substitution errors.

We considered two types of substitution errors: neighbor (instead of touching the intended key, users touch an adjacent key) and cognitive (when users touch a different key from the expected) substitution errors. After analyzing the touch data, we found that touch points are skewed to the bottom and slightly to the right for users that interacted with their right hand. Other studies have also reported this result [13, 6]. We also found that the horizontal direction of the shift was related to the hand being used to type. For users that used their left hand, we could not verify the pattern across all keyboard, but it could be that our data might not be enough (only 2 participants used the left hand). Regarding participants that used both hands, we verified that the left side of the keyboard has its touch points skewed towards the bottom-left, while the right side of the keyboard has its touch points skewed towards the bottom-right. These results were true for both QWERTY and Color variant, which means that highlighting keys does not influence aiming. We verified that shifts have a bigger vertical deviation (Mean=13px; SD=11.5px) when comparing to the horizontal deviation (Mean=4.5px; SD=14.7px), for all typing methods. We also found that the vertical shift increases gradually, from the top to the bottom row (average vertical deviations: row1=11px; row2=14px; row3=18px; row4=20px).

In the QWERTY keyboard, users committed 29 neighbor substitution errors and 9 cognitive substitution errors. However, users significantly committed more cognitive substitution errors on *Color* variant (Z=-1.845, p=.065); they committed 30 neighbor and 30 cognitive substitution errors. We verified that in 65.5% of cognitive substitutions the user inserted a character that was highlighted by the *Color* variant. And, in the remaining 34.5%, the expected key was highlighted, but it did not prevent the user from inserting an erroneous character which was not highlighted. We also noted that in 20.7% of the cognitive substitution errors both expected and inserted keys were highlighted. Despite acknowledging this result, we could not find a justification for it.

Omission errors.

We subdivided omissions into 3 sub-categories: failed (the user presses an empty space instead of the intended key – only applicable to the keys in the edges), slide (the press action was in a different key when compared to the release action) and cognitive (user forgets to insert an expected character). Omission errors had approximately the same proportion across variants, being the cognitive most frequent (52%), followed by slide (27%) and failed (21%) omissions. We also found that forgetting to enter a blank space between words was a common issue among older people (44.8% of the total cognitive omissions), most likely due to a lack of practice in typing on computers. Since the Color variant highlights the next most probable keys, it would be expected that, if correct, the suggestion could minimize omissions. Still, cognitive omissions were as frequent as on the QWERTY keyboard. When further analyzing this type of error, we found that in 65% of cognitive omissions the expected key was highlighted. However, the next key taped by users (which was an error), was highlighted only in 22% of the cases. This means the Color variant was often helping the participant, but still they pressed an erroneous key that was not highlighted 78% of the time.

The slide omissions differ from the previous, because the user presents the intention to type a character, but fails in the execution. It occurs when the user presses and lifts his finger on different keys and therefore no output is generated. We classified slide omissions in three subcategories: (1) correct land-on, characterized by the finger landing on the intended key, and then sliding to another key; (2) correct lift-off, characterized by the finger landing on a neighbor key, and then sliding to the intended key; (3) and accidental slide, on which the user has no intention to tap either of the keys. The first type accounted for 36.4% of the slide omission errors, the second 57.6% and the third 6%. We found that all the errors classified as correct land-on, ended always in a key below the intended one; that is, the slide was always performed from the top to the bottom. Contrary to this, 89.5% of the errors classified as correct lift-off, ended in a key above the pressed one. On the remaining cases the slide was performed from the right to the left. This means that when a user performs a slide starting at a key in a given row, and lifts his finger on a key in the row above, we are 100% sure that the user intended to tap the key in the row above. When the slide is downwards, in 85.7% of the times, the user also wants the key in the row above (the key were he landed his finger). In the remaining 14.3% times, we do not know what the intentions of the user were, since the slide was accidental. This pattern was also verified for the *Color* variant. We hypothesize that this occurs because when the user slides down, it is because he is already moving his hand to the rest position, bellow the tablet. When the movement is upwards, it is a corrective movement, because the user adjusted the touch position in a contrary motion to the resting position. This pattern, to our knowledge, has not been reported by any other study, presenting an opportunity for improvement of virtual keyboards.

5.4 User satisfaction

At the end of the user study participants were debriefed and asked about their preferred keyboard. We also collected comments during and after the test about their opinion regarding the several keyboard variants. When asked about their satisfaction (5-point Likert scale) regarding each variant, participants gave a higher rate to the QWERTY keyboard (Mean=3.8; Median=4), closely followed by the *Color* variant (Mean=3.75; Median=4) and finally by the *Predict Words* variant (Mean=3.1; Median=3). Still, 6 participants rated the *Color* variant with the highest score (5), while only 1 participant rated each of the remaining keyboards with the highest score. Statistically significant differences were only found between Predict Words and the other variants; participants were not as satisfied when using Predict Words.

Some users also reported that the tablet was too sensitive, referring to the fact that it is easy to make typing mistakes by lightly touching the device. A participant reported that it was faster to type with the *Color* variant, referring to a specific case when the system was able to always suggest the right letter. Some participants told us that the *Color* variant was really helpful but, in order to take full advantage of it, paying attention was necessary. When participants were asked about why they did not use the suggestions presented in the *Predict Words* variant, most participants said it was a feature too complex and they would need more practice in order to correctly use it.

6 Design Implications

From our results, we derive the following design implications.

- **Keep visual changes to a minimum**. As verified in the user study, visual changes that aim to focus the user attention on the most probable keys have a negative impact in text-input speed. Also, the *Color* variant had twice the cognitive substitution errors, when compared with the traditional QWERTY. Therefore, visual changes should only occur to give feedback about the pressed and released key.

- **Shift the touch points to the top and to the opposite side of the hand the user is using to type**. Our results confirmed that users who used only their right hand to interact with the virtual keyboard had a tendency to touch on the bottom-right of targets. This means that users will benefit from a top-left shift of their touch points to compensate the tendency. Conversely, users who only used their left hand benefit with a top-right shift of their touch points. Users who interact with both hands will benefit from a top-left shift on touch points performed on the right side of the keyboard, and a top-right shift of the touch points performed on the left side of the keyboard. If it is not possible to detect the user's hand posture, an upward vertical shift of touch points will also benefit users.
- **When a vertical slide occurs between two keys of subsequent rows, produce the character in the row above**. When users perform a vertical slide from one row to a subsequent row (up or down), 96.4% of the times the user intends to select the key from the row above. In the remaining 3.6% times, we do not know exactly the intentions of the user were, since the slide was an accidental touch.
- **Choose single touch over multi-touch**. Older users have different necessities and capabilities. Regarding a generic keyboard that should fit all types of older users, single touch is the best choice. The quality of the sentences of the 2 most problematic participants in our user study increased drastically, while it only slightly prejudiced some other participants and had no effect at all on most participants.
- **Omit touch interactions that are below a certain threshold**. Sometimes, the older users would quickly and accidentally insert two characters instead of one. This occurs due to poor coordination and hand tremor. These insertions are characterized by a reduced time interval between the release of the first key and the press of the second key. Therefore, to enhance older adults' error rate, we can omit interactions that occurred below a certain time threshold.

7 Conclusion

Given the increasing use of touch mobile devices and, in particular, tablets, this study is timely and pertinent. The use of tablets by older citizens brings into sharp focus the need to bridge the gap between our aging population and advances in information technology. This is particularly important for tasks that are difficult to perform on touch devices, such as text-entry.

In this study, we investigated the text-entry performance of 20 older adults on a touch-based device. Our user study featured 3 virtual keyboards: traditional QWERTY, Color and Predict Words variants. We found that users typed faster with the traditional QWERTY keyboard. Regarding the quality of transcribed sentences, no significant differences were found across variants. We also found that older adults have difficulties using Predict Words variant mainly because it was too complex and they needed more training to use it. Lastly, we identify some design implications that should improve typing accuracy and encourage researchers to create more effective solutions for older adults. Future research should apply the design implications described here and investigate their effect on text-entry performance.

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