Effects of Interaction Style and Screen Size on Touchscreen Text Entry Performance: An Empirical Research

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Abstract. In this paper we investigate text entry performance for mobile touchscreen devices with emulated QWERTY keyboards, with special emphasis on interaction style and screen size. When addressing interaction style, we are referring to the five most common combinations of hands postures and device orientations while executing text entry tasks. Both single-finger and two-thumb methods for typing in portrait and/or landscape layout are considered. As for screen sizes, several classes of popular mobile devices are examined, specifically smartphones and tablets with smaller and larger form factor. In addition, the mobile device emulator is included in the study, in order to report the comparative analysis of text entry with an actual device and its emulation-based counterpart. The touchscreen desktop monitor was used so as to provide touch input for the device emulator. Results obtained from experimental testing, supported by thorough data analysis, provide a valuable insight into the user behavior when typing on touchscreens.

Keywords: text entry, interaction style, screen size, touchscreens, mobile devices.

1 Introduction

Following the commercial success of touchscreen mobile devices, virtual keyboards (soft/touchscreen/on-screen keyboards) turned into dominant tools for typing "on the move". However, when compared with typing on physical keyboards, text entry on popular touchscreen smartphones and tablets is considered slow, uncomfortable, and inaccurate [1]. These usability issues, derived mainly from limited screen size and "fat finger syndrome", are usually addressed by making use of virtual keyboards' software based characteristics. Soft keyboards can be easily programmed to accommodate different layouts, screen sizes, device orientations, and languages, as well as to provide dictionary support and auto-correction features. Furthermore, innovative

C. Stephanidis and M. Antona (Eds.): UAHCI/HCII 2014, Part II, LNCS 8514, pp. 68–79, 2014.

interaction methods can be utilized, such as in gestural text input [2, 3], and in tilt-based text entry [4, 5]. Although multimodal text entry represents a valuable benefit in the area of universal access, users are in general resistant to waste their time in order to learn new text-input techniques [1]. This could be the actual reason why QWERTY still stands as the default keyboard layout in contemporary mobile touch-screen devices.

In studying text entry performance for mobile touchscreens, screen size is definitely the factor worth to consider. Larger devices naturally offer layouts with more convenient key button sizes, thus ensuring lower probability of making pointing errors. On the other hand, wider layouts come with increased distance between buttons, implying longer path that has to be covered by finger movements. Consequently, screen size can have a certain impact on both text entry speed and accuracy. The way of holding a mobile device can also play a significant role in touch typing scenarios. Users may interact with the mobile device in ways that are detrimental to performance, as the grip on a device determines several performance-affecting factors: the degrees of freedom in joint movement, the controlling muscles, and the orientation of the fingers' joints in relation to the display [6].

Owing to above mentioned remarks, we decided to carry out an empirical research of touchscreen text entry performance with two factors being in the main focus: (i) mobile device screen size, and (ii) interaction style – a combination of hands posture and device orientation used in text entry tasks.

2 Related Work and Motivation

In the context of touchscreen text entry study, HCI-based research is commonly called in to provide for trouble-free and more efficient touch typing. This includes dealing with typical problems such as the "fat-finger syndrome", optimal character layout, and appropriate size of key buttons. A huge amount of work has already been done by introducing many alternative keyboard designs and new input modalities, investigating typing behavior, and providing new metrics for text entry performance measurement.

The effect of soft button size on touch pointing and typing performance is already well documented [7, 8, 9]; however, there is a lack of focused studies related to present-day mobile devices' native keyboards. Recent research on touchscreen based text entry that addresses the way of holding mobile devices can be found in [10] and [11]. Nicolau and Jorge [10] focused their research exclusively on thumb typing, while considering three possible hand postures under three mobility settings. For an HTC Desire smartphone device, the two-thumbs landscape method was reported as the fastest one, followed by two-thumbs portrait and one-thumb portrait. Interaction based on forefinger usage was not included in this study. Azenkot and Zhai [11] explored touch behavior on soft keyboards when used with two thumbs, a forefinger, and one thumb. The Samsung Galaxy S smartphone was the only testing device used, and the corresponding results confirmed the two-thumbs text entry method as the

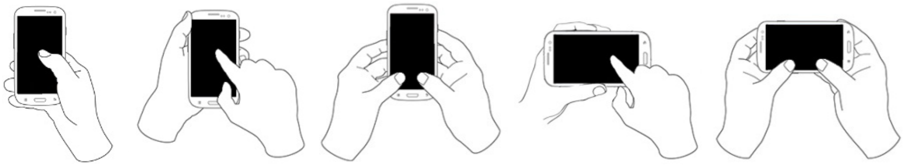

Fig. 1. Examples of well-suited interaction styles for smartphone text-entry. From left to right: one-thumb/portrait, forefinger/portrait, two-thumbs/portrait, forefinger/landscape, two-thumbs/landscape.

fastest one, followed by forefinger usage and the one-thumb technique. The error rates among postures reflected a speed-accuracy trade-off, since classification regarding erroneous input was the same as with the typing speed. Although both thumb usage and forefinger usage were considered, device orientation (portrait/landscape) was not addressed in the mentioned research.

Regarding the above reported related work, the motivation for our research stems from the need to strengthen the understanding of touchscreen text entry performance by providing a comparative analysis of all convenient interaction styles, as defined on Fig. 1.

Forefinger-based interaction styles correspond to use cases wherein one hand is holding the device, while the other – usually the dominant one – performs the text entry. In his field study regarding mobile device grip, Hoober [12] terms this interaction style as *cradling*, mentioning that either forefinger or thumb can play the role of the pointing tool. While both cradling and two-thumbs techniques are also fully eligible for text entry on touchscreen tablets, single-handed usage is not appropriate due to the tablets' form factor. Apart from smartphone and tablet classes, we additionally want to tackle text entry on a mobile device emulator. To the best of our knowledge, there is no study reporting the comparative analysis of interacting with an actual touchscreen smartphone/tablet and its emulator counterpart. For that reason, we make use of a touchscreen desktop monitor, and assume forefinger-based interaction style as the only option for text entry. The complete set of device classes, corresponding screen sizes, and interaction styles targeted by our research is presented in Table 1.

Table 1. Terget device classes, corresponding screen sizes, and interaction styles within our text entry research

Device class	Touchscreen size	Text entry interaction style				
		one-thumb portrait	cradling portrait	two-thumbs portrait	cradling landscape	two-thumbs landscape
Smaller smartphones	< 4"	✓	✓	✓	✓	✓
Larger smartphones	[4" - 5"]	✓	✓	✓	✓	✓
Smaller tablets	~ 7"		✓	✓	✓	✓
Larger tablets	~ 10"		✓	✓	✓	✓
Emulator	4.3" emulation		✓		✓	

3 Empirical Evaluation: Materials, Methods, and Metrics

For testing purposes, we implemented a simple Android application for gathering text entry events and the corresponding timing data. The application stores measurement results, along with the information about user ID and utilized interaction style, in CSV format on the device's internal SD card. Built-in text entry tasks are transcription-based, meaning that each trial requires rewriting a displayed text phrase randomly selected from a 500 instances set developed by MacKenzie and Soukoreff [13]. We consider a single task to be done when a particular phrase is fully and correctly transcribed, so a distinct cognitive load for error checking is assumed. Since input verification can impact the text entry speed, we try to decrease this cognitive demand by providing visual feedback about (in)correct letters (see Fig. 2.).

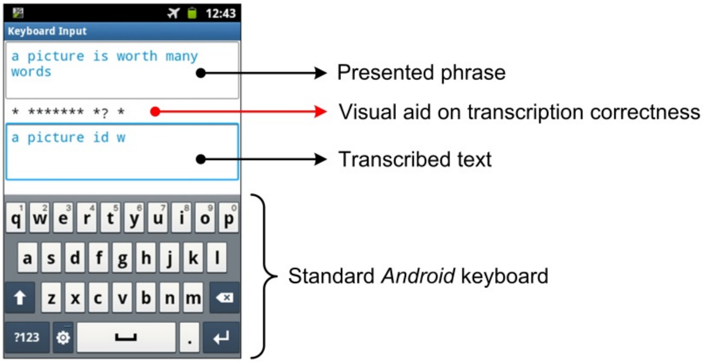

Fig. 2. Testing application: mistaken letters in the input stream are indicated with a question mark. Snapshot taken on *Samsung Galaxy Mini 2* (GT-S6500D).

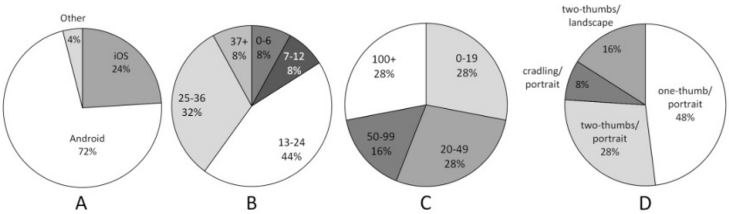

Fig. 3. A – operating systems of mobile devices owned by test users; B – users' experience with touchscreen mobile devices (in months); C – approximate number of touchscreen text entry tasks made per day; D – preferred interaction style when texting with smartphone

Twenty-five users were involved in our empirical research (20 males, 5 females), their age ranging from 21 to 35 with an average of 24 years. The statistics about their touchscreen usage is depicted in Fig. 3.

In the experiment we used four different mobile devices (D1–D4) running the Android OS, two from the smartphone class (D1, D2), and two from the tablet one (D3, D4). A default emulator from the Android SDK, with a 4.3" target skin, was tested on a touchscreen desktop monitor (D5), thus providing the basis for comparison with the larger smartphone (D2). Details about all used devices are presented in Table 2.

Table 2. Devices used in text entry empirical research. In order to minimize possible bias caused by devices' different technical specifications, a single manufacturer's products were selected. Also, testing application was developed targeting minimal CPU and RAM requirements.

Device	**D1**	**D2**	**D3**	**D4**	**D5**
Class	Smaller smartphone	Larger smartphone	Smaller tablet	Larger tablet	Touchscreen desktop monitor
Model	*Samsung Galaxy Mini 2*	*Samsung Galaxy S II*	*Samsung Galaxy Tab 2*	*Samsung Galaxy Tab 2*	*Dell Multitouch ST2220T*
W/H/D [mm]	58.6×109.4×11.6	66.1×125.3× 8.5	122.4×193.7× 10.5	256.6×175.3× 9.7	528.1 × 380.1 × 58.5
Weight [g]	105	116	341	587	6300
Display	3.27" 320×480 ~176 dpi capacitive	4.27" 800×480 ~218 dpi capacitive	7.0" 1024×600 ~170 dpi capacitive	10.1" 1280×800 ~149 dpi capacitive	21.5" 1920×1080 ~102 dpi IPS TFT optical
CPU	ARM Cortex-A5 (800MHz)	ARM Cortex-A9 (1.2GHz)	ARM Cortex-A9 (1 GHz)	ARM Cortex-A9 (1 GHz)	Run under: i5-2400 (3.1GHz)
RAM	512MB	1 GB	1 GB	1 GB	Run under: 4 GB
OS	Android 2.3.6	Android 2.3.4	Android 4.0.3	Android 4.0.3	Run under: Win 7

At the beginning of the testing session, users were involved in a short practice session (about 30 minutes) in order to familiarize with available devices, standard keyboard layouts, and testing application features. In the actual experiment, for each device D1–D5, participants were instructed to enter three different text phrases "as quickly as possible, as accurately as possible", using all interaction styles – according to the mapping presented in Table 1. Changing interaction styles on the touchscreen monitor implied shifting the emulator skin to proper orientation. Both the device order and the interaction style order were counterbalanced using balanced Latin squares design [14], so as to compensate for possible learning effect. Each participant entered 60 text phrases in total: 3×5 per smartphone, 3×4 per tablet, and 3×2 on the emulator. All auxiliary features of the standard Android keyboard, such as dictionary support, predictive text, auto-capitalization, and auto-punctuation were turned off. The backspace key was the only option allowed for deletion. Text entry tasks could have been accomplished while sitting or standing in a laboratory environment, so each participant had to make a choice of respective position in regard to her/his own preference.

Text entry performance was evaluated using data obtained from the devices' CSV files. Text entry speed was measured in words per minute (WPM). Three error rate types, as provided in the work by Soukoreff nad MacKenzie [15, 16], were used as accuracy metrics: T_{ER} (*Total Error Rate*), CAW_{ER} (*Corrected-And-Wrong Error*

Rate), and CBR_{ER} (*Corrected-But-Right Error Rate*). CAW_{ER} and CBR_{ER} represent corrections made on letters that were actually in error, and on letters that were correct, respectively.

Altogether 1500 text phrases were entered using five different touchscreens and five different hand postures, thus making a good basis for studying effects of interaction style and screen size on touchscreen text entry performance.

4 Results and Discussion

Mean values and standard deviations for text entry speed and accuracy metrics are presented in Table 3. As opposed to WPM, T_{ER} standard deviation values indicate that the error rate data deviates from a bell shaped curve. This assumption was later confirmed as Shapiro-Wilk tests of the observed values for T_{ER} showed no fit with normal distribution.

Table 3. Results: descriptive statistics summary for WPM and T_{ER} metrics

Device (D)	Text entry interaction style (S)									
	S1: one-thumb portrait		S2: cradling portrait		S3: two-thumbs portrait		S4: cradling landscape		S5: two-thumbs landscape	
	WPM	T_{ER} [%]	WPM	T_{ER} [%]	WPM	T_{ER} [%]	WPM	T_{ER} [%]	WPM	T_{ER} [%]
D1	28.80 ±6.67	5.38 ±6.07	27.97 ±7.07	6.80 ±6.52	32.41 ±9.16	5.55 ±4.88	32.43 ±8.04	3.00 ±5.94	37.21 ±7.93	2.59 ±3.65
D2	30.23 ±5.29	3.12 ±4.69	29.24 ±5.30	3.69 ±5.04	32.11 ±6.79	5.42 ±6.13	33.27 ±6.57	1.51 ±3.67	37.41 ±8.31	3.70 ±5.42
D3	not appropriate		31.71 ±6.11	2.66 ±4.90	36.80 ±8.23	2.97 ±3.59	32.05 ±7.51	2.59 ±5.65	33.43 ±6.99	2.83 ±6.08
D4	not appropriate		34.85 ±6.06	0.78 ±1.19	36.78 ±7.87	2.15 ±3.51	33.01 ±5.82	1.32 ±2.27	32.12 ±6.23	3.06 ±4.45
D5	not appropriate		16.36 ±5.64	6.62 ±7.35	not appropriate		16.47 ±4.90	6.44 ±7.24	not appropriate	

Since WPM data normality was verified on majority of conditions, a two-way repeated-measures ANOVA was selected for further WPM-related analysis. The goal of statistical analysis is to check whether the null hypothesis, stating "there is no difference in text entry speed with respect to the screen size and interaction style used", can be rejected. However, given that our experiment design is rather complex, single two-way RM ANOVA run would not be appropriate. Not all interaction styles (5 levels of factor S) are appropriate for every screen size (5 levels of factor D), so there is no complete data set for all D×S combinations. Consequently, our data analysis consists of three separate RM ANOVA runs that encompass all valid conditions, as illustrated in Fig. 4.

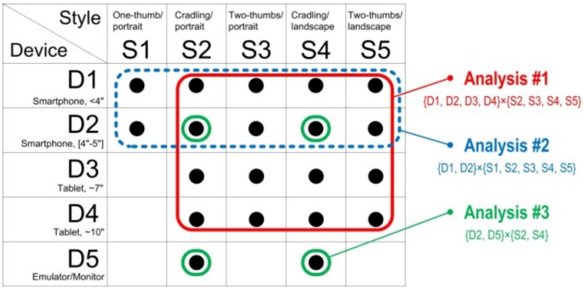

Fig. 4. WPM data analysis strategy

The first analysis (Analysis #1) deals with a complete set of mobile devices (D1–D4), and corresponding interaction styles suitable for every mobile device (S2–S5). Since one-thumb interaction is considered appropriate for smartphone class exclusively, the related analysis that covers all interaction styles, here including S1 also, applies only to D1–D2 set (Analysis #2). Indeed, there is no justification in comparing one-thumb/portrait with any other style used with devices D3–D5, because neither emulator nor tablets support equivalent interaction. Finally, the last stage of data analysis (Analysis #3) refers to text entry speed achieved using emulator and its mobile device counterpart. The larger smartphone (D2) is selected as the target device for comparison, because its screen size matches the emulator's skin dimensions.

4.1 Interaction Styles Common for All Mobile Devices

The outcome of the first analysis revealed a significant effect of interaction style (factor S) on WPM: $F_{3, 72}=12.225$, $p<0.001$. Post-hoc pairwise comparisons with Bonferroni adjustment showed that:

- text entry using S5 is significantly faster with respect to using S4 ($p<0.05$) and S2 ($p<0.001$)
- text entry using S3 is significantly faster with respect to using S2 ($p=0.001$)
- text entry using S4 is significantly faster with respect to using S2 ($p<0.05$).

As expected, two-thumbs interaction generally results with faster text input, while cradling in portrait mode produces by far the slowest typing. The influence of screen size cannot be completely neglected in this analysis, as significant interaction between factors D and S was also found: $F_{9, 216}=9.495$, $p<0.001$. The effect of D*S interaction is presented in Fig. 5, where several different "trends" can be observed. For example, it can be seen that cradling in portrait mode (S2) becomes more efficient when used with larger touchscreens. This can be explained by the increased key button sizes which allow easier targeting and, consequently, faster typing. However, text entry with two-thumbs in landscape orientation (S5) shows a completely different tendency, as typing performance declines with larger touchscreens. Once again we can address the role of keyboard dimensions, with the main difference being that larger button size is not a decisive factor in the related case, as the longer distance that fingers have to cross for button activation becomes critical instead.

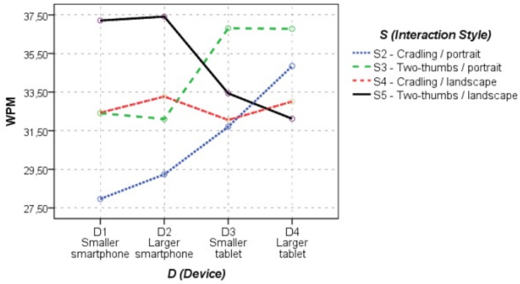

Fig. 5. Estimated marginal means of WPM

Afore mentioned observations can also support explaining the difference in two-thumbs typing between landscape (S5) and portrait (S3) orientation on different mobile devices. While two-thumbs interaction in portrait mode is clearly more efficient when used on tablets, landscape mode implies faster two-thumbs typing on smartphones. Using two hands for typing on portrait-oriented smartphones can be cumbersome because of diminutive high-density keyboard layouts, hence it is understandable that a tablet represents a faster texting device in the two-thumbs/portrait context. Regarding two-thumbs usage in landscape orientation, smartphone keyboards happen to be well-suited considering appropriately larger buttons and reasonable fingers workload, as opposed to tablets that become less efficient because thumbs are required to travel more from one key to another.

The same effect can be seen in cradling-based interaction styles S2 and S4. Concerning these cradling styles, WPM mean values for device D3 represent an especially interesting case since they approximately form a point of equal performance ($WPM_{D3,S2}$=31.71, $WPM_{D3,S4}$=32.05). Apparently, keyboard layouts displayed on smaller tablets, although with different geometry in landscape and portrait orientation, define almost equal conditions for typing with the dominant hand while the non-dominant one provides stability.

4.2 Smartphone Class

The second two-way RM ANOVA was applied to the smartphone class exclusively, and the involved complete set of interaction styles (S1–S5). This is where one-thumb text entry was also being considered. A significant effect of interaction style on WPM was found again: $F_{3.044,\ 73.049}$=21.722, p<0.001. Greenhouse-Geisser correction was applied, as Mauchly's test showed violation of sphericity (W=0.457, p=0.041). Post-hoc pairwise comparisons with Bonferroni adjustment showed that:

- text entry using S5 is significantly faster with respect to using S4 (p<0.05), S3 (p<0.001), S2 (p<0.001), and S1 (p<0.001)
- text entry using S3 is significantly faster with respect to using S2 (p<0.05)
- text entry using S4 is significantly faster with respect to using S2 (p<0.001).

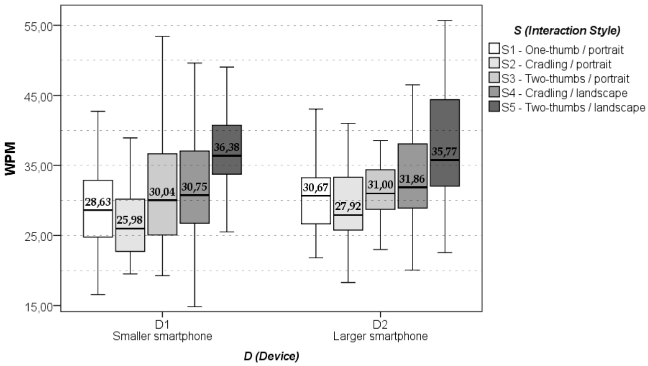

Fig. 6. Text entry speed (WPM metrics) for smartphone class. For every observed D×S combination, the corresponding box plot shows minimum and maximum, 25 percentile (Q1), 75 percentile (Q3), and median value. Outliers are excluded.

Two-thumbs text entry in landscape orientation is by far the fastest for smartphone devices. While cradling in landscape mode and two-thumbs typing in portrait mode are somewhat equally leveled, portrait-oriented cradling once again showed to be the least efficient interaction style for text input. When it comes to one-thumb typing (S1), its usage produced the second worst performance, although comparison with the best interaction style (S5) is the only one statistically significant. It is interesting to find out that S2 does not outperform S1, meaning that forefinger-based targeting with provided device stability does not help in gaining better text entry results.

In this stage of data analysis, significant effects of screen size and D*S interaction were not found. Descriptive statistics summary (in boxplot form) for text entry speed in smartphone class is presented in Fig. 6

4.3 Emulator Case

The third two-way RM ANOVA provided a special case investigation by addressing difference in text entry speed between emulator and actual mobile device. Cradling-based interaction styles were tackled only, as they represent valid methods for providing touch input on desktop monitor. The outcome of the analysis showed significant effect of both the screen size ($F_{1,24}$=156.6, $p<0.001$) and the interaction style ($F_{1,24}$=10.755, $p<0.05$), as well as significant D*S interaction ($F_{1,24}$=6.66, $p<0.05$). Although such a type of outcome is less frequent in data analysis, it makes sense in the observed context. Text entry using emulator (D5) is significantly slower with respect to using its device counterpart (D2), with WPM mean values being nearly two times larger for the actual smartphone device. As for the interaction style factor, text entry with cradling in landscape mode (S4) is significantly faster with respect to cradling in portrait orientation (S2), what is an expected outcome in line with previously derived conclusions. The significant effect of D*S interaction can be explained by the fact that interaction style does not make such a difference when using an emulator, as opposed to using a smartphone. In fact, while landscape-oriented cradling with smartphone benefits with 20 more letters in a minute (4 wpm) with respect to portrait orientation, text entry speed on the touchscreen desktop monitor is equal regardless of the emulator's display orientation. Due to the monitor's native resolution, key buttons within the emulator skin are somewhat larger than the ones on the real device, so changing orientation doesn't really play a critical role. However, the emulation mechanism does matter, as it imposes a latency that drastically decreases overall performance. Accordingly, for smartphone-emulator comparison, we can address screen size as the factor with essential influence on WPM, although *device* would be a better name for this factor in the observed context.

4.4 Errors

For text entry accuracy, we report descriptive statistics only. Table 4 includes mean values for total error rate (T_{ER}), as well as mean values for both CAW_{ER} and CBR_{ER} corresponding fractions.

Table 4. CAWER and CBR_{ER} contributions to the T_{ER} metrics (mean values)

Device (D)	Text entry interaction style (S)									
	S1: one-thumb portrait		S2: cradling portrait		S3: two-thumbs portrait		S4: cradling landscape		S5: two-thumbs landscape	
	T_{ER} [%]	CAW_{ER} CBR_{ER}	T_{ER} [%]	CAW_{ER} CBR_{ER}	T_{ER} [%]	CAW_{ER} CBR_{ER}	T_{ER} [%]	CAW_{ER} CBR_{ER}	T_{ER} [%]	CAW_{ER} CBR_{ER}
D1	5.38	61.01% 38.99%	6.80	58.98% 41.02%	5.55	62.12% 37.88%	3.00	73.20% 26.80%	2.59	73.19% 26.81%
D2	3.12	71.98% 28.02%	3.69	68.78% 31.22%	5.42	67.70% 32.30%	1.51	93.37% 6.63%	3.70	51.51% 48.49%
D3	not appropriate		2.66	37.73% 62.27%	2.97	57.38% 42.62%	2.59	38.03% 61.97%	2.83	94.44% 5.56%
D4	not appropriate		0.78	84.19% 15.81%	2.15	80.43% 19.57%	1.32	94.41% 5.59%	3.06	86.06% 13.94%
D5	not appropriate		6.62	86.71% 13.29%	not appropriate		6.44	86.43% 13.57%	not appropriate	

When generally addressing mobile devices, we can say that text entry is more erroneous on touchscreen smartphones in portrait orientation. Other conditions involve more appropriate keyboard layouts wherein higher level of target precision is easier to achieve. Emulator-based text entry is highly error-prone, contributing to its overall low-level performance. Obtained CAW_{ER} and CBR_{ER} values are quite interesting to examine. In 18 out of 20 observed conditions CAW_{ER} is larger than CBR_{ER}, indicating that users in general made majority of corrections on letters that were actually in error. In other words, users were able to notice their errors quickly after misspell, what could be the result of built-in visual aids for enhancing transcription correctness.

5 Conclusion

Touchscreen text entry performance has been examined on several classes of mobile devices, including an AVD (*Android Virtual Device*) – mobile device emulator. All convenient interaction styles were included in the study, meaning that all valid combinations of hand postures and device orientations have been tested. As expected, it was confirmed that different conditions induce diverse text entry speed and accuracy.

Interaction style showed to have a decisive impact on touchscreen text entry performance, however screen size have to be taken into account as well. In fact, certain interaction styles are more appropriate for typing on tablets, while others are better fitted for smartphones. In general, two-thumbs text entry in landscape orientation allows higher input rates, as opposed to low efficiency when typing is performed with one finger in portrait mode. It is worth noting here that only 16% of participants reported two-thumbs/landscape as their preferred interaction style, opposing to 56% that favor one-finger portrait-oriented typing. In many cases text entry speed demonstrates a tradeoff between size of key buttons and their mutual distance, thus being dependant on keyboard layout geometry.

Mobile device emulators are often used for testing user interfaces and look-and-feel of related mobile applications. Unfortunately, even the most popular emulators are in general considered slow and frustrating. We were able to quantify emulator shortcomings, at least from the text entry standpoint. Poor typing performance has been confirmed on standard Android SDK emulator, with obtained WPM values being twice as lower as the ones achieved on the equivalent smartphone device. Future research could investigate whether text entry performance differs in the case when the emulator is operated by mouse instead of a touch.

The results described in this paper may provide a baseline for future text entry studies that would address all well-suited interaction styles, various touchscreen mobile devices, and different types of soft keyboards. The described empirical research is limited in scope since the related experiment took place in laboratory settings, and only tapping modality was considered valid for text input. Further work need to be done in order to investigate the observed effects in a real-life mobile context, as well as their impact on gesture-based text entry performance.

Acknowledgments. This paper describes the results of research being carried out within the project 036-0361994-1995 *Universal Middleware Platform for e-Learning Systems*, as well as within the program 036-1994 *Intelligent Support to Omnipresence of e-Learning Systems*, both funded by the Ministry of Science, Education and Sports of the Republic of Croatia. The authors wish to thank Susanne Bahr for valuable help in providing comments on several data analysis strategies.

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