The Effects of Hand Posture on Touch and Gesture Typing Performance

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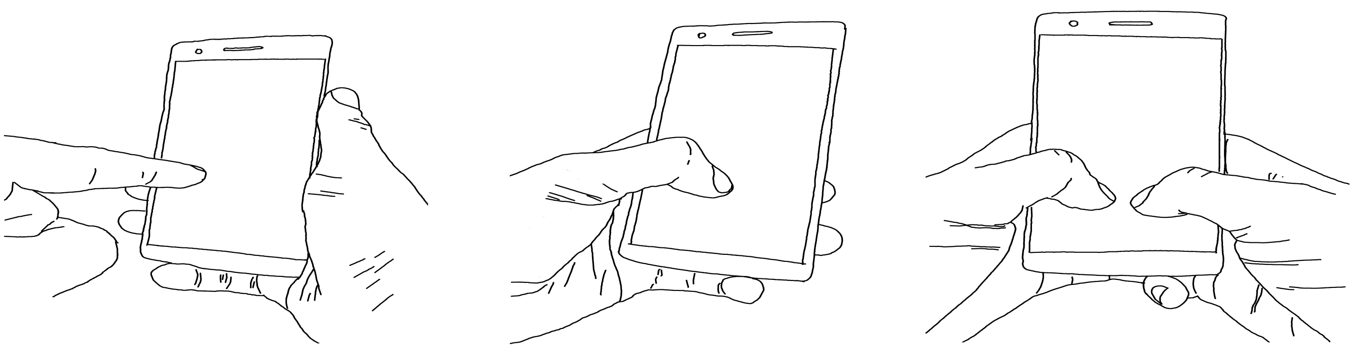

Figure 1: The hand postures assessed in our study. From left: one finger, one thumb and two thumbs.

ABSTRACT

The "best" technique for text entry using a touchscreen is highly contextual and depends on a variety of factors, including device size and mobility. So far, we are yet to discover one technique to rule them all. Two popular techniques for text entry on mobile devices are touch and gesture typing. Despite substantial research on smart features, such as auto-correction and prediction algorithms, and on the comparative performance of touch and gesture typing, one under-researched area is how hand posture effects performance. To address this, we performed a study to investigate the effects of hand posture on touch and gesture typing speed and accuracy on smart touchscreen keyboards. Our results show that hand posture significantly effects text entry speed, and that there are significant combined effects of hand posture and text entry technique. These results have implications for designers investigating mobile text entry or text entry on soft keyboards where hand posture is constrained.

KEYWORDS

gesture typing, touch typing, hand posture, text entry

1 INTRODUCTION

In contrast to typing on a full-size physical keyboard, the "best" method for text entry on a touchscreen mobile device is highly contextual. As the name implies, mobile devices are designed to be used on-the-go; in some situations, two-handed use is possible, but in many situations the luxury of using both hands is not practical.

Two popular methods for touchscreen text entry are using smart touch keyboards (STKs) and smart gesture keyboards (SGKs) [Reyal et al. 2015]. Using a touch keyboard, the user enters text by tapping on the keys of an onscreen keyboard, whereas using a gesture keyboard the user enters text by drawing a path through each key in each word. The "smart" behaviour comes from the inclusion of advanced prediction, auto-correction, and, in the case of SGKs, recognition behaviours. Smart touch and smart gesture keyboards are available on all major mobile operating systems. Examples include Swype, SwiftKey and Google Keyboard.

Often, soft keyboard applications, including those listed above, support both touch and gesture methods for text entry, and the user is free to switch seamlessly between the two. This is useful for example if the gesture recognition algorithm fails to recognise the gesture for a word it is not familiar with, in which case the user can resort to the traditional method of tapping the keys. The ability to switch between methods also has other benefits, including switching method depending on the context in which the user finds themselves in. This brings us to the question of this paper; does hand posture have a significant effect on text entry performance using STKs and SGKs? And if so, are there conditions under which touch typing or gesture typing is more efficient?

These are important questions, as for many applications hand posture is constrained by the nature of the task. A good example of such an application is smartwatches. In the case of smartwatches, the fact that the device is strapped to one wrist explicitly prohibits any use of the hand on the arm of which the watch is attached. There are also situations where hand posture is implicitly constrained. An example of this are in-car infotainment or GPS systems mounted on the centre of the dashboard. For such devices, even though technically possible to use both hands, using the had on the side of the body furthest away from the system is highly impractical. Moreover, the mounted nature of the screen would most likely limit the user to input with only a single finger.

To determine if hand posture has a significant effect on text entry performance on touch screen mobile devices, we performed a laboratory study to assess the typing speed and error rate of people using both a STK and a SGK with different hand postures. These hand postures were: one finger, one thumb or two thumbs. Each of these hand postures are displayed in Fig. 1.

This study produced several findings about text entry performance using smart touch and smart gesture keyboards when hand posture is controlled:

- Hand posture has a significant effect on the speed of text entry using smart touchscreen keyboards.
- There are significant combined effects of hand posture and text entry technique (touch or gesture typing)

This information is valuable for designers who wish to use smart touch or smart gesture keyboards for devices designed for use cases where hand posture is constrained. It also has implications for researchers looking to improve touch screen keyboards.

2 RELATED WORK

Empirical Findings on Hand Posture

The most comprehensive studies on the comparative performance of smart touch and gesture keyboards are Reyal et al.'s studies [2015] on performance in both a lab controlled setting, and in daily life over a period of one month. They found that in the lab controlled setting, participants were both faster and more accurate with the STK. However, outside of the lab conditions participants were faster with the SGK, yet still more accurate with the STK.

In their same paper, Reyal et al. also presented preliminary results on the effects of hand posture on text entry performance. However, hand posture was not controlled in either of their studies and was inconsistent and self-reported. In the lab study, in order from fasted to slowest, the input methods were: 1) STK using two thumbs, 2) SGK using one finger, 3) SGK using one thumb, 4) STK using one finger and 5) STK using one thumb. Regarding error rates, in order from most to least erroneous, the input methods were: 1) STK using one thumb, 2) SGK using one thumb, 3) SGK using one finger, 4) STK using two thumbs and 5) STK using a single finger.

In their longitudinal study, no one used one thumb touch input. In order from fasted to slowest, the input methods were: 1) SGK using one thumb, 2) SGK using one finger, 3) STK using two thumbs and 4) STK using one finger. In order from most to least erroneous, the input methods were: 1) SGK using one finger, 2) SGK using a single finger, 3) STK using a single finger and 4) STK using two thumbs.

Researchers have also investigated the speed of smart touch and smart gesture keyboards on smartwatches, where hand posture is constrained to the use of one finger. Comparative studies have been performed for the Swype [Turner et al. 2017] and WatchWriter [Gordon et al. 2016] keyboards. Both studies, found using the SGK to be the fasted input method. However, Turner et al. [2017] found that error rate was highest for touch typing, whereas Gordon et al. [2016] that error rate was higher for gesture typing.

An area where the effects of hand posture have been researched is for the purposes of gathering information to improve key detection, error correction and key/key-target resizing algorithms for soft keyboards. To the best of our knowledge, this research has so far focused solely on the effects of hand posture on touch typing using a soft keyboard and without the use of any smart features.

Azenkot and Zhai [2012] assessed touch typing performance using two thumbs, one finger and one thumb. They found typing with two thumbs to be the fasted, followed by one finger and finally one thumb. When it came to accuracy however, the reverse was true; one thumb was most accurate, followed by one finger and finally two thumbs.

Thomas and Jennings [2015] directly followed up on the work by Azenkot and Zhai [2012], inspecting the surface areas of taps using different hand postures. They only reported error rates, but produced contrasting results to Azenkot and Zhai [2012]. They found that using two thumbs was most accurate, followed by one finger and then one thumb. One potential reason for these differences is the difference in device size. Thomas and Jennings [2015] carried out their experiment using a device with a larger screen (5.5" vs 4"). The target area for each key would be bigger on a larger screen, though when using their thumb participants would have had to stretch more to reach keys on the other side of the display.

Theoretical Findings on Hand Posture

For touch typing, researchers have developed human performance models for single finger and stylus use [Soukoreff and MacKenzie 1995], and one or two thumb use [Oulasvirta et al. 2013]. Similarly, there exist various different models for gesture typing performance using a single finger or stylus, such as the CLC model [Cao and Zhai 2007]. However, as far as we are aware, nobody has explicitly assessed the performance of gesture models when holding a mobile device in one hand and using a thumb. Performance using a thumb may be substantially different because it is anchored to one corner of the device, and research has shown that using a thumb is less accurate for touchscreen pointing [Wang and Ren 2009].

Finally, Zhai and Kristensson [2012] gave some theoretical reasons for the differences in efficiency between touch and gesture typing:

Continuity of movement. When touch typing, text is entered using a sequence of taps, which requires to lift and place their finger or thumb(s) more often than when word gesture typing, where the user is only required to release from the screen once per word.

Auto-spacing. The word level nature of gesture typing means that users are not required to manually enter space characters themselves, a space is automatically entered after each gesture.

Error-tolerance. With gesture typing, the user does not have to accurately trace exactly through the centre of each key, which may result in increased error-tolerance over touch typing.

Bi-manual input. The use of multiple fingers (or thumbs) is far more intuitive when touch typing compared to gesture typing. For example, when two thumb touch typing the user can mentally split the keyboard and enter characters on the left and right sides of the keyboard with their left and right thumbs respectively. As far as we are aware, no research has been undertaken exploring bi-manual gesture typing.

3 METHOD

Participants

For our study we recruited six participants[1], five of whom were university students and one of whom was a professor. All of the participants were male and right-handed. The ages of the participants ranged from 21-52 (mean = 26.7, SD = 12.4). For all participants, English was their native language. The usual smartphone device type used by five of our participants was Android, the remaining one participant used an iOS device. All of our participants had previous experience with touch typing on soft keyboards, only one participant did not have previous experience with gesture typing. Participants were not reimbursed for their time.

Apparatus and Software

We conducted our experiment using a OnePlus One smartphone running Android 8.1. The physical device size measured 152.9 × 75.9 × 8.9 mm and it had a 5.5" display with a resolution of 1080 × 1920 pixels. The software we used to present each trial to the participants, record the presented and transcribed text, and record performance metrics was the Text Entry Metrics on Android (TEMA) application [Castellucci and MacKenzie 2011]. TEMA was developed for the purpose of performing experiments using different text entry methods on Android, and has been widely used. We used the stock Android Open Source Project (AOSP) keyboard shipped with Android 8.1 for both touch and gesture typing. The personalised predictive text settings were turned off to prevent any learning of behaviour across participants or phrases. Autocapitalisation settings were also turned off as the phrase set we used contains no capital letters.

[1] We understand that this is an insufficient sample size. However, this was the largest sample we could obtain within the available time.

Procedure

The experiment consisted six blocks of 20 trials for each participant. Each trial consisted of transcribing a presented phrase. In each block of trials, participants were asked to use one of six conditions for entering text, these conditions covered every combination of *posture* (*one finger*, *one thumb* and *two thumbs*) and *technique* (*gesture* and *touch* typing). To mitigate transfer effects, participants each completed the blocks in the order determine by a balanced Latin square. Before commencing the session, participants were allowed time to familiarise themselves with each of the hand postures and typing methods. Between each block of trials, participants were allowed to rest, and relax and stretch out their hands. Between blocks, participants also completed a NASA-TLX questionnaire. Participation took between 30 and 40 minutes, including time for breaks.

We used the phrase set created by MacKenzie and Soukoreff (2003). This phrase set contains 500 phrases and 1163 unique words. Phrases vary in length from 16 to 43 characters, with a mean length of 28.61. The word frequencies in the phrase set are highly correlated with the letter frequencies in the English language [MacKenzie and Soukoreff 2003]. Word lengths vary from 1 to 13 characters, with a mean length of 4.46. The phrases in the dataset contain no numbers or punctuation, and all characters were lowercase. For each condition, the 20 phrases the participants were asked to transcribe were randomly chosen from the dataset. Participants were asked to enter each phrase as quickly and accurately as possible. They were also encouraged to use the suggestions and corrections offered up by the keyboard as they typed. Participants were seated at a desk during the experiment and were not subject to any external distractions.

Design and Hypotheses

Our experiment was designed as a 3 × 3 RM-ANOVA for factors *posture {one finger, one thumb, two thumbs}* and *technique {gesture, touch}*. The dependent variables are entry rate, measured in words-per-minute (WPM) and character error rate (CER). CER is defined as the Levenshtein distance (minimum string distance) between the presented and transcribed phrases, divided by the number of characters in the presented phrase. We include partial eta-squared (η_p^2) as an estimate for the effect size for significant differences reported by our ANOVA analyses.

We chose to use phrase transcription over word repetition or text generation as it emulates real usage better than word repetition, and has the benefit over text generation of being able to assess accuracy. The first five trials in each block were classified as practice trials to allow participants to get used to the new technique and posture and were not included in our analysis. Any trials for which the entry or error rates exceeded three standard deviations of the mean for that block were identified as outliers and were also discarded from our analysis.

Our primary hypotheses, based on the findings of the related work discussed above, were as follows:

- **H1:** The comparative speed of *gesture* and *touch* typing will vary with *posture*.
- **H2:** Typing with *two thumbs* will be faster than typing with *one finger*, due to parallelism, and typing with *one finger* will be faster than typing with one thumb, due to increased freedom of movement and being able to support the device with two hands.
- **H3:** Accuracy will be highest using *one finger*, followed by *two thumbs* and then *one thumb*.
- **H4:** Accuracy will be higher with *touch* than with *gesture*.

4 RESULTS

There were no outlying trials which needed to be removed. Therefore, we analysed 15 trials per condition for each participant. This gave us 90 data points for each condition.

Text Entry Rate

The results for text entry rate are summarised in Fig. 2. Mean entry rates were fastest with *two thumbs* (35.95 WPM, s.d. 12.68), followed by *one finger* (31.39 WPM, s.d. 7.85) and *one thumb* (26.60 WPM, s.d. 8.38), giving a significant main effect of *posture*: $F_{2,10} = 15.10$ $p = .001$, $\eta_p^2 = .36$. Using *one finger*, the mean entry rates for the *gesture* and *touch* were almost identical (31.35 WPM and 31.43 WPM respectively). Using *one thumb*, the mean entry rates for *gesture* and *touch* were again similar, though slower than when using *one finger* (26.15 WPM and 27.05 WPM respectively).

As shown in Fig. 2, the mean entry rates for *gesture* and *touch* were substantially different when using *two thumbs*. The entry rate using *two thumbs* for *gesture* (28.60 WPM) was similar to the other *gesture* entry rates, but the entry rate using *two thumbs* for *touch* (43.29 WPM) was substantially higher than all other combinations of *posture* and *technique*. As a result, there is a significant *posture* × *technique* interaction ($F_{2,10} = 21.07$, $p = .0003$, $\eta_p^2 = .30$), and we therefore accept **H1**.

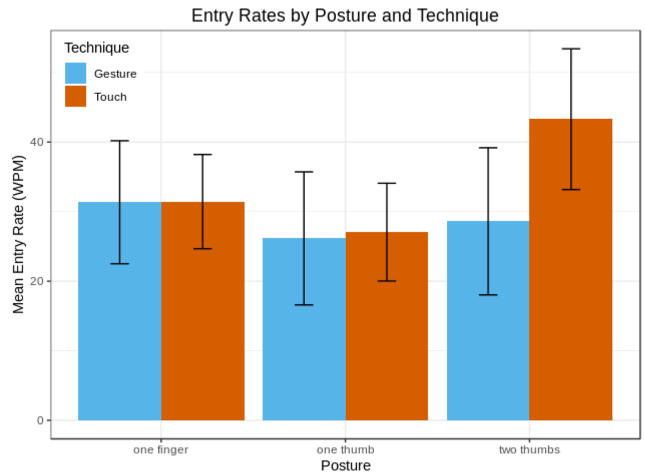

Figure 2: Mean text entry rates for each hand posture when using the smart touch and smart gesture keyboards.

Post hoc Bonferroni-adjusted pairwise comparisons ($\alpha = 0.05$) showed that *one finger* and *two thumbs* were significantly faster than *one thumb*, but there was no difference between *one finger* and *two thumbs*. As a result, we fail to find sufficient evidence to support **H2**.

The mean text entry rates for *gesture* and *touch* are 28.70 WPM (s.d. 9.88) and 33.92 WPM (s.d. 10.61) respectively. There was no significant effect of *technique* found ($F_{1,5} = 5.17$, $p = .072$, $\eta_p^2 = .21$).

Character Error Rate

The results for error rate are summarised in Fig. 3. Error rates were highly variable across *posture*, but were highest using *one thumb* (3.35%, s.d. 8.33), followed by *one finger* (2.74%, s.d. 5.4) and *two thumbs* (2.45%, s.d. 3.82). There is no significant main effect of *posture* ($F_{2,10} = .23$, $p = .78$, $\eta_p^2 = .013$), meaning we have insufficient evidence to support **H3**.

Likewise, there was high variability in error rates across *technique*, but they were higher for *gesture* (3.49%, s.d. 7.92) than for *touch* (2.20%, s.d. 3.50) and there is no significant main effect of *technique*: $F_{1,5} = 1.20$, $p = .32$, $\eta_p^2 = .037$. Again, as a result we fail to find support for **H4**. There was also no significant *posture* × *technique* interaction ($F_{2,10} = 2.14$, $p = .17$, $\eta_p^2 = .061$).

Perception of Effort

The mean results from the NASA-TLX surveys completed after each block of trials are shown in Fig. 4. Friedman tests

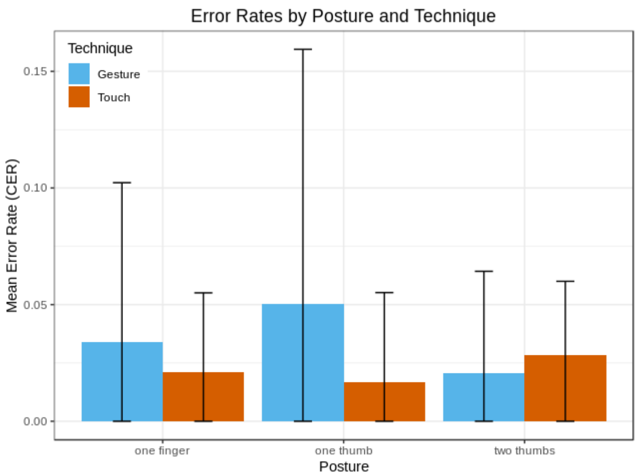

Figure 3: Mean text error rates for each hand posture when using the smart touch and smart gesture keyboards.

show significant differences in physical demand with condition ($\chi_r^2 = 13.10$, $df = 5$, $p = .022$) and in frustration with condition ($\chi_r^2 = 14.54$, $df = 5$, $p = .013$). However, post hoc Bonferroni-adjusted pairwise comparisons ($\alpha = 0.05$) showed no significant differences. Perhaps with more data we would be able to tease the conditions apart.

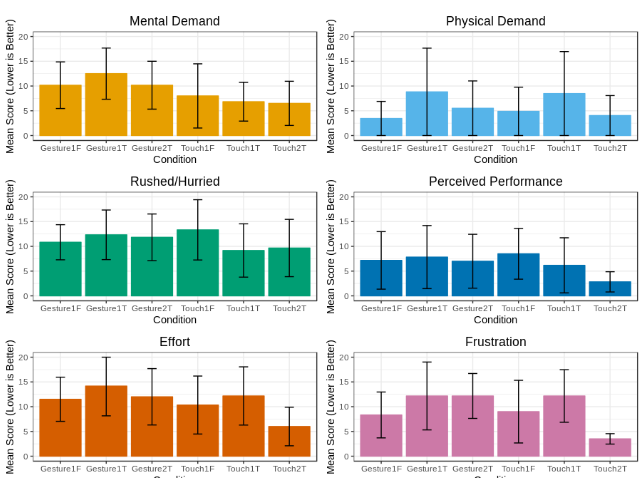

Figure 4: Mean scores for each question of the NASA-TLX survey for each posture-technique combination (1F = one finger, 1T = one thumb and 2T = two thumbs).

More enlightening are the comments we recorded during and after participation. We received consistent feedback on some of the posture and technique combinations. All but one of the participants commented on how they found using one thumb when touch typing to be uncomfortable or found it difficult to reach letters on the far side of the keyboard. The only participant who didn't comment on this was the person who reported using gesture typing with a single thumb most often in daily use. Similar comments were made regarding gesture typing with one thumb.

When allowed to gesture type with two thumbs, participants rarely used their non-dominant thumb to enter text. One participant commented that gesture typing with two thumbs felt "counter-intuitive", which is unsurprising because gesture typing is designed for uni-manual input. Despite still extensively using one thumb, none of the participants complained about discomfort during gesture typing using two thumbs, we expect that this is because they were able to support the device using two hands. A recurring piece of feedback on touch typing with one finger was that it felt slow and a result was frustrating.

5 DISCUSSION

Summary of Findings

Our main findings are that hand posture and technique do effect text entry performance, but not entirely in the way we hypothesised.

Firstly, our results show that text entry rates using smart touch or smart gesture keyboards are similar when using uni-manual input, i.e. one finger or one thumb. However, when using bi-manual input (i.e. two thumbs) it appears touch typing is faster than gesture typing. In general, typing using one finger is significantly faster than using one thumb. We found no significant different between entry rates using one finger and two thumbs, though this is likely due to the fact that the mean entry rates for the SGK using two thumbs were lower than those for one finger, despite the means for two thumb touch typing being substantially higher than one finger touch typing for the STK.

Secondly, despite there being visible differences in the mean error rates between techniques and postures, we found no significant differences in error rate for either posture or technique. This is likely due to high variability.

Finally, subjective assessments of the effort required for each combination of posture and technique showed significant differences in physical demand and frustration, but post hoc Bonferroni-adjusted testing was not able to pinpoint significant differences with the amount of data we had.

Reasons for Results

Experimental factors. One aspect of our experiment design which clearly influenced performance was device size. Unfortunately, we had to use a device with such a large screen as it was the only device we had access to. Another factor which impacted the statistical power of our results was our small sample size. With only six participants, our results were highly variable which made it hard to tease out differences between the conditions. This is particularly evident in our evaluation of error rates.

Other Factors. Our results showed that text entry using one thumb is significantly slower than when using two thumbs or one finger, though, contrary to our hypothesis, we found no significant difference between two thumbs and one finger. This is likely because gesture typing using two thumbs was no better than one finger performance. From observing our participants during the study, it is clear that the parallelism of two thumb gesture typing is far lower than for touch typing. Participants themselves stated that the found gesture typing with two thumbs "counter-intuitive" and reported using their non-dominant thumb sparingly.

We expected gesture typing performance to be faster than touch typing performance when using one thumb or one finger, however this proved not to be the case. Aside from the limiting factor of device size, which based on participant comments appears to have impacted gesture typing more than touch typing, one possible reason is the difference in the use of smart features. From our observations, and participant comments, participants seemed to use the available smart features less when gesture typing and reported finding them less useful. One participant reported that they used the predictive and suggestive functionality less when gesture typing because they had to focus more on the task of typing.

Limitations and Future Work

The main limitations in our study were device size and lack of participants, both of which will be addressed in future work. On top of this, our results and observations have highlighted several areas which warrant further investigation:

- The importance of screen size on STK and SGK performance. Our experience suggests that screen size plays an important role in both accuracy and speed.
- Improving parallelism for two-thumb gesture typing, possibly through the use of optimised two-thumb keyboard layouts.
- Assessing performance over time and in mobile situations, instead of in stationary, seated conditions.

6 CONCLUSION

Touchscreens are becoming an increasingly important interface technology. Our results show that hand posture has a significant effect on the speed of text entry using smart touchscreen keyboards. We also show that there are significant combined effects of hand posture and technique (touch or gesture typing). These results have implications for designers and researchers investigating mobile text entry or text entry on soft keyboards where hand posture is constrained.

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