Touch Typing using Thumbs: Understanding the Effect of Mobility and Hand Posture

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ABSTRACT
Mobile touch devices have become increasingly popular, yet typing on virtual keyboards whilst walking is still an overwhelming task. In this paper we analyze; firstly, the negative effect of walking on text-input performance, particularly the users' main difficulties and error patterns. We focused our research on thumb typing, since this is a commonly used technique to interact with touch interfaces. Secondly, we analyze how these effects can be compensated by two-hand interaction and increasing target size. We asked 22 participants to input text under three mobility conditions (seated, slow walking, and normal walking) and three hand conditions (one-hand/portrait, two-hand/portrait, and two-hand/landscape). Results show that independently of hand condition, mobility significantly decreased input quality, leading to specific error patterns. Moreover, it was shown that target size can compensate the negative effect of walking, while two-hand interaction does not provide additional stability or input accuracy. We finish with implications for future designs.

Author Keywords
Text-entry; Mobile; Walk; Thumb; Hand Posture.

ACM Classification Keywords
H.5.2 [Information Interfaces and Presentation]: User Interfaces - Input devices and strategies;

General Terms
Human factors, design, experimentation.

INTRODUCTION

Mobile devices are being increasingly used whilst walking. This new interaction context poses new challenges to mobile users since they usually compete for the same human resources that are needed to fully control electronic devices. However, interfaces are designed, developed, and evaluated for static and controlled situations, ignoring these problems. When on the move the whole body is prone to vibrations, particularly hand oscillations can hamper interaction with a mobile device [2]. This effect is worsened when the interface features small targets [8], such as virtual keys.

Studies regarding the effect of mobility report that users spontaneously reduce speed by 30-37% when performing reading tasks in a mobile device. Similarly, Bergstrom-Lehtovirta et al. [2] have shown that to maintain target selection accuracy users need to reduce speed by 26%, as compared to their preferred walking speed. Lin et al. [5] examined stylus-based tapping behavior whilst walking. Results show that walking had no effect on the time needed to select a target, yet they saw an increase towards error rates. Mizobuchi et al. [6] also focused on stylus interaction and analyzed the effects of mobility and keyboard sizes on text-entry tasks. The authors report no effect on text input speed; however, error rates tend to increase. Additionally, they saw an effect of target size: larger targets allow higher input rates and lower error rates. Although the authors also analyze the effect of walking and key size in text input, a key difference to our work lays in the fact that in their study a stylus was used and therefore, only two-handed interaction was analyzed. In our study, in addition to target size, we also considered both one-hand and two-hand interaction, in which participants use their thumbs to input text, as this is currently one of the most commonly used technique with touch screen devices.

Interaction with thumbs has been studied in target selection tasks [8], and static conditions [7], yet there is a lack of knowledge pertaining text-entry tasks whilst mobile. The study presented in this paper tries to bridge this gap by analyzing the effect of walking on text-entry performance, and secondly to understand the effects of two-hand interaction and target size. Moreover, we describe the users' typing difficulties and error patterns whilst walking, as well as their causes.

METHOD

We evaluated the participants' performance in three mobility settings: sitting, walking at average human pace (2 steps per second), and walking at 65% of average human pace (1.3 steps per second) [1]. The experiment was conducted on an indoor test track built-up at the university campus (without obstacles). In both walking conditions, we asked participants to follow a pacesetter while entering text. Although other designs could be chosen [4], we opted to keep a fixed pace rather than measure it as a dependent variable in order to ensure a comparable level of walking demand across trials. The experimenter instructed participants to stay within 2 meters of the pacesetter as he walked. If the participant fell behind by more than 4 meters, the experimenter logged a walking deviation for that trial. The pacesetter carried a mobile phone, which gave him feedback through vibration about the intended pace.

Participants

Twenty two participants, 3 females and 19 males, took part in the user study. Their age ranged from 23 to 40 with a mean of 26.5 years old. They were recruited from Campus University. None of the participants had visual or motor impairments and all of them owned a mobile phone, whereas only 15 used touch screen technology regularly. All participants were right-handed.

Procedure

At the beginning of the experiment participants were told that the overall purpose of the study was to investigate how text-entry performance was affected by walking conditions. Subjects were then informed about the experiment and how to use our evaluation application.

Before each mobility condition participants had a 5 minute practice trial to get used to the pace and text-entry task. For each mobility setting, subjects were asked to enter text with 3 hand conditions (chosen randomly) always using their thumbs: one-hand/ portrait, two-hand/ portrait, and two-hand/ landscape. For each condition participants copied seven different sentences (first two sentences were practice trials), displayed one at a time, at the top of the screen. Copy typing was used to reduce the opportunity for spelling and language errors, and to make error identification easier. Participants were instructed to type phrases as quickly and accurately as possible. Error correction (delete) was not available, since we wanted a single measure of accuracy.

Each participant entered a total of 63 different sentences, extracted from a written language *corpus*, each with 5 words, an average size of 4.48 characters per word, and a minimum correlation with the language of 0.97. Both sentences and mobility conditions were chosen randomly to avoid bias associated with experience.

Apparatus

An HTC Desire with a capacitive touch screen was used during the user study. A QWERTY virtual keyboard was used to simulate a traditional touch keyboard, where each key was 10x10mm on landscape mode, and 7x10mm on portrait mode. Letters were entered using a lift-off strategy. Neither word prediction nor correction was used. Acceleration data was captured through device's accelerometer for posterior analysis.

Design and Analysis

We used a within subjects design where each participant tested all mobility and hand conditions. In summary the study design was: 22 participants x 5 sentences x 3 hand conditions x 3 mobility settings = 990 sentences overall.

Shapiro-Wilkinson tests of the observed values for *Words per Minute (WPM)*, *Minimum String Distance (MSD) Error Rate,* incorrect characters (*Substitutions*), omitted characters (*Omissions*), and added characters (*Insertions*), showed to fit a normal distribution for all conditions. Therefore, a two-way repeated-measures *ANOVA* was used in further analysis. Greenhouse-Geisser's sphericity corrections were applied whenever Mauchly's test of sphericity showed a significant effect. Pairwise Bonferroni corrected t-tests were used for post-hoc tests.

RESULTS

Two-hand input is faster

To assess speed, we used the words per minute (*WPM*) text input measure. Overall, input speed was very similar between mobility conditions. Participants obtained an average of 24 (CI 1.4 wpm), 24.9 (CI 1.4 wpm), and 24.5 (CI 1.4 wpm) words per minute on seated, slow walking and regular walking conditions, respectively. The results show that there was no significant main effect of *Mobility* on *WPM* ($F_{2,42}$=.97, p>.1). This effect was expected since participants could not perform corrections to transcribed sentences.

Regarding hand posture, participants wrote an average of 20 (CI 0.9 wpm) words per minute with one-hand. Two-hand interaction allowed participants to reach higher input speeds: 25 (CI 1.2 wpm) and 29 (CI 1.3 wpm) words per minute with portrait and landscape positions, respectively. A repeated measures ANOVA revealed a significant main effect of *Hand Posture* on *WPM* ($F_{2,42}$=84.878, p<0.001). *Bonferroni* post-hoc tests showed significant differences between all hand conditions. As expected, writing with the two-hand landscape mode is significantly faster, followed by two-hand portrait and one-hand.

Two-hand input does not provide additional stability

In this study we measured the quality of the transcribed sentences using the *Minimum String Distance (MSD) Error Rate* (Figure 1). *Mobility* effect can be clearly seen as *MSD Error Rate* increases with amplitude of hand oscillation

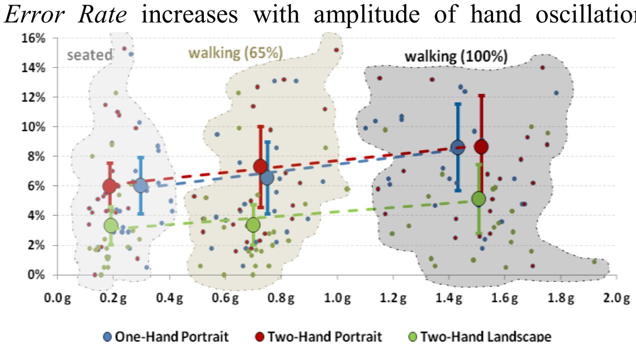

Figure 1. *MSD Error Rate by hand oscillation amplitude. Vertical bars denote 95% CI. Lines illustrate linear regression.*

(calculated as standard deviations of average accelerations [2]). Between seated and normal walking, quality of transcribed phrases decreased on average, approximately, 2.4%. Participants achieved an average *MSD Error Rate* of 5.1% (CI 1.7%), 5.7% (CI 2.3%), and 7.5% (CI 3%) on seated, slow walking, and normal walking, respectively. Results show a significant main effect of *Mobility* on *MSD Error Rate* ($F_{1.244,26.115}$=4.962, p<.05), with significant differences between seated and normal walking conditions.

Regarding the effect of two-hand interaction, oscillation was very similar for both portrait modes. Indeed, *MSD Error Rate* was very similar with an average of 7.1% (CI 2.5%) and 7.3% (CI 2.7%) for one-hand and two-hand, respectively, demonstrating that two-hand interaction by itself does not provide additional stability. Nevertheless, in landscape mode, accuracy increased nearly 3.4%, resulting on a significant main effect of *Hand Posture* ($F_{2,42}$=16.546, p<.001). This suggests that key size has a greater influence than hand grip on text input accuracy and can compensate the negative effect of mobility. No interactions between *Mobility* and *Hand Posture* were found.

Hand oscillation causes poor aiming, not finger slips

Figure 2 illustrates error types per mobility and hand conditions. We analyze only *Substitution Errors* because both *Insertion* and *Omission Errors* accounted for only a minority of error rates and there were no significant differences over conditions.

Substitution Errors significantly increased with *Mobility* ($F_{1.440,\ 30.243}$=5.195, p<.05) with differences between seated and normal walking conditions. Similarly, we also found a significant main effect of *Hand Posture* on *Substitution Errors* ($F_{2,42}$=16.578, p<.001). Differences were found between two-hand landscape (2.1%) and both one-hand (5.3%) and two-hand portrait (4.8%) conditions.

Overall, substitutions were the most common type of error and the most sensitive to mobility conditions. One could assume that due to hand oscillation the users' fingers could slip to a near key before entering the letter, resulting in a *Substitution Error*. However, on average, slips accounted for less than 10% of substitutions and were not affected by *Mobility* ($F_{2,42}$=1.005, p>.1). A thorough analysis revealed that 72%-92% of substitution errors are due to poor aiming, i.e. incorrect land-on target. Although participants could compensate for land-on errors, most performed quick taps as if they were typing with a physical keyboard.

Substitution errors occurred as adjacent keys in the same row.

Based on our results, we created confusion matrices for each condition. Substitution error rate per letter for one-hand portrait conditions is shown in Figure 3. When seated, the most frequent substitution errors were: E→R (4.6%), R→T (6.5%), S→D (11.5%), T→Y (4%), U→Y (4.5%), U→I (3.4%). As we can see there is a clear predominance

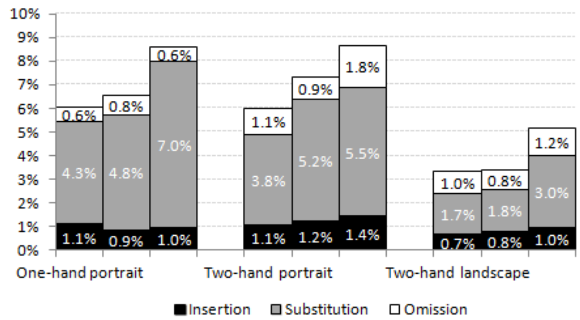

Figure 2. *Insertion, Substitution, and Omission* error rates, grouped by hand condition. Left, middle, and right bars correspond to seated, walking (65%), and walking (100%), respectively.

of same-row errors in the data, which suggests that participants found it easier to hit keys in the vertical direction than horizontally. This may be because key height was slightly higher than key width. Additionally, all errors are at a distance of one key and typically at the right. These findings need further investigation, but may be related to hand dominance. In the normal walking condition the most frequent substitution errors were: D→F (10.4%), R→T (9.3%), S→D (11.8%), T→Y (5.2%), T→R (4.6%). In this case, the highest error rate keys seem to be somewhat the more distant from the users' dominant hand (Figure 3), and once again the pattern of substitution remained the same (adjacent key). It is noteworthy that although hand oscillation increased from seated to normal walking condition, substitutions remained at a distance of one key.

Regarding the two-hand portrait condition, error rates follow the same substitution pattern. As mobility demand increase, higher error rates seem to cluster on the left side of the keyboard, suggesting that the non-dominant hand is less accurate. Frequent substitution errors were: S→A (12.6%), C→X (4.4%), E→R (3.5%), U→I (4.3%), D→F (2.7%). With the two-hand landscape posture, participants committed much fewer errors due to target size, and error rates are fairly distributed among keys.

Overall, mobility seems to increase error rate magnitude, however the substitution pattern is similar between conditions: same row errors and adjacent keys. Additionally, on one hand interaction letters are usually substituted by their right-side keys, while in two hand interaction this effect dissipates. Nevertheless, the non-dominant hand seems to have a lower accuracy, particularly when hand oscillation is higher.

Lower error rates means higher walking performance

In this user study, participants had to follow a pacesetter on mobility conditions. Walking errors were counted when users stopped or lagged behind the pacesetter by more than 4 meters. When that happened, the pacesetter waited for the participant and then resumed the pace. We found a significant main effect of mobility condition on walking

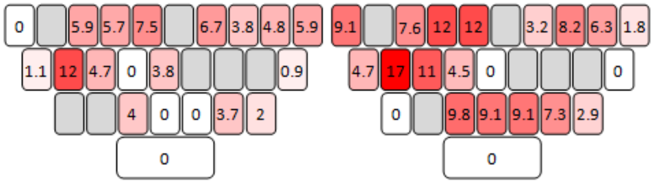

Figure 3. *Substitution* error rates per key in one-hand portrait condition whilst seated (left) and normal walking (right).

errors as participants committed significantly more errors whilst walking at a normal pace than whilst walking at slow pace ($F_{1, 21}$=10.010, p<.05). Regarding hand conditions, the average number of walking errors per participant was 0.5, 0.4, and 0.3 for one-hand portrait, two-hand portrait, and two-hand landscape, respectively. Results show a significant effect of *Hand* on *Walking Errors* ($F_{1.575, 33.082}$=3.847, p<.05). Significant differences were found between landscape and both portrait conditions. This result suggests that easier text-entry methods allow for better performance on walking tasks.

Most users prefer larger keys

Regarding preference, 81.8% of participants preferred the landscape mode, with a 95% adjusted-Wald binomial CI ranging from 60.9% to 93.3%, a lower limit above the three-choice chance expectation of 33.3%. None of the participants chose this interaction mode as the least preferred, showing that generally users prefer larger keys to input text. The one-hand portrait condition shown to be the least preferred for 13 of the participants. Moreover, none chose this interaction mode as his/her preferred. Regarding the two-hand portrait condition, while it was disliked by nine users, four participants preferred this interaction mode due to convenience or input speed. Interestingly, this preference was not correlated with their performance.

DESIGN IMPLICATIONS

Do not over rely on two-hand interaction for physical stability. Future mobile text-entry solutions should not rely on hand grip to improve typing effectiveness. Data shows that two handed interaction do not decrease hand oscillation nor does it improve input quality. As an alternative, increasing key size allow users to compensate the negative effect of mobility. However, this solution is not always possible due to limited screen size.

Adjacent substitutions. Results show that substitutions are the most common type of error and usually occur on the same row and adjacent keys. Therefore, predictive text-entry methods, correction algorithms or adaptive keyboards should take into account this typing behavior. These solutions will mostly likely work for different mobility conditions, since the pattern remains unchanged.

Design for poor aiming, especially whilst mobile. Alternative modalities have been used to improve touch typing and reduce slip-based errors [3]. However, these solutions only address a minority of input errors. Future designs should focus on dealing with poor aiming. For instance, text-entry methods may automatically compensate touch locations by sensing hand tremor or increase some key sizes, thus significantly enhancing user performance.

CONCLUSION

The results described in this paper present the negative effect of walking on touch typing using thumbs. It was shown that independently of hand condition, i.e. one-hand portrait, two-hand portrait or two-hand landscape, mobility significantly decreased input effectiveness, leading to consistent substitution patterns. Moreover, two-hand interaction allowed higher input rates, however it did not provide additional physical stability or text-entry accuracy. On the other hand, when compared to portrait mode, landscape interaction can compensate the negative effects of mobility due to larger key size. Those results, in addition to the described design implications, can improve future mobile designs towards more effective text-entry solutions.

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