Enhancing Gesture Typing on the T9 While Maintaining Standard Keyboard Layout

by

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Abstract

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Gesture typing is a unique text entry paradigm on the touchscreen since it has good tactile feedback and is easy to use. Additionally, typing on the T9 keyboard can alleviate text input difficulties on small screen devices. However, many words contain consecutive letters that share the identical key on the T9 keyboard. For typing these words with gestures, users need to rely on the combination of tap typing and gesture typing. In this study, T9 with an enhanced key 1 and T9 with wiggle gestures were proposed to resolve the issues of interrupting gestures of swipe typing on the T9 while maintaining the standard keyboard layout. In comparison with gesture typing on conventional T9 in terms of performance and subjective feedback, T9 with an enhanced key 1 showed significant advantages over the other two T9 keyboards in almost all metrics according to the results collected from a user study. For instance, T9 with an enhanced key 1 was 25.7% faster than conventional T9 and was also favored by the subjective ratings of all six NASA-TLX measures. As for T9 with wiggle gestures, it required higher learning costs and at least did not significantly degrade the performance of the T9 keyboard.

Keywords: Gesture Typing; Text Entry; Touchscreen; Smart Watch; T9 Keyboard

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1 Introduction

With the launch of the iPhone, touchscreens with soft keyboards have become the most popular form of text entry. However, when typing on a small touchscreen, it will be challenging to perform the correct keystrokes or some other precise operations on a Qwerty keyboard, which allocates the 26 letter keys to the already limited screen area, making the area occupied by each key minuscule.

Currently, the popularity of smartwatches is soaring, and so is the interest of customers, especially young people. It is evident that typing on a watch-sized touchscreen with a Qwerty keyboard is challenging. For those users with large fingertips, "fat finger" problem (Siek et al., 2005) can result in frustrating typing on small devices such as a smartwatch while a user's finger is larger than the key size.

Keyboards with a multi-letter key layout can alleviate this problem to some extent (Qin et al., 2018) since fewer keys on the keyboard lead to keys occupying a larger screen area. Typing on the T9 keyboard, in particular, provides benefits over other ambiguous keyboards in terms of typing performance since it is one of the most recognizable ambiguous keyboards for users (Wong et al., 2018). As T9-like keyboards are especially popular on small screens (Qin et al., 2018), the T9 keyboards can definitely be used as an input option on the smartwatch as well.

Apart from this, touchscreen also makes finger-operated gesture typing possible, which allows users to input a word through one continuous movement, and it can also be seen as a tapping keyboard (Zhai & Kristensson, 2012). But, different from tap typing, gesture typing does not require the user to have precise operations of the touch position. In other words, gesture typing can be another way to perform typing on small touchscreens by improving the error tolerance, while users also prefer typing at a lower error rate (Wong et al., 2018).

Although the gesture keyboard is compatible with gesture typing and tap typing, users will not have much mental burden for switching between typing methods, even children can use it easily (Zhai & Kristensson, 2012). Thus, gesture typing is widely used due to its characteristics such as enhancing tactile feedback (Qin et al., 2018). Especially, for older adults, gesture typing was around 15% faster than tap typing (Lin et al., 2018).

In addition, when performing gesture typing, the T9 keyboard has certain advantages over the Qwerty keyboard in terms of gesture ambiguity since a gesture on the T9 keyboard can hardly have more than two extraneous keys between two letters due to its 3*3 key layout. As shown in Figure 1, gesture typing on the Qwerty keyboard can possibly contain several unexpected keys.

However, when performing gesture typing on the conventional T9 keyboard, there are some issues which include the gesture being inevitably be interrupted due to two consecutive letters sharing the identical key.

For example, as shown in Figure 2, while a user tries to input the word "APPLE", the user can perform the swipe gesture starting from key 2 to key 7, but then the gesture must be finished and be replaced by another gesture to complete the text entry since the second letter and the third letter of "APPLE" are identical, supposing that there are no features such

Figure 1. If the users want to type a word "QUICK" with gestures, the gesture path on the Qwerty keyboard is much more ambiguous than on the T9 keyboard.

as auto-complete and auto-correct.

Figure 2. If the users want to type the word "APPLE" with gestures on the conventional T9 keyboard, two swipe gestures are necessary.

That is, when swipe gesture typing on the T9 keyboard, the user must perform multiple gestures by lifting the fingers several times to type a certain word that contains consecutive letters corresponding to the same key. If all letters of a word are on the same key, gesture typing will be practically equivalent to tap typing. For instance, if "MOON" is the target word, the user can only tap the key 6 four times rather than perform gesture typing.

According to the frequently used words (Dolch, 1936), 68 out of 220 frequently used non-nouns and 45 out of 95 frequently used nouns meet the above limitations of gesture typing on the T9 keyboard.

Admitting that auto-completion and auto-correction functions can also help solve some of the issues with same-key letters, keyboard layout optimization is compatible with these features of the predictive text algorithm. In other words, the optimization of the word suggestion algorithm and the improvement of the keyboard itself should work together without being mutually exclusive. Especially, auto-completion for an imprecise typing can result in higher ambiguity for word prediction and therefore lead to more candidates.

1.1 Problem and Significance

Compared to tap typing, gesture typing is considered advantageous in some ways (Lin et al., 2018). As mobile devices become popular and text input on small screens is a problem, the T9 keyboard will be superior to Qwerty keyboard for text entry to some extent since fewer keys lead to larger key sizes. In addition to young people who like to use small screen devices such as the smart watch, this study will also benefit those who have a personal preference for the T9 keyboard, as this study is dedicated to making the T9 keyboard perform better on a touch screen.

However, while the T9 keyboard is a kind of multi-key layout, for inputting a word containing letters of the same key in succession, such as shown in Figure 2, it will be difficult for users to use gesture typing to complete single word input at once, which will weaken efficiency and user experience to a certain extent. Therefore, it is worth improving gesture typing on the T9 keyboard to type on small devices such as mobile phones and smart watches while currently gesture typing on the conventional T9 keyboard has a limited user experience.

In the field of optimizing text entry, most research has focused on rearranging the keys on the keyboard or redesigning the whole layout. However, such a redesign of the keyboard layout can possibly lead to difficulties in marketing, because even a fraction of the learning cost can prevent mass adoption while users are used to the traditional layout (Zhai & Kristensson, 2012).

There is still a lack of research on strengthening the function of specific weak keys that conventionally exhibit insufficient functionality, for enhancing typing performance without significantly tweaking or redesigning the layout, which can lead to the minimum learning cost of the optimized keyboard. This study intended to enhance gesture typing on T9 while maintaining the standard keyboard layout. In other words, the optimized keyboard is supposed to be a superset version of the conventional keyboard. Therefore, the solution can minimize learning costs while retaining the original typing habits that affect users.

With the probable improvement of user experience and performance of gesture typing on the T9 keyboard, users of small-screen devices, especially those who are keen on T9 keyboards, can possibly use the augmented gesture typing to get a distinct experience and even get better input efficiency if the final result indicates the superior performance of gesture typing compared to tap typing on the T9 keyboard.

This study identified an opportunity to optimize the gesture typing on the T9 keyboard without rearranging the conventional keyboard layout, which can result in good learnability. This project can also help any users who want to perform gesture typing on the T9 keyboard to get a smoother typing experience and potential stronger typing performance.

1.2 Summary and Key Contributions

In this study, we have proposed two approaches for enhancing gesture typing on T9 while keeping its keyboard layout and have implemented two T9 variants: T9 with an enhanced key 1 and T9 with wiggle gestures. Then, we recruited fourteen participants to test the two T9 variants compared to the conventional T9.

To facilitate user study remotely, we have developed a self-serviceable online testing platform. With such a web app, we can easily record and monitor in real time all typing activities that occurred on it while participants did not need to install any software particularly for this study.

Based on the data collected from the user studies, we compared these three T9 keyboards in terms of typing performance and subjective feedback. We have found that T9 with an enhanced key 1 significantly outperformed the other two T9 keyboards in almost all metrics, such as typing speed (WPM), word error rate, and subjective ratings. Especially, all participants selected T9 with an enhanced key 1 as their favorite input method.

Moreover, for the T9 with wiggle gestures, we also found that had higher learning costs and at least did not significantly degrade the typing performance of the conventional T9 keyboard.

Overall, one of the approaches proposed in this study to some extent demonstrated the feasibility of optimizing the performance and user experience of gesture typing on the T9 keyboard without rearranging its standard layout.

2 Related Work

2.1 Text Entry on Mobile Devices

While users always prefer to type with higher speed and lower error rates, the T9 can be one of the optimal options if we need to choose an ambiguous keyboard, because users are more familiar with T9 than other multi-letter layout, which can generally result in faster typing (Wong et al., 2018).

Zhai and Kristensson (2012) proposed three key factors that affect whether the input method is accepted by the users, namely input speed, learning cost, and growth. Especially, the high learning cost for novices will greatly affect subsequent promotion (Zhai & Kristensson, 2012). Keeping the standard keyboard layout can, at least, remove the cost of learning a whole new layout.

Furthermore, compared with tap typing, there is a certain speed advantage of gesture typing in addition to auto spacing, error-tolerance, and one-finger operation (Zhai & Kristensson, 2012). Gesture typing, in particular, allows users to enter words with a rough shape and placement (Billah et al., 2019), which ensured that gesture typing has error-tolerance properties. There are also additional chances for touchscreens to provide users with richer haptic feedback through gesture typing (Billah et al., 2019).

2.2 Optimizing Gesture Typing

While gesture typing is efficient and error-tolerant, it is ambiguous for typing the words sharing a similar or identical gesture, so some subtle gesture variation can be leveraged to eliminate the ambiguity (Alvina et al., 2016). Alvina et al. (2016) conducted three experiments to test if the users can consciously control the ongoing gesture in terms of some nuance gesture variation.

Unlike tap typing, for gesture typing, there is certain gesture ambiguity that is highly relevant to accuracy and speed (Smith et al., 2015). Smith et al. (2015) developed a Qwerty-like keyboard that reduced error rates by 52% and 37% over Qwerty by double and triple optimizations, which can possibly increase the path length of gestures but is still considered one of the best compromises.

While the aim was to optimize gesture typing, the approach for that was to adjust the keyboard layout, starting with measures like gesture clarity and Qwerty resemblance (Smith et al., 2015). Smith et al. (2015) also mentioned that tweaking the layout can cause some discomfort of learning the modified keyboard even the frustration may be short-term while the benefits can be long-term.

2.3 Optimizing Keyboard Layouts

The optimization based on the rearrangement of keys can introduce a learning curve, which usually makes users unwilling to adopt the optimized keyboard (Bi & Zhai, 2016). For minimizing the learning cost, Bi and Zhai (2016) tried to optimize the layout according to a rule that only two adjacent keys can be swapped. Admitting that it can solve the learnability problem to a certain extent compared with other work of keyboard optimization, it also showed that even swapping one pair of keys can introduce some learning cost (Bi & Zhai, 2016) since the users need to intentionally control their fingertips, which can be affected by the typing habit based on the traditional layout.

As the one-letter layouts are unambiguous and have smaller keys while the multi-letter layouts are ambiguous and have larger keys, QWERTH, a semi-ambiguous keyboard, can increase the key size and maintain a near-Qwerty layout (Dunlop et al., 2012). Although QWERTH has absorbed the advantages of Qwerty and multi-letter layout, it has insufficient consideration in terms of learnability. Besides learnability and performance, clarity is another key factor of the multi-letter layout optimization, which is relevant to mitigate the word collisions problem (Qin et al., 2018). Qin et al. (2018) introduced Qwerty-bound constraints for high learnability and then proposed Optimal-T9, which reduced the error rate over Qwerty and was faster than T9 (Qin et al., 2018).

2.4 Data Logging Text Entry

In order to conduct a large-scale data collection, Palin et al. (2019) developed a web-based test platform that enables performing transcription typing and automatic data logging. However, as Palin et al. (2019) did not develop a built-in keyboard for the test platform, participants used their own preferred keyboard, which caused different degrees of compatibility issues.

Across these studies, it is evident that learnability is a significant factor in optimizing typing performance, but adjusting the key arrangement will inevitably introduce a steep learning curve for the novel layout. In this project, while improving typing performance, we expect to maintain high learnability by augmenting the functionality of key 1 or gesture typing itself that is initially not strong enough. That is, the user should only need to learn a special rule applicable to a certain key or a certain gesture.

Moreover, a test platform with built-in keyboards is supposed to be convenient for testing the keyboards that are assigned as the within-subject independent variable, so participants will not be required to install additional software. We can also learn that visual signals can affect the user's conscious control of the ongoing gesture while typing on a soft keyboard (Alvina et al., 2016), adding some kind of visible hint will help typing.

3 Method

This section aims to propose two new approaches to solve the problems of gesture typing on the T9. Then, It will also go through how this study was set up in terms of the user study.

3.1 Keyboard Design

Unlike the prior work focusing on creating a new keyboard or rearranging the keys, this research aims to empower the functionality of some keys on the T9 keyboard, which can conventionally show weak features.

3.1.1 Enhanced Key 1

Key 1, in particular, is the one with the most promise for enhancement since it does not indicate any letters on the traditional T9 keyboard, which configures 26 letters to key 2 through key 9.

In detail, key 1 is proposed to perform as a regex quantifier key, which can be a certain type of quantifiers of the regular expression such as "2" that repeats the last entered key one time, and "+" that repeats the previously entered key one or infinite times, etc. For instance, supposing key 1 can perform as "+" and the user tries to enter the word "APPLE", the initial swipe gesture (see Figure 3) still starts from key 2 and then moves to key 7 for inputting "AP".

Then, different from conventional gesture typing on the T9 keyboard, the user can continue this swipe gesture rather than lift up the finger to perform another gesture for completing the input of the remaining letters "PLE" since key 1 can be considered key 7 (PQRS) when the user's fingertip enters key 7.

Figure 3. For inputting the word "APPLE", the swipe gesture is supposed to start from key 2 to key 7 then to key 1, finally to key 5 and key 3. The letters corresponding to Key 1 change with the movement of the finger.

Moreover, when users try to type the word "MOON" with gestures, as shown in Figure 4, they can utilize the enhanced key 1 to achieve the goal while "MOON" can be typed with gestures on the conventional T9 keyboard.

Therefore, the user can complete the input of a word without interrupting the gesture. Additionally, key 1 can display its current status in real-time, which is also a kind of visual hints in case that the current key is covered by user's finger.

Figure 4. For inputting the word "MOON", the swipe gesture is supposed to start from key 6 to key 1 then to key 6, finally to key 1.

3.1.2 Wiggle Gesture

Besides this modified T9 keyboard with an enhanced key 1, we can also create another T9 variant working with a predefined gesture for achieving target feature, such as the wiggle gesture (Billah et al., 2019), which demands the user to change the swiping direction on a specific key more than three times, as shown in Figure 5. For example, it is like drawing a pattern like an M, or a W or a 3, but the lines can overlap.

Theoretically, we could specify any gesture pattern to achieve our goal. In this study, we specified wiggle gesture. This differs from T9 with enhanced key 1 in that a wiggle gesture is introduced on every key, whereas enhanced key 1 is a modification on a single key.

Similar to enhanced key 1, wiggle gesture can be used to repeat the current key as well. For example, supposing that the target word is "APPLE" and "AP" has been entered by gesture typing, the user should now have the finger on key 7, then another "P", specifically the key 7, will be entered if the user wiggles the performing finger on the key 7 to vary the swiping direction three times.

While enhanced key 1 can inevitably increase the gesture ambiguity, a performance of wiggle gesture should only swipe within the target key in theory, so a flawless wiggle gesture should not influence the ambiguity of the gesture. However, wiggle gestures on a small touchscreen are unlikely to be always ideal.

Overall, a wiggle gesture can still be a potential choice to enhance the performance of gesture typing on the T9 keyboard without rearranging layout.

3.2 Implementation

Considering the current situation of COVID-19, the entire study was conducted fully remotely, so the participants used their own smartphone to complete the typing tests. In order to avoid software compatibility issues on different devices and reduce development costs, the enhanced keyboard will exist as a built-in function of the test platform.

In other words, the keyboard is a component of the web page of the experiment platform, so the participants do not need to install any additional software of the input method since the platform including the keyboard is web-based. Participants should perform the typing tasks with a modern browser, such as Google Chrome, to ensure greater experiment stability. Ideally, as shown in Figure 5, participants can even help themselves to complete all the typing tasks in this study. But there will still be at least one moderator to instruct every participant who is supposed to follow the instructions given by the investigator and the test platform.

In detail, the size of the T9 keyboard is $34.8mm \times 28.6mm$, which is close to the display area of the Apple Watch Series 5. In particular, page scaling is disabled for any user using this web-app, while modern browsers on cell phones can guarantee similar results displayed on usual devices according to the preset CSS configuration. Technically speaking, the app is built by Typescript, Next.js, and Nest.js, while the database is MongoDB Atlas, and the app is deployed on Heroku. The source code can be found in Appendix A.

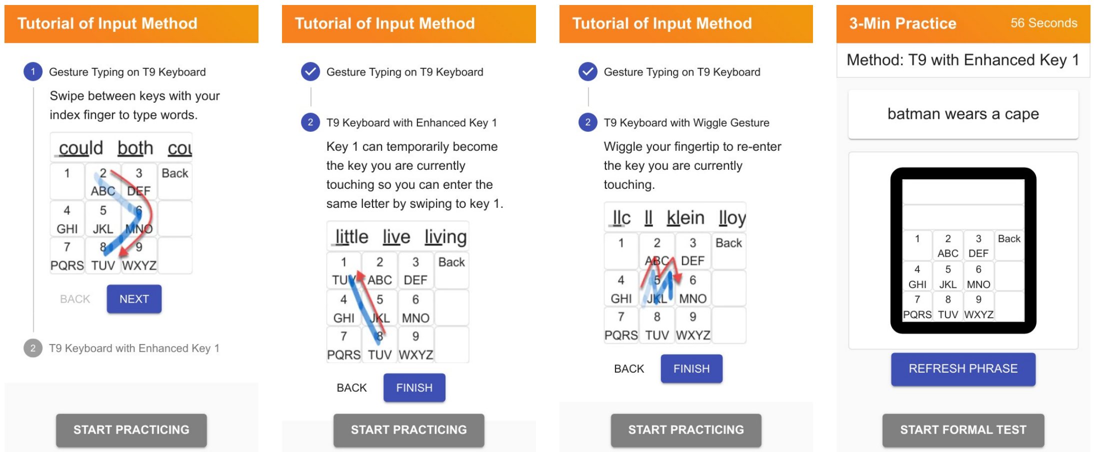

Figure 5. Task flow of each input method. The first three figures are brief descriptions of conventional T9, T9 with an enhanced key 1, and T9 with wiggle gesture, respectively. The blue line in the figure indicates the motion trajectory of the gesture typing, while the red line indicates the direction. The fourth figure shows the UI during the practice session for T9 with an enhanced key 1, which allows the user to change the target phrase.

All text entry activities performed in the test platform were recorded by the background program with the timestamp and more context information, which were synchronized to the database. Then, according to the collected information, data necessary to do performance analysis can be calculated, such as the input speed based on word per minute (WPM), uncorrected error rate based on minimum word distance (MWD), backspaces, and efficiency based on keystrokes per character (KSPC), etc. Specifically, there was automatic entry of a space between words since such a feature is regarded a benefit of gesture keyboards (Zhai & Kristensson, 2012).

3.3 User Study Design

3.3.1 Participants and apparatus

A total of 14 young participants (5 female) aged from 20 to 32 ($Mean = 26.4, SD = 3.09$) were recruited for this study. Six of the 14 participants used Android phones, while the other eight used iPhones, as shown in the "yaswype-report-survey.ipynb" file in the Appendix. The web-app was confirmed to be fully displayed and working correctly on their phones before the formal test started. In order to avoid introducing unnecessary variables, participants did not have a motor impairments.

Before the formal test, participants were required to report their familiarity with the gesture typing and the T9 keyboard. The median familiarity with gesture typing (1: never heard of it; 5: expert) was 2.5 while the median familiarity with the T9 keyboard was 2. In particular, every participant was required to perform gesture typing with the index finger of the dominant hand throughout the study while they used the other hand to hold the phone..

As all experiments were expected to be done remotely, participants were asked to use their own smart phone to complete every typing task assigned to them.

3.3.2 Procedure

Participants connected to the investigator via Zoom, and were instructed to access the link of test platform with their own smartphone. As this study is a within-subject design where the independent variable was the type of T9 keyboards, participants were required to complete typing tasks given the test platform, which was a web-app as shown in Figure 5. In particular, participants can always perform a practice session before the formal test, and they were required to try their best to perform gesture typing and to utilize the special features introduced by two T9 variants.

There were 20 short phrases randomly selected from Mackenzie phrase set (MacKenzie & Soukoreff, 2003), as shown in Appendix B. Each formal test provided a phrase for participants to complete the transcription task. During the typing tasks, participants just needed to transcribe the target phrase with gesture typing, and to select the words from the candidate list, which was supported by word prediction with the unigram language model. In particular, participants were informed that once a word was selected from the candidate list, they should continue transcribing the next word, even if they noticed that the previous word was incorrect.

As the conventional T9 was practically a prerequisite of the other T9 variants, participants should always perform gesture typing on conventional T9 at first. Then the orders of the T9 variants were balanced across participants. While we asked participants to stay in the 3-min practice session until they were satisfied with their typing performance before the formal test, the learning effect of starting the task from conventional T9 should be offset to some extent. Even there was already enough warm-up and learning time for simple tasks like typing on the T9 keyboard, we still need to admit that the two T9 variants that were scheduled after conventional T9 would still have a certain advantage. In detail, the study collected: 3 keyboards $\times$ 4 blocks $\times$ 5 phrases $\times$ 14 participants = 840 phrases.

Once participants completed all the typing tasks of a certain method, they were instructed to fill in a survey of NASA-TLX before the next step. At the very end, after completing all the typing tasks and surveys, participants were expected to answer a few questions verbally about the whole experience with the following five questions:

- Since you used three methods during the study, which one did you like the most and why? Which one did you like the least and why?
- What are some challenges that you encountered using the conventional method?
- What are some challenges that you encountered using the wiggling method?
- What are some challenges that you encountered using the enhanced T9 keyboard?
- What are your thoughts specifically on the enhanced key 1 keyboard?

Ten user studies were conducted in about 1 hour and 30 minutes, while four user studies were completed in nearly 2 hours.

4 Results

This section contains all quantitative findings derived from the participants' typing records and expressed in different elements of typing performance, such as text input speed, error rate, and so on. Additionally, the results of some post-test interviews are also presented for qualitative analysis.

In particular, in this section, almost all data were computed by python and scipy libraries, except for one-way repeated measures ANOVA, which was done with the help of an online calculator on socscistatistics.com. Please refer to the ".ipynb" files in the appendix for details of the specific calculation scripts.

4.1 Typing Speed (WPM)

The typing speed was calculated in the following way:

$$WPM = \frac{|S| - 1}{T} \times \frac{1}{5}$$

where S is the total number of transcribed characters during the task, and T represents the amount of time it took to transcribe all of the phrases in the typing task in minutes. Each five-character string, including the space, was treated as a single word (MacKenzie, 2015).

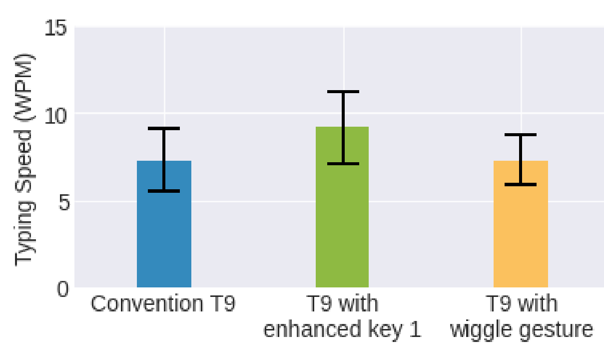

Figure 6. Means (95% confidence interval) of typing speed by T9 keyboards

As shown in Figure 6, the T9 with an enhanced key 1 resulted in the highest typing speed, which was 9.17 words per minute ($SD = 2.10$), among all the methods. The average speed was 7.29 WPM ($SD = 1.81$) for conventional T9, and 7.30 WPM ($SD = 1.43$) for the T9 with wiggle gesture. In other words, T9 with an enhanced key 1 was 25.7% faster than conventional T9, and 25.6% faster than T9 with wiggle gesture.

Moreover, there was a main effect of methods on the typing speed ($F_{2,26} = 10.89341$, $p < 0.001$). According to pairwise t-tests, the differences between conventional T9 vs. T9 with an enhanced key 1 ($p = 0.0027$) and T9 with an enhanced key 1 vs. T9 with wiggle gesture ($p < 0.001$) were significant.

4.2 Learnability

Learnability is an important statistic for illustrating the learning curve of typing methods, and therefore an analysis of typing speed that changed over time was conducted, as shown in Figure 7. In detail, we used the same calculation method as for the typing speed (WPM), except that the learnability analysis is based on blocks rather than on the full data from the experiment. There was a significant influence of block number on the overall average speed of T9 keyboards($F_{3,39} = 15.42$, $p < 0.001$).

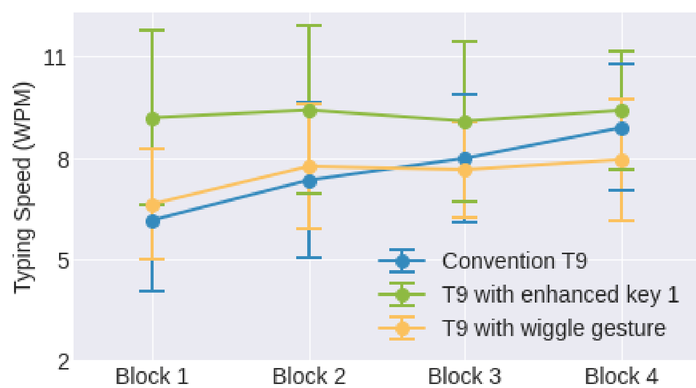

Figure 7. Means (95% confidence interval) of typing speed by T9 keyboard and block

Then, pairwise t-tests between blocks, for all three T9 keyboards, showed that the differences were significant between the first block vs. the second block ($p = 0.0027$), the first block vs. the third block ($p < 0.001$), the first block vs. the fourth block ($p < 0.001$), and the second block vs. the fourth block ($p = 0.0077$).

In detail, there were no significant differences between any two blocks for T9 with an enhanced key 1 ($F_{3,39} = 0.269$, $p = 0.847$). For the conventional T9 ($F_{3,39} = 10.77$, $p < 0.001$), pairwise t-tests revealed significant differences between the first block vs. the second block ($p = 0.0115$), the first block vs. the third block ($p = 0.0017$), the first block vs. the fourth block ($p < 0.001$), and the second block vs. the fourth block ($p = 0.0054$). For the T9 with wiggle gesture ($F_{3,39} = 3.717$, $p = 0.019$), pairwise t-tests revealed significant differences between the first block vs. the third block ($p = 0.0040$), and the first block vs. the fourth block ($p = 0.0088$)

4.3 Keystrokes Per Character (KSPC)

The KSPC is the average number of keystrokes necessary to generate each character of text using a specific typing method (MacKenzie, 2002), and to some extent it can represent the efficiency of typing on a certain keyboard (Zhai & Kristensson, 2012). In this study, it was also the average number of times a finger touches the screen and then leaves it while typing a single character, and it was calculated in the following way:

$$KSPC = \frac{NumOfGestures(S) + NumOfSelections(S) + NumOfDeletes(S)}{LengthInCharacters(S)}$$

where S is the transcribed phrase, $NumOfGestures(S)$ is the amount of gestures performed to transcribe S, $NumOfWordSelections(S)$ is the times of selecting a word from candidate list during transcribing S, and $NumOfDeletes(S)$ is the times of deleting a entered key during transcribing S. Specifically, the sum of the numbers should also be the times of lifting the finger.

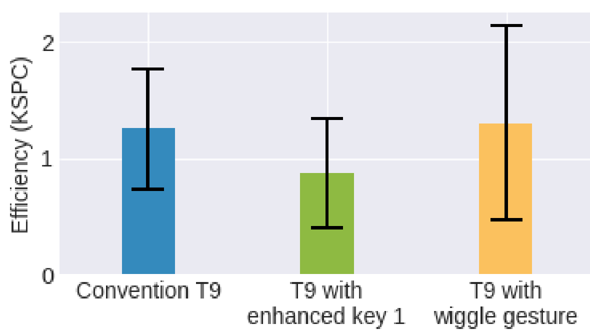

Figure 8. Means (95% confidence interval) of KSPC by T9 keyboards

As shown in Figure 8, the T9 with an enhanced key 1 also result in the best performance in terms of keystrokes per character while the mean (SD) KSPC was 1.25($SD = 0.52$) for conventional T9, 0.86($SD = 0.47$) for T9 with an enhanced key 1, and 1.30($SD = 0.84$) for T9 with wiggle gesture.

Specifically, repeated measures ANOVA demonstrated that typing methods had a main effect on the KSPC ($F_{2,26} = 10.43, p < 0.001$). Furthermore, paired t-tests revealed significant differences between T9 with an enhanced key 1 and the other two T9 keyboards (both $p < 0.001$).

4.4 Word Error Rate (WER)

This metric is an uncorrected error rate based on minimum word distance (MWD) between the transcribed phrase S and the presented target phrase P. Specifically, it was calculated in the following way:

$$WER = \frac{MWD(S,P)}{LengthInWords(P)} \times 100\%$$

where $LengthInWords(P)$ is the amount of words contained in P.

As shown in Figure 9, T9 with an enhanced key 1 led to the lowest error rate on average. In detail, the participants made the most uncorrected input errors on conventional T9 ($Mean = 8.60\%$, $SD = 6.30\%$), followed by T9 with wiggle gesture ($Mean = 6.44\%$, $SD = 6.21\%$), and T9 with an enhanced key 1 ($Mean = 6.04\%$, $SD = 6.24\%$).

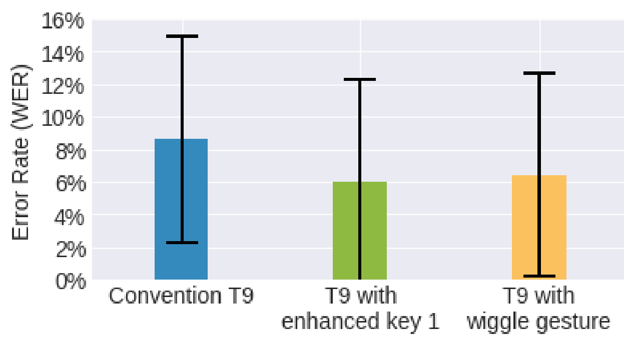

Figure 9. Means (95% confidence interval) of word error rate by T9 keyboards

But repeated measures ANOVA failed to show a main effect of typing methods on the word error rate ($F_{2,26} = 3.324, p = 0.052$).

4.5 Deletes Per Word

Deletes per word was used in this research to compare the performance in terms of corrected input errors (Lin et al., 2018; Palin et al., 2019; Qin et al., 2018). In detail, the T9 with an enhanced key 1 resulted in the least amount of backspace usage, which is on average 0.94($SD = 0.83$) while the mean (SD) was 1.42($SD = 1.10$) for conventional T9, and 1.71($SD = 1.45$) for T9 with wiggle gesture.

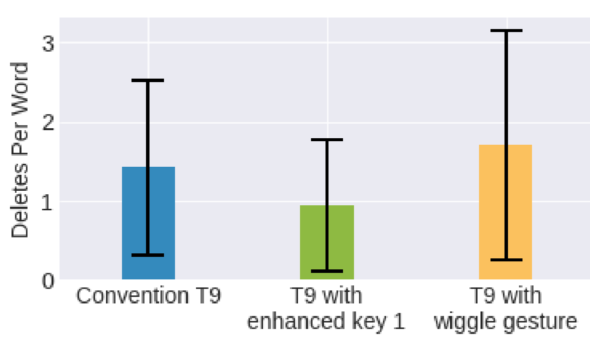

Figure 10. Means (95% confidence interval) of deletes per word by T9 keyboards

There was also a main effect of typing methods on the average deletes per word ($F_{2,26} = 8.179, p = 0.0018$). With pairwise t-tests, it showed that the difference between T9 with an enhanced key 1 and the other two T9 keyboards was significant ($p = 0.0113$ for T9 with an enhanced key 1 vs. conventional T9, $p = 0.0035$ for T9 with an enhanced key 1 vs. T9 with wiggle gesture).

4.6 Usages of New Features of T9 Variations Per Word

While both of these new T9 keyboard variations added a distinct feature to the basic functionality of the standard T9, an investigation of how often their unique features were used in the user study revealed another comparison of their performance.

In detail, the average usage per word of the special feature was 0.45 ($SD = 0.08$) for the enhanced key 1, and 0.38 ($SD = 0.17$) for the wiggle gesture. That is, the enhanced key 1 was utilized more frequently than the wiggle gesture.

However, t-test did not show a significant difference between the usage of enhanced key 1 and of wiggle gesture ($p = 0.226$).

4.7 Subjective Ratings

After completing all of the transcription tasks for a specific T9 keyboard, each participant was instructed to fill a brief survey including the six questions in NASA-TLX (Hart & Staveland, 1988) in (1-20) scale.

As shown in Figure 11, the T9 with an enhanced key 1 also presented an overall advantage in terms of the perceived workload. With the exception of the performance term, the repeated measures ANOVA revealed significant differences in all the measures: mental demand ($F_{2,26} = 7.510, p = 0.0027$), physical demand ($F_{2,26} = 5.376, p = 0.0111$), temporal demand ($F_{2,26} = 5.552, p = 0.0098$), effort ($F_{2,26} = 4.085, p = 0.0287$), frustration ($F_{2,26} = 5.644, p = 0.0092$).

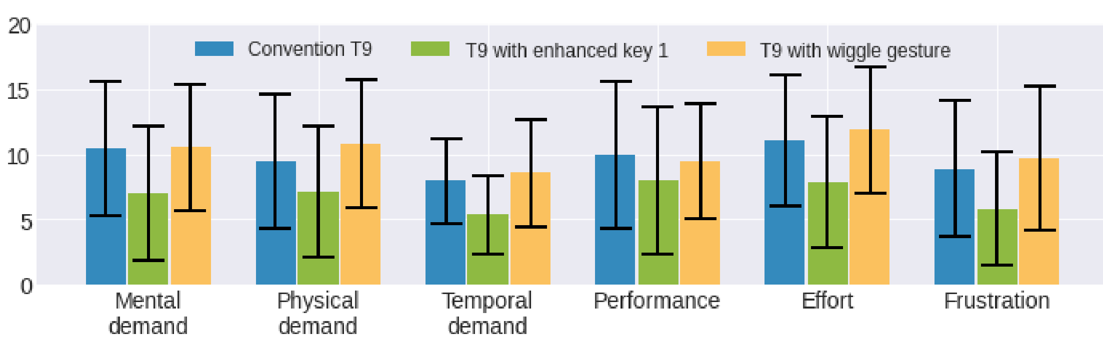

Figure 11. Means (SD) of the NASA-TLX measures in (1-20) scale where 1 is the most positive rating and 20 is the most negative rating.

Furthermore, Wilcoxon signed-rank tests indicated significant differences between T9 with an enhanced key 1 vs. conventional T9 in terms of mental demand ($p = 0.0021$), temporal demand ($p = 0.0137$), effort ($p = 0.0156$) and frustration ($p = 0.0101$), and between T9 with an enhanced key 1 vs. T9 with wiggle gesture in terms of mental demand ($p = 0.0125$), physical demand ($p = 0.0050$), temporal demand ($p = 0.0142$), effort ($p = 0.0104$) and frustration ($p = 0.0049$).

Besides the evaluation of NASA-TLX, all participants also provided some feedback on their preferences for the typing methods they performed in the study on the scale of 1 (Dislike a great deal) to 5 (Like a great deal). As shown in Figure 12, T9 with an enhanced key also had an advantage in this regard since the median rating for T9 with an enhanced key 1 (5) was the highest compared to the median ratings for conventional T9 (3) and T9 with wiggle gesture (2).

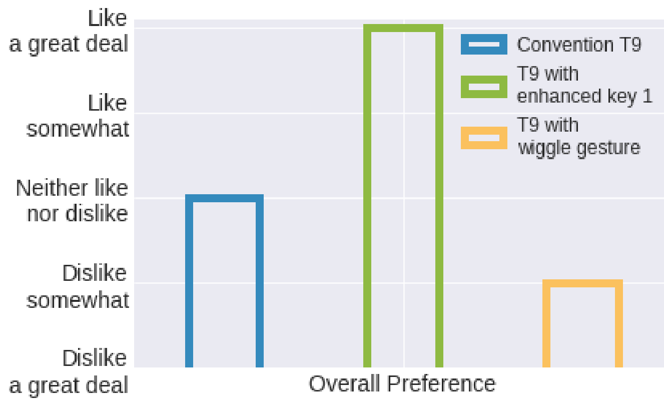

Figure 12. Medians of the overall preference of each keyboard in (1-5) scale where 1 means the most negative rating and 5 means the most positive rating

4.8 Observations and Subjective Feedback

Various qualitative data were collected through a structured interview with each participant.

4.8.1 T9 with an enhanced key 1

All fourteen participants preferred the T9 with enhanced key 1 as their favorite typing method. Three people commented that they didn't have to lift their fingers to break the gesture, which might save time. Based subjective feelings, P8 indicated that swiping to key 1 may be the most convenient method for the users who like gesture typing. Besides, it was also remarked that an enhanced key 1 was also a kind of visual hint which alleviates vision problems caused by fingers blocking the keys..

The following are some comments on T9 with an enhanced key 1 from the participants:

P1: "I like the enhanced one the most because it gives you the option to continue your gesture, so you don't have to pick up your finger and then to the other one."

P3: "I think that's great, and I think that the design is very impressive, and I like the method ... the user experience was very good."

P5: "... seems to be much faster (while) having the same characters so you just move quickly over there ... especially nice."

P6: "I felt even to be like quite interesting, I have never seen such kind of a keyboard before ... I think that might work because. The other two methods are like quite stressful ..."

P7: "... to the character(s) in the same key area then it's easier (for me) to perform (typing) I guess ... easy to type."

P8: "It's just a feel. Sometimes, when you realize, you have to tap ... so it kind of just to save your time to develop your finger and you can continue our response ... so yeah definitely I can say (it) is very convenient for people (who) just prefer swiping gesture to tapping."

P9: "I think it just meets my expectations on it ... I think it's really easy to use."

P10: "This is easier compared to the first part, because (it) is easier to use the (key) one ... it actually makes my typing speedier than the old one."

P12: "I think it's easy, easy to understand, to go back and forth versus like stopping in between ... No trouble(, it is) pretty easy (to) learning as we go. I like the enhanced one the best. I think it was the easiest for me to understand ... I think it was like more seamless and then I also think that my phone registered it faster ..."

P13: "It does have issues like a conventional keyboard, but it still is better than the conventional one or the wiggling one. It was easy to take when there is a repeated late."

P14: "I think this is the best within the three. methods, I mean the the craftiness and the speed (are) both much better compared with the other two ... especially for such a small window though wiggling ways very hard to us but, you know, the enhanced key 1 works very well."

In terms of the learning curve and typing performance, several participants stated that it was simple to comprehend how to use enhanced key 1 without difficulties, while some noted that typing is considerably faster when using an enhanced key

4.8.2 T9 with wiggle gesture

Twelve participants, on the other hand, disliked the T9 with wiggle gesture. Wiggle gestures, they claimed, needed more effort to gauge how much wriggling they had to perform because there was insufficient feedback. Specifically, some kind of signal or pattern that shows the progress of a one-time wiggle gesture to completion in real time (such as a turning number or progress bar) would give the user better control. It was also remarked that a wiggling motion was prone to errors, and that they had mistakenly entered two letters that were the same.

They also said that wiggling within the small region of one key was challenging, and that sliding the finger to the adjacent key and unintentionally entering any undesired key was a waste of time.

Also, two individuals believed that wiggling gestures should really need to get some practice. Due to the restricted sizes of keys and screens, one participant indicated that a wiggle gesture is more complicated than an enhanced key 1, while another suggested that the wiggle gesture may be a better technique if the key could be larger. Moreover, three participants deemed that even performing another tap can be easier than performing a wiggle gesture.

> P1: "And I did not like the wiggle because it's tough to wiggle ... it's a small space, so if your wiggle (gesture) falls into a different number, and then it basically takes a different word so that actually is facing the issue."
>
> P2: "it was cool ... when it works"
>
> P3: "I think you need to practice because sometimes when you wiggle it takes, I mean several seconds for the system to recognize your cluster that's a challenge, and as for that I think the experiments is generally okay was."
>
> P4: "I cannot wiggle. It's hard to be good."
>
> P5: "I will try to move up and down, but sometimes we just move to the side."
>
> P6: "Oh, I think, though, wiggling one because it was kind of confusing and sometimes it it created a problem for me, you know, like because I don't know like how much time I have touched I ... yeah, wiggling was like first the area where I have to visualize like really very small second the feedback which I'm getting like I wasn't sure where I am in terms of number of words I have done. For example, if I have to wiggle three times in the same (key) and I have bigger like three times I don't know where am I, there was like no feedback how many times I have."
>
> P9: "Sometimes I move my fingers in the same box, but actually you know the the repeat to let it's not appearing in the you know, in the suggestion box so it's it's really hard to tell one I should move."
>
> P10: "The wiggling one may be because of the delay of the web page sometimes ... it does not show up immediately ... It might be the reason I mean make my experience, not as good as ..."
>
> P11: "Sometime is hard for me to like wiggling ... And also like sometimes we're just trying to create a curve to like slide to another word it automatically wiggles itself, so I got like one more word."
>
> P12: "It was too difficult to registered on the device I think so like whenever

I would do it, it would just it was really frustrating, because you would do it, and it would either not work or work too many times."

P14: "I think it should work, but in this windows ... it's hard to ... always in one square."

4.8.3 Conventional T9

Finally, as for the conventional T9, two participants liked the conventional T9 the least since it lacks functions in comparison to to the other two T9 variants. Specifically, one participant mentioned that the conventional T9 has neither shortcomings nor exciting points.

For typing the following identical key, one participant noted that it was error-prone to tap on the wrong key after lifting the finger to type the same key again. In order to enter the word containing 3 or more consecutive letters which correspond to the same key, typing can be error-prone on conventional T9, while it may be clear to know how many times the key was repeated with an enhanced key. But nobody thought that conventional T9 was too challenging to type words on it even an individual evaluated it as tedious.

P1: "I think, good enough, but still, ..., as I mentioned earlier, that if you have multiple letters that belongs to the same number, then what you do so, you have to just step it multiple times and then get back to get back to the gesture again, so there is a breaking I guess."

P3: "I will say the first one (is the method I like the least), because I have like more powerful function to conventional."

P5: "... a few more challenging than tapping I felt like."

P6: "I felt comfortable up for learning the conventional one."

P9: "I think it's good. ... because the size is kind of small. Yeah so it's hard for me to find the next letter ... it takes some time for me to get familiar with, but other than that I do not see any (challenge) ... Move, move, move your fingers, up and down in order to type the word, um nothing really exciting, you know.

P10: "Because it's like a small area within the cell phone screen and my finger actually sometimes can cover to. Two taps at the same time, sometimes. So I need to lift my finger and again ... the most of the time I made mistakes, I have to delete something and return."

P12: "I think it's so tiny and I haven't actually done it ever so. I haven't used the T9 since probably high school so it's been a long time I can't it's hard for me to remember the letters."

P13: "(Wiggling) wasn't that good. Especially the one which had like double letters, one after the other, like keep K E E P ... I am (familiar with gesture typing on T9) ... (but) maybe I'm not used to it anymore."

P14: "I believe if it's like the same size as, you know, our normal phone window, I think it works very well."

4.8.4 Gesture Typing

In addition to the feedback relevant to three T9 keyboards, some participants also commented on the gesture typing itself. Especially, several participants mentioned the fat finger problem on the small-size touchscreen. P8 said that "Sometimes I just hold it for a long time and feel tired"

P11 said that "Since my dominant hand is right hand, so it kind of why I have blocks on my visions, but probably as another story for the left hand like people who use left hand, or are there and so ... Also, ..., like move the button to another somewhere else who'd be more either for people to see or find the thing.". She brought up a visual problem with gesture typing. That is, their index finger may cover a broad area during performing gesture typing. One of the participants made the following additional comment: If the user is right-handed, the visual problem may be further aggravated by enhanced key 1 because key 1 is in the upper left corner of the keyboard, which can cause the right index finger on key 1 to cover certain other keys and prevent the user from seeing them, but she also mentioned that left hand can possibly lead to another story.

5 Discussion

According to the analysis above, T9 with an enhanced key 1 demonstrated the best overall performance in terms of transcribing phrases and subjective feedback among all three T9 keyboards.

5.1 Typing Performance

Text entry speed is one of the most significant indications of input method performance is text entry speed. As noted in the results section, while paired t-tests showed that there were significant differences between T9 with an enhanced key 1 and the other two methods, we can know that T9 with an enhanced key 1 resulted in a higher typing speed when compared to conventional T9 and T9 with wiggle gestures.

According to the analysis of learnability, T9 with an enhanced key 1 failed to exhibit a learning effect across blocks, although it still resulted in the highest average typing speed per block. It is indeed straightforward in seeing how enhanced key 1 is effortless for users to learn and comprehend, so there are not many obvious distinctions between their initial typing performance and the performance after they have fully mastered it.

In contrast, conventional T9 and T9 with wiggle gestures demonstrated an overall increasing typing performance over blocks. In comparison to enhanced key 1, we might interpret this trend as a greater learning cost for both the T9 keyboard and wiggling movements. In other words, the enhanced key 1 is an easy-to-learn technique.

Then, T9 with an enhanced key 1 still had a considerable edge over the other two methods when it came to typing efficiency as measured by keystrokes per character. It is evident to have seen how, as compared with the conventional T9 gesture typing, an enhanced key enables continuous and smooth gesture typing.

Surprisingly, the performance of T9 with wiggle gesture in terms of KSPC was inferior to conventional T9 while wiggle gesture was designed to reduce KSPC by reducing the number of gesture interruptions. To explain this phenomenon, we have to explore the aspect of error rate.

However, from the analysis of the uncorrected error rate, there were not really a significant differences between the three T9 keyboards, although the T9 with enhanced key 1 still has a small advantage. Through examining the causes of the uncorrected errors in this study, we can see that the uncorrected errors should mainly depend on the participants' ability to accurately choose the target word from the candidate list, which should be the same for all three keyboards used. Therefore, it is reasonable that there was no significant difference in word error rate between the three keyboards.

Furthermore, the corrected error rate, as measured by deletes per word, convincingly demonstrated the cause of the poor performance of T9 with wiggle gestures. As shown in Figure 10, the T9 with wiggle gestures even resulted in more backspace usage than the conventional T9, which can tell the error-prone nature of wiggle gesture. In addition, T9 with an enhanced key 1 still maintained its performance advantage over the other two methods in terms of corrected error rate.

As for the actual usage, an enhanced key 1 is slightly more frequently utilized than the wiggle gesture, although the difference is indeed not considerable.

Overall, in terms of quantitative statistics, the T9 with an enhanced key 1 outperformed the conventional T9 and T9 with wiggle gestures in all aspects of typing performance.

5.2 Subjective Evaluations

We can see that T9 with an enhanced key 1 still has a significant overall advantage based on NASA-TLX measures. Besides, we can also see that T9 with wiggle gestures had ratings that were extremely close to that of traditional T9 based on the results of paired t-tests.

Furthermore, we can validate the overall benefits of T9 with an enhanced key 1, which was everyone's favorite input method, in terms of typing performance and subjective experience based on subjective comments from participants. Especially, an enhanced key 1 is as easy to learn as we expected.

Contrary to our expectations, most participants did not like T9 with wiggle gesture. In particular, we underestimated the learning cost of wiggle gesture in real-world applications. Although both the invention of an enhanced key 1 and the introduction of wiggle gesture were designed to improve the efficiency of gesture typing by reducing KSPC, T9 with wiggle gesture did not show the same advantage in terms of KSPC as T9 with an enhanced key 1. This even happened when T9 with wiggle gesture should have some advantage resulted from learning effect compared to conventional T9.

5.3 Limitations

This study focused only on the effect of the fat finger problem on alphabetic keys but ignored another potential bottleneck when typing on small screens with the ambiguous keyboard. Namely, the behavior of selecting candidate words from the list given by the word prediction algorithm should not only be time-consuming but also be affected by the fat finger problem.

There is a lack of studies on optimizing gesture recognition and predictive text algorithms since this project focuses on proposing and verifying if the enhanced key 1 and wiggle gesture can improve the gesture typing on the T9 keyboard while keeping the standard keyboard layout.

However, as mentioned in the user study procedure, there was still a degree of bias due to learning effects, even though we gave participants enough time to practice and asked them not to proceed to formal test until they felt confident and comfortable with the T9 keyboard and notified the moderator.

Moreover, some common auto-completion and auto-correction approaches were not employed in this study for various reasons, and only the most fundamental unigram language model was adopted for the language model. In practice, more modern automated correction and complementing techniques will undoubtedly narrow the performance difference between methods in this study.

In addition, due to the nature of remote experimentation, there are discrepancies in the hardware and software performance of the participants' test equipment, as well as the investigator's capacity to observe participants more efficiently in a multidimensional way during the user studies. At the same time, an optimal gesture recognition engine, which should have a better failure tolerance, was not implemented in this study for cost and performance reasons. Especially, in this study, video or textual tutorial can hardly include all skills of gesture typing on the T9 keyboards while most of participants were not familiar with the T9 keyboards.

As the enhanced key 1 mainly affects the performance of gesture typing, this project can hardly improve the tap typing on the T9 keyboard since the user can directly tap the key twice rather than tap the enhanced key 1 for repeating the previously entered key. Although this project is compatible with tap typing, the only meaning of enhanced key 1 for tap typing is working as a visual hint to inform the user which key is tapped at the moment.

Finally, it will be helpful that participants with richer demographic characteristics can join the experiment, especially those who are more enthusiastic about T9 keyboard or gesture typing.

6 Conclusion

This study focused on the use of ambiguous keyboards such as the T9 keyboard and gesture typing with higher fault tolerance to solve the problem of typing difficulties on small touch screens caused by problems such as the fat problem. Then, the present work proposed two possible approaches to enhance gesture typing on the T9 keyboard, while maintaining the keyboard layout to reduce the learning cost.

In particular, one was to add functionality to key 1 in T9 for gesture typing while the other was to keep all the functions of the original T9 keyboard, but introduced a wiggle gesture for each key to complete the specified function. They can both be used to perform gesture typing of consecutive same-key characters.

While the contributions of this study are mainly of practical significance, fourteen participants were recruited and experimented with typing using three T9 keyboards. Through the user studies, we found that T9 with an enhanced key 1 outperformed T9 with wiggle gesture and the conventional T9 in terms of both typing performance and subjective evaluations. Besides, we also knew that T9 with wiggle gesture was at least not significantly worse than the conventional T9, even if it was not as strong as we expected.

Overall, this study proposed two T9 variants and verified the feasibility of optimizing gesture typing while maintaining the classical layout of the T9 keyboard.

6.1 Recommendations

This research needs to include a more thorough theoretical analysis, particularly for the two proposed approaches. Before the trial, more theoretical analysis is likely to adjust the anticipated findings of the study. While it is evident that a substantial proportion of words entail consecutive same-key characters on the T9 keyboard, the inclusion of a word prediction system may unnecessitate the user entering consecutive same-key letters for words that come in the middle or later section of the word.

Additionally, since the three keyboards in this test theoretically differ only for words containing consecutive letters of the same T9 key, tests for qualified words and unqualified words, respectively, would possibly yield more meaningful results, given that this study was originally designed to simulate a daily use scenario.

6.2 Future Work

All participants in this study were young and predominantly male. The vast majority of them were very new to the T9 keyboard. It is then a potentially valuable aspect of the study to compare the differences in typing performance and subjective ratings between younger and older adults when experimenting with the three T9 keyboards.

Apart from that, based on the outcomes of this trial's data thus far, females may have a unique edge when it comes to gesture typing on T9. This might be because the fat finger problem was less severe in female participants than in male participants due to substantial disparities in men's and women's finger sizes. So, using gender as an independent variable might also be explored in the future.

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A Source Code

https://drive.google.com/file/d/1oRxPgvouiVIIqa0d1g_CxyvcNsazZ4L5/view?usp=sharing

B Selected Phrases

1. limited warranty of two years
2. construction makes traveling difficult
3. sprawling subdivisions are bad
4. they watched the entire movie
5. sharp cheese keeps the mind sharp
6. a problem with the engine
7. this library has many books
8. protect your environment
9. a lot of chlorine in the water
10. do not walk too quickly
11. I can play much better now
12. in sharp contrast to your words
13. a much higher risk of getting cancer
14. good jobs for those with education
15. reading week is just about here
16. our silver anniversary is coming
17. fall is my favorite season
18. shivering is one way to keep warm
19. a good joke deserves a good laugh
20. my favorite sport is racketball