The Effect of Screen Size and Interaction Style on Mobile Device Usability

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***Abstract*—Mobile devices are widely used nowadays boosted by the fast development of technology. Most mobile device embedded touch screen user interface which come in various sizes. This study investigates the usability of mobile device based on four different screen sizes and three styles interaction gestures; specifically, it focuses on the ergonomics factor of the user. Usability test was conducted to 100 university students in Indonesia who used mobile device regularly. Result found that screen size and interaction style affect the completion time and numbers of errors. Hand dimension significantly affect users' performance when they used one and two thumbs gestures.**

***Index Terms*—interaction style, ergonomics, interface design, mobile device**

I. Introduction

THE fast development of technology has driven various innovations in mobile devices such as different sizes of screen (small, medium, phablet, small tablet and tablet). Undeniably it also impacted the way user interacting with their devices. At the present time, there seems to be a trend toward larger screens. Kim & Sundar [1] found that large screen compared to a small screen is potentially encouraging higher smartphone adoption by users. Nonetheless, larger screen suggests bigger devices, along with certain aspects of their design may have been linked to both fatique [2][3] and musculoskeletal disorders [4], especially during typing.

This experiment is part of study on mobile device usability based on user's anthropometry. In the previous study on the effectiveness of button size on mobile device based on hand dimension, Restyandito & Nugraha [5] has successfully showed the effect of hand dimension and button size on the usage of mobile device. Larger device with bigger screen may be more preferable by some users because it can display more information. However, if they have small hands it may not be effective in doing task such as typing. Moreover, it can cause a musculoskeletal disorder when used in a long time. Larger button size can reduce typing error, but it will also lessen the display space for the content. Thereupon, an interface designer should consider these tradeoffs when designing an interface for mobile device. On the previous study, the author investigated different button size on a 4.0" display device, in this study the author investigates the effectiveness of touch interaction using different size of display devices with the same target size. This research also taking into consideration user's anthropometry when analyzing the usability factors.

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II. Related Study

Two main concerns in designing mobile device are user interface and the size of the device [6]. User interfaces consist of the following components: interaction, navigation, metaphors, and mental models [7]. Mobile device with touch screen ability provide several ways in which user can interact with it using gesture. Some of these gestures are pressing (touch), swiping and pinching. Each part of a touchscreen dedicated to functionality precludes the display of content in that area, making gestures a crucial component of mobile interaction design. Operational gestures on interface influence operational gestures [8]. Small display space in mobile device requires partitioning information into several sections resulting increase in users' navigation activity [9]. Users must scroll up and down more often when navigate through small display space, thus lower their performance significantly [10]. The use of the right metaphor can improve users understanding of an interface [11]. It help user construct mental model relate to their understanding of how the device works.

Researchers have studied the effect of screen size on the user's experience. Findlater & McGrenere [12] found that screen size impacts user behavior. This finding is supported by Kim et. al [13] that showed screen size has effect on the user's psychology based on the communication modality. There was empirical evidence that high accuracy adaptive menus may have a larger positive benefit on small screen displays [12]. Furthermore, Kim et. al [13] found that smaller screen-size elicited greater perceived mobility while larger screen-size was key to greater enjoyment. However, there has not been many study conducted on the effect of screen size on mobile device usability, moreover from the perspective of ergonomic field by considering user's hand dimension. Ergonomics related to the optimization, the efficiency of health safety and comfort of humans [14]. Anthropometric is used to consider the level of ergonomics in designing a product or interface that required human interaction [5].

Good user interface should meet the ergonomic criteria [15][16]. User's performance may vary because their hand size is variable. In their previous study, Restyandito & Nugraha [5] identified palm width and thumb length among significant predictors in typing performance. Hence in this

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experiment, three different interaction gestures including one thumb interaction and two thumbs interaction were examined. Palm width and palm length were also considered as independent variable in determining user performance.

III. Method

A. Participants

One hundred students from the undergraduate and graduate program of Duta Wacana Christian University participated in this research (male = 56, female = 44). They were 18-34 years old (Average = 22.25, SD = 4.6). Participants were selected using Hallway testing (i.e. randomly selected people passing the hallway). All of the participants are familiar with using touch screen on mobile devices.

Additional information which can influence the result of the experiment were also recorded such as: their height and weight; the dimension of the mobile device they used and how long they have been using it. The average height of the respondents was 169.58 cm (SD = 9.33) and their average weight was 62.37 kg (SD = 13.91). Most of the participants were using a 5.0" screen device (30.1%), 4.0" screen device (20.5%) and 5.5" screen device (12.0%).

Participants' height and weight were recorded due to the time limitation during the experiment. The data acquired were used to predict participants' hand anthropometry. Table I summarize the anthropometry data of Indonesian adult from research conducted by Chuan et. al [17], obtained from 377 respondents (male=245, female=132) and Hastuti [18], obtained from 600 respondents (male = 292, female = 308). Based on this data, the author was able to make prediction on participants' hand anthropometry based on their height and weight. In this experiment the average of male participants' hand dimension: palm length = 19.02 cm (SD = 0.77) and palm width = 8.99 cm (SD = 0.37); the average of female participants' hand dimension: palm length = 18.26 cm (SD = 0.77) and palm width = 8.11 cm (SD = 0.31)

TABLE I
INDONESIAN ANTHROPOMETRY DATA SUMMARY
(CHUN, ET AL., 2010; HASTUTI, J., 2013)

Percentile	5th	50th	95th	SD
Average Height (cm)				
Male	162	172	183	6.23
Female	150	159	169	5.76
Average Weight (kg)				
Male	50	63	89.25	6.23
Female	39.8	53	80	5.76
Average Palm Length (cm)				
Male	17	19	22	1.64
Female	16	18	20	1.72
Average Palm Width (cm)				
Male	7	9	11	1.09
Female	6	8	10	4.85

B. Materials

Four different sizes of mobile phone were used in this experiment to investigate the influence of ergonomics factor on the effectiveness of task completion. To reduce the bias of device's form and design factor, all mobile phone used were Sony Xperia product of different series (Table II). All of the Sony Xperia design have square and thin form factors. Sony Xperia Z1 Compact and C3 have 720x1280 pixel resolution, while Sony Xperia Z3 Dual and Ultra have 1080x1920 pixel resolution.

TABLE II
MOBILE DEVICE SPECIFICATION

No	Sony Xperia	Screen Size (inch)	Dimension (mm)	Weight (gr)
1	Z1 Compact	4.3"	127.0 x 64.9 x 9.5	137.0
2	Z3 Dual	5.2"	146.0 x 72.0 x 7.3	152.0
3	C3	5.5"	156.2 x 78.7 x 7.6	149.7
4	Z Ultra	6.4"	179.4 x 92.2 x 6.5	212.0

The mobile application was made using Java SDK ver 1.7, Android SDK (Standard Development Kit) and IDE Basic4Android.

C. Design

The International Standards Organization (ISO 9241-11) identifies three aspects of usability, defining it as "the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use" [19]. There are several ways to measure product usability using performance metrics, issue-based metrics, self-reported metrics, behavioral metrics, physiological metrics and the combination and comparison of those metrics. This experiment focus on the effectiveness and efficiency of mobile device usability by evaluating the effects of screen size and interaction style. Performance metrics was used in this experiment with completion time and error rate as the observed variable.

The author adopted a within-subject design. The factors and levels studied were the screen size (4.3" (109.22mm), 5.2" (132.08mm), 5.5" (139.70mm) and 6.4" (162.56mm)) and interaction style (touch using index finger, touch using one thumb and touch using two thumbs). However, to avoid tedium participants were only asked to use one device and tested four different interaction styles.

A game application was made where participants were asked to hit a 10x10mm target marker (despite played on different screen size and resolution) showed on the screen. When the participants hit the marker, the device will vibrate to inform them that they have hit the target.

The screen is divided into 15 areas (Figure 1). The target appeared on a series of 8 consecutive sequence on different areas of the screen as follow:

- WL: {T7 – T9 – T2 – T14 – T1 – T15 – T3 – T13}
- WR: {T9 – T7 – T14 – T2 – T15 – T1 – T13 – T1}
- ML: {T7 – T9 – T5 – T11 – T4 – T12 – T6 – T10}
- MR: {T9 – T7 – T11 – T5 – T12 – T4 – T10 – T6}
- TL: {T4 – T6 – T2 – T8 – T1 – T9 – T3 – T7}
- TR: {T6 – T4 – T8 – T2 – T9 – T1 – T7 – T3}
- BL: {T10 – T12 – T8 – T14 – T7 – T15 – T9 – T13}
- BR: {T12 – T10 – T14 – T8 – T15 – T7 – T13 – T9}

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This sequence was designed to ensure the coverage of interaction occurred on different parts of the screen (top / bottom / left / right / center) and movement distance (closest / further). To minimize the bias of learning effect, these sequence patterns were presented in random order. Example of this target sequence pattern can be seen in Figure 2. The application kept record of the time it takes for participants to hit the marker, it also counted how many times participants miss the marker (error).

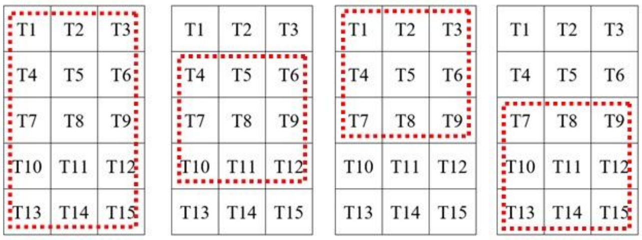

Fig. 1. Target area on the device screen: (W)hole, (M)idle, (T)op and (B)ottom.

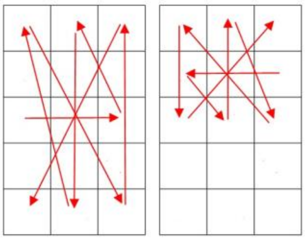

Fig. 2. Example of the target pattern sequence. (WL) : Whole area starting from the left side and (TR) : Top area starting from the right side.

D. Procedure

Prior to taking the test, participants were asked whether they have a touch screen mobile device. Only participants with experience of using a touch screen interface were asked to do the test. They were asked to fill in their personal data such as age, gender, height and weight. They may fill a nickname to guarantee anonymity. They also asked to fill in the screen size of their current mobile device, in case they did not know the screen size, they were advised to type the manufacture and the series of their mobile device. The author would then look up the specification of the mobile device dimension. Figure 3 shows the screenshot of the application.

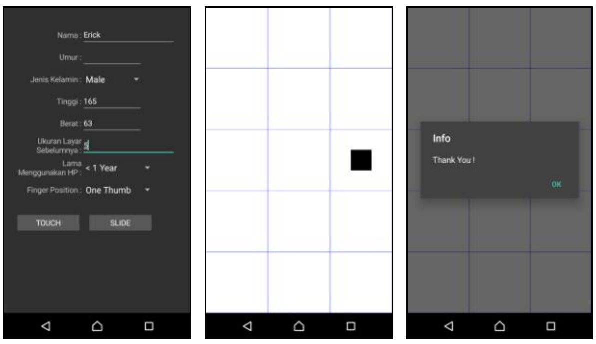

Fig. 3. The snapshot of the application: personal data screen , game mode screen, and finish screen.

IV. Results and Discussion

A one-way Anova was conducted to compare the effect of screen size on the task completion time and number of errors. An analysis of variance showed that the effect of screen size on task completion time and number of error was significant for all of the interaction style except for number of error occur when using only one thumb (Table III). The data shown in Table IV revealed smaller device (Screen #1 and #2) are more effective since it took less time and error to complete the task. Larger device (Screen #4) tend to cause longer time and error occurs more frequently. This result is in correspond with Fitt's Law which predict the time needed to quickly move to a target area is a function of the ratio between the distance to the target and the width of the target [20]. This finding is not in line Oehl et al. study conducted in 2007, they found with small screen devices tend to increase difficulty level [8]. Even so, in 2007 the most widely available touch screen size mobile device is 3.5" phone (for example iPhone first generation) while currently most mobile device has 5.0-6.0" screen size.

TABLE III
The P-Values of Different Screen Sizes.

Gesture	Index Finger	One Thumb	Two Thumbs
Task Time	0.00000*	0.00000*	0.00000*
Number of errors	0.00000*	0.51084	0.00000*

Note : * = $p < 0.05$

TABLE IV
Data Recapitulation on Task Time and Number of Errors.

Gesture		Index Finger	One Thumb	Two Thumbs
Task Time	Min	Screen #2	Screen #1	Screen #2
	Max	Screen #4	Screen #3	Screen #4
Number of errors	Min	Screen #2	Screen #1	Screen #1
	Max	Screen #4	Screen #3	Screen #4

Note : Screen Size #1: 4.3" inch, #2: 5.2" inch, #3: 5.5" inch , #4: 6.4" inch

A one-way Anova was also conducted to compare the effect of interaction style on the task completion time and number of errors (Table V). An analysis of variance showed that the effect of interaction style on task completion time and number of error was significant across all screen sizes. Table VI revealed using index finger to interact with mobile device yielded faster completion time and less error, while using one thumb gave slowest completion time and more error. Despite using index finger is faster and yield less error, during survey only 8.3% of the participants use index finger as their common way to interact with their mobile devices, most of the participants (58.9%) use both of their thumbs. On the contrary, even though using one thumb proven to yield worse performance, 32.8% of the participants were used to interact with one thumb when using their mobile device.

There are two possible reason that can explain this phenomenon. The first explanation, may be due to the type of activities they do with their mobile device. Most of the participants use their mobile device for texting which is suitable with using two thumbs. The millennial generation are connected to each other in the digital world (such as social media, blog, vlog, etc.) which required a lot of typing activities (to communicate to each other, posting status, leaving comment on friend's wall, etc.). QWERTY keyboard are used for typing input to mobile device, hence most activities are focused on the lower part of the screen. In this case, most of the target area are reachable by using both thumbs. The second explanation, may be due to the habit of millennial generation who are multitasker [21]. They tend to do several things at once, therefore interacting using one thumb (one assisted hand) enables them to use their other hand for other task. Study by Zhu and Li also confirm in the one-handed operation, thumb is most likely to be used [22]. However, using one or both thumbs are limited because of the hand size constraint.

TABLE V
THE P-VALUES OF DIFFERENT INTERACTION STYLES.

Screen Size	4.3"	5.2"	5.5"	6.4"
Task Time	0.00030*	0.00000*	0.00000*	0.00000*
Number of errors	0.01062*	0.00033*	0.00000*	0.00000*

Note : * = p < 0.05

TABLE VI
DATA RECAPITULATION ON TASK TIME AND NUMBER OF ERRORS.

Screen Size		4.3"	5.2"	5.5"	6.4"
Task Time	Min	IF	IF	IF	IF
	Max	OT	OT	OT	OT
Number of errors	Min	IF	IF	IF	IF
	Max	OT	OT	OT	OT

Legend : IF: Index Finger, OT: One Thumb, TT: Two Thumbs

An observation conducted by Steven Hoober in 2013 (as cited by Clark, 2015), found that from 1300 people he observed most people interact with their mobile device using one-handed grip / one thumb (49%) followed by cradled the phone in one hand and jabbed with the index finger (36%) and lastly two-handed prayer posture using two thumbs (15%) [21]. Hoober's observation result differ from participants' preferences in this study. Further study can be conducted to investigate whether this difference is caused by cultural issue, generation gap or other cause. Even so, both the survey result of this study and Hoober's observation suggest participants do not favor index finger as their main way to interact with their device, despite it is the most effective and efficient gesture. Further study can be conducted to investigate other factors that may influence how people interact with their device.

To examine the effect of hand dimension on the usability, the author calculate palm length ratio compared to the mobile device used in the experiment, palm width ratio compared to the mobile device used in the experiment and difference between the size of mobile device used by the participants and the size of mobile device used in the experiment.

A multiple linear regression was calculated to predict completion time using index finger on gender, palm length ratio, palm width ratio, and size difference. A significant regression equation was found (F(4,95)= 4.709, p<0.001), with an R^2 of 0.61. Participants' predicted completion time is equal to 19359.7 + 1256.5 (gender) - 18660.0 (palm length ratio) + 30665.7 (palm width ratio) + 88.2 (size difference), where gender is coded as 1 = Male, 2 = Female and size difference is measured in millimeters. Gender, palm length ratio, palm width ratio and size difference were not significant predictors of completion time.

A multiple linear regression was also calculated to predict completion time using one thumb on gender, palm length ratio, palm width ratio, and size difference. A significant regression equation was found (F(4,95)= 4.009, p<0.005), with an R^2 of 0.78. Participants' predicted completion time is equal to 39460.5 - 5276.1 (gender) - 36060.1 (palm length ratio) - 98099.0 (palm width ratio) - 5.9 (size difference), where gender is coded as 1 = Male, 2 = Female and size difference is measured in millimeters. Palm length ratio and palm width ratio were significant predictors of completion time.

Lastly, a multiple linear regression was calculated to predict completion time using two thumbs on gender, palm length ratio, palm width ratio, and size different. A significant regression equation was found (F(4,95)= 7.911, p<0.000), with an R^2 of 0.70. Participants' predicted completion time is equal to 22832.2 + 666.4 (gender) - 8586.5 (palm length ratio) + 6351.3 (palm width ratio) + 14.2 (size difference), where gender is coded as 1 = Male, 2 = Female and size difference is measured in millimeters. Palm length ratio and palm width ratio were significant predictors of completion time. The summary of the multiple linear regression analysis on completion time can be seen on Table VII.

A multiple linear regression was calculated to predict number of errors using index finger on gender, palm length ratio, palm width ratio, and size difference. A significant regression equation was found (F(4,95)= 2.946, p<0.025), with an R^2 of 0.53. Participants' predicted completion time is equal to 0.8029 – 0.0166 (gender) – 0.3446 (palm length ratio) + 0.0284 (palm width ratio) + 0.0078 (size difference), where gender is coded as 1 = Male, 2 = Female and size difference is measured in millimeters. Gender, palm length ratio, palm width ratio and size difference were not significant predictors for number of errors.

A multiple linear regression was also calculated to predict number of errors using one thumb on gender, palm length ratio, palm width ratio, and size difference. A significant regression equation was found (F(4,95)= 1.155, p<0.034), with an R^2 of 0.62. Participants' predicted completion time is equal to 0.4037 + 0.5949 (gender) – 9.3044 (palm length ratio) + 19.1569 (palm width ratio) - 0.0457 (size difference), where gender is coded as 1 = Male, 2 = Female and size difference is measured in millimeters. Palm length ratio and palm width ratio were significant predictors for number of errors.

Lastly, a multiple linear regression was calculated to predict number of errors two thumbs on gender, palm length ratio, palm width ratio, and size difference. A significant regression equation was found (F(4,95)= 2.546, p<0.044), with an R^2 of 0.51. Participants' predicted completion time is equal to 1.1654 – 0.1737 (gender) + 1.4232 (palm length ratio) – 3.8831 (palm width ratio) + 0.0007 (size difference), where gender is coded as 1 = Male, 2 = Female and size difference is measured in millimeters. Palm length ratio and palm width ratio were significant predictors for number of errors. The summary of the multiple linear regression analysis on number of errors can be seen on Table VII.

TABLE VII
SIGNIFICANT PREDICTORS OF THE REGRESSION ANALYSIS

	Index Finger	One Thumb	Two Thumbs
Completion Time			
Gender			
Palm Length Ratio		+	-
Palm Width Ratio		-	+
Size Difference			
Number of Errors			
Gender			
Palm Length Ratio		-	+
Palm Width Ratio		+	-
Size Difference			

The result suggests there was no correlation between hand dimension and usability using index finger. On the contrary hand dimension (i.e. palm length and palm width) was strongly correlated with usability using both one thumb and two thumbs. Study by Fei [23] support this finding, he found the optimal touch target size of Chinese users differs based on their physiological measurements.

The result also implied there was no significant correlation between the habit of using a certain size mobile device and usability. User who bought new device larger or smaller than their old device may not encounter meaningful problem. Yet, comfort and performance do not perfectly align [23]. In his article, Clark [24] pointed out when using one thumb gesture, only one third of the screen is an effortless zone. This area covers the bottom and the side opposite the thumb. When using two thumbs, this zone changes to the bottom and the side closer to each thumb. Interacting with mobile device outside the effortless or comfort zone for long time may trigger fatigue and muscular skeletal injuries. While touching the screen, six muscles including adductor pollicis, flexor pollicis brevis, abductor pollicis brevis (APB), abductor pollicis longus, first dorsal interosseous (FDI) and extensor digitorum are being used [25]. These muscles get fatigue very fast on single-handed performance [22].

V. CONCLUSION

Screen size influences the usability performance when using touch screen interface on mobile device. Users in this study (Indonesian) perform better when using less than 5.5 inch display mobile device. The result of this study implied hand dimension has significant affect on usability. Interacting using index finger may be faster and give less error, nevertheless not always favorable among users. This may be due to their type of activities. Likewise, user may not lie their preference on choosing screen size based on their hand dimension. Larger device with bigger screen may be more preferable by some users because it can display more information. Therefore, mobile device interface designer should consider this fact when placing major user interface components.

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