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The Effect of Text Information Frame Ratio and Font Size on the Text Readability of Circle Smartwatch

Seungtaek Park[1], Jaekyu Park[1], Jaeho Choe[2], Eui S Jung[1]

[1]Department of Industrial Management Engineering, Korea University, Seoul, 136-713
[2]Department of Industrial System Engineering, Daejin University, Pochen, 487-711

Corresponding Author
Eui S Jung
Department of Industrial Management Engineering, Korea University, Seoul, 136-713
Phone : +82-2-3290-3901
Email : ejung@korea.ac.kr

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Objective: The objective of this study was to examine frame ratio of text information and font size in the circle smartwatch.

Background: Recently, electronic manufacturers try to develop the original metaphor of traditional wrist watch (circle) in terms of smartwatch. They endeavor to break the square display in order to improve emotional customer satisfaction.

Method: The experiments examined twenty level of text information design, combinations of four frame ratios (1:1, 4:3, 16:9, 21:9) and five font sizes (6pt, 7pt, 8pt, 9pt, 10pt). Nineteen participants volunteered for the experiment. Dependent variables were WPM (Words per Minute), reading preference, design preference and total preference. Furthermore, small circle display was made by using circle display data (1.3inch), which was exhibited in IFA (International Funkausstellung) 2014.

Results: As a result, ANOVA (Analysis of Variance) revealed that WPM, and task time preference affect the specific frame ratio and font size. Results of ANOVA for reading preference, design preference, total preference were grouped by post-analysis LSD (Least Significant Difference). Among users, display ratio (16:9, 21:9), and font size (9pt) were preferred. In conclusion, 16:9 display ratio and 9pt are adaptable for text information in 1.3inch circle display.

Conclusion: From the study, it is shown that 16:9 display ratio and 9pt size are more adaptable for text information in 1.3inch circle display than others. It is mainly due to the fact that the order of frame ratio and font size may affect the usability of reading long text information in a small circle display. Therefore, when developers design a circle display, the square frame ratio and font size are required to be considered according to circle size.

Application: The 16:9 display ratio and 9pt font size may be utilized as a text information frame in the circle display design guideline for smartwatch.

Keywords: Smartwatch, Circle display, Frame ratio, Text information, Scrolling

1. Introduction

As the Internet contents are provided from portable devices, the use of smartphones have become more common, and users can check frequently the push notification offered by the device and applications (Francis, 1997; Lim and Lee, 2013). The information search process, after a user takes out a smartphone from a pocket, takes about 20 seconds (Starner, 2013). Meanwhile, it takes about two seconds to acquire

information with a smartwatch (Ashbrook, 2007). Consequently, a smartwatch is utilized for quick information search concerned with push notification on a smartphone.

In 2012, Sony and Pebble released smartwatches, and not only leading IT companies, but small and medium businesses are competitively developing wearable devices for consumers (Yang and Kim, 2014). Taking into account emotional satisfaction, as well as prices and performance, when consumers buy products, has become a general phenomenon (Gerstheimer and Lupp, 2004). Manufacturers try to maintain the metaphor of existing wrist watch's circle shape by deviating from existing square display in order to enhance emotional customer satisfaction.

Limitations in small touch screen devices including smartphones and smartwatches are the constraints of a display device and an input device (Haseloff, 2001). The appearance shape characteristics of a small mobile device decide the size and ratio of display. In this regard, the circle display causes spatial loss on the left top, right top, left bottom and right bottom in displaying text information on the internal square frame, unlike the existing square display. In order to solve the constraint of display size, scrolling is used. Actually, more scrolling is required in a smartwatch with the size of 1.3~2inch in acquiring long text information, compared to the 3~6inch smartphone (Dillon et al., 1990). In displaying text information with scrolling, if the number of letters that can express without spatial loss, according to square display ratio within the circle display becomes different, and time to acquire information becomes longer, proper objective cannot be selected (Jones et al., 1999). In carrying out scrolling, previous information needs to be remembered, and the information in the vision-concentrating direction becomes clear, and the surroundings become incomplete, when the field of view (FOV) is considered, due to the need for short-term memory. Therefore, scrolling enables to guess the previous and following information in providing continuous information, although it is incomplete. In scrolling screen composition, the influence of visibility should be considered, rather than manipulability (Kim, 2011). However, when it comes to a circle smartwatch, internal square frame ratio should be considered, due to round edge of the circle smartwatch. Frame is a very important factor visually, because the frame limits the boundary area of viewing, and it enables to concentrate on the material concerned the most, without the dispersion of attention, when components are placed in the middle of the frame (Woolman and Bellantoni, 1999).

The perfect text information exposure ratio becomes different, according to internal square frame ratio, due to text information being cut by round edge upon scrolling the text information up and down. Therefore, square frame's aspect ratio needs to be considered. However, people prefer a wide display, because horizontal vision angle is wider than vertical vision angle (Kim and Oh, 2008). This study aims to find proper display ratio in consideration of square frame's width within the circle with the current market-released display products' display ratios.

Because, text information is an essential factor to efficiently deliver information together with medium development, the study on it has been continuously carried out (Lee, 2005). The font size also needs to be different, because the display of a smartwatch became smaller. Actually, legibility is higher, as the font size is bigger (Bouma, 1971). However, as the font size becomes bigger, the number of characters that can be demonstrated in the display becomes smaller. The font size decides the length of characters' line. As the characters per line (CPL) of the presented text are more, total reading time is reduced (Kolers, 1983). In composing text information in the circle display, line length becomes different, and scrolling is conducted in acquiring long text information from the movement between lines (Lee, 2004). In doing so, this study tries to find the font size suitable for the circle display.

This study is to research the efficient square ratio and font size within the circle on user's information acquisition extend upon scrolling up and down in displaying text information within the internal square in the circle display, because studies on information search, performance and preference lack, when the alternatives of the maximum square frame information display mode and font size are considered in composing information within the circle display.

2. Method

2.1 Research procedure

2.1.1 The size of display according to display ratio

This study aims to conduct research on the ratio and font size, when internal text information is composed with a square frame in the circle smartwatch environment. The size of the circle display (LG G Watch R) exhibited in IFA (International Funkausstellung) 2014 is 1.3inch, and the square frame was composed within the 1.3inch circle display.

Figure 1. Circle smartwatch exhibit at IFA 2014

In the first step, this study selected square frame ratios 1:1, 4:3, 16:9 and 21:9 used for current displays within the smartwatch's circle frame in the market. At the end of both ends of the display, text information was tuned. Width becomes 2.75mm, height becomes 2.75mm and area becomes 7.5625mm^2 in composing text information in the square display part with 1:1 ratio of square frame within the used 1.3inch circle display. If continued surrounding display parts at both upper and lower ends are considered, width becomes 2.75mm, height becomes 3.87mm and area becomes 10.6425mm^2. If text information is composed with 4:3 ratio of square display part, width becomes 2.92mm, height becomes 2.18mm and area becomes 6.3438mm^2, and also width becomes 2.92mm, height becomes 3.87mm and area becomes 11.3004mm^2 in the surrounding display part. In the case of displaying with 16:9 ratio, when composing with the ratio that can be displayed with maximum value, width is 3.27mm, height is 1.84mm and area is 6.0168mm^2, and width becomes 3.27mm, height becomes 3.87mm and area becomes 12.6549mm^2 in the continued surrounding display part. Lastly, when text information is composed with 21:9 ratio in the internal square frame, width becomes 3.57mm, height becomes1.53mm and area becomes 5.4621mm^2. Concerning the continued surrounding display part, width becomes 3.57mm, height becomes 3.87mm and area becomes 13.8159mm^2. In composing the square display inside of the circle display, the ratio that can display the most without spatial loss is 1:1 ratio. In the composition at continued surrounding display, 21:9 ratio can display the most continuing information.

Continuing external frame area changes, according to square display domain ratio of the text display of the circle display, and text information acquisition may be influenced. In this manner, this study checks the text information display method, according to internal square display ratio.

Table 1. Text information display frame ratio according to the square frame

Display ratio	Total dimension (mm^2)	Square frame dimension (mm^2)	Total width (mm)	Total height (mm)	Width (Square frame) (mm)	Height (Square frame) (mm)
1:1	10.6425	7.5625	2.75	3.87	2.75	2.75
4:3	11.3004	6.3438	2.92	3.87	2.92	2.18
16:9	12.6549	6.0168	3.27	3.87	3.27	1.84
21:9	13.8159	5.4621	3.57	3.87	3.57	1.53

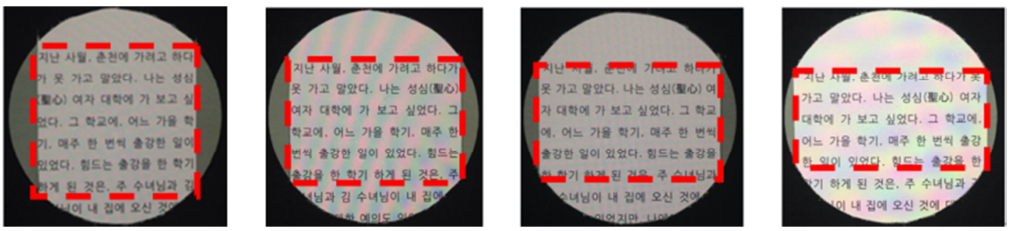

Figure 2. Total Dimensions according to the Square frame

2.1.2 The size of font according to present smartwatch

To view contrast on the font size, this study let information be acquired at standard reading distance, 14inch (35.5cm), in terms of font size in the VDT (visual display terminal) environment. In consideration of minimum reading distance height, 1.5~1.8mm, (0.06~0.07inch) (Shurtleff, 1967; Taylor, 1975), based on which, this study selected alternatives with 7pt, 8pt, 9pt and 10pt of font sizes composing the current smartwatch from the applicable font size 6pt (1.8mm) in the smartwatch environment. Search time for text information and errors increase, according to the increase of density (Tullis, 1988). In the case of an 1.3inch smartwatch, proper font size can be different, due to display size, because of size reduction, compared to 3~6inch smartphones (Kim and Ji, 2006). To identify suitable font size in the circle smartwatch display, this study presented the text information size with 100% in width/height ratio of a character, 160% between lines, and 0% in margin, which are basically offered ratios in terms of text information dimensions that affect readability, while setting font size differently with 6pt, 7pt, 8pt, 9pt and 10pt.

The square frame proportion, font size, characters per line width, lines per page within the square frame and total lines per page in proportion to the square frame ratio within the circle display are presented the following Table 2.

Table 2. Font size, number of letters, number of rows per square frame, number of rows per total frame according to the square frame ratio

Ratio	Font size	Number of letter	Number of rows per page (Square frame)	Number of rows per page (Total Frame)
1:1	6pt	14	7	10
	7pt	12	6	8
	8pt	10	5	7

Table 2. Font size, number of letters, number of rows per square frame, number of rows per total frame according to the square frame ratio (Continued)

Ratio	Font size	Number of letter	Number of rows per page (Square frame)	Number of rows per page (Total Frame)
1:1	9pt	9	4	6
	10pt	7	4	6
4:3	6pt	15	5	10
	7pt	13	4	8
	8pt	11	4	8
	9pt	10	3	7
	10pt	9	3	6
16:9	6pt	15	5	10
	7pt	13	5	9
	8pt	11	5	8
	9pt	9	4	6
	10pt	9	3	6
21:9	6pt	16	4	10
	7pt	13	4	8
	8pt	12	3	7
	9pt	10	3	7
	10pt	9	3	6

3. Experimental design

The subjects in this experiment read the prepared text information with 10pt font size at usual speed by turning over pages through scrolling the circle display with 1:1 display ratio, composed of a touch mode, for 30 seconds. 20 experiment conditions in total were generated with 4:1 display ratio and 5pt font size as independent variables by carrying out a full factorial experiment. Content offered per step of the experiment was differently prepared to prevent learning effect. This study calculated the number of characters for 30 seconds with WPM (words per minute) as a dependent variable by scrolling the display for objective evaluation.

Equation (1)

$$\text{WPM (Words per Minute)} = (\text{Number of words read} \div 30) \times 60$$

As subjective evaluation, this study measured reading preference to evaluate cognitive performing time in acquisition of text information. To evaluate preference for display ratio and font size, this study measured design preference. And then, this study evaluated total satisfaction with 9-point scale. Table 3 shows the experiment plan that summarized independent and dependent variables.

Table 3. Independent variable and Dependent variable

Variables		Description			
Independent variable	Display Ratio (width)	2.75mm	2.92mm	3.27mm	3.57mm
	Font Size	6pt, 7pt, 8pt, 9pt, 10pt			
Dependent variable	Objective measurement	WPM			
	Subjective measurement	Reading preference			
		Design Preference			
		Total Preference			

3.1 Subject

The subjects participating in this experiment were 19 postgraduates in their 20s and 30s. 14 male students and 5 female students participated in the experiment, and their average age was 28.37±2.65. The subjects did not have the history of vision-related diseases, all had normal corrected vision of 0.8 and higher and had one year and more of smartphone use experience. An explanation on the purpose and details of the experiment was offered to them, and the subjects who knew the details of an essay, "Connection", were excluded from the experiment.

3.2 Experiment apparatus and setting

The experiment was conducted with an Android smartphone (Samsung SHV-E300K) with 1,280x800 resolution, and the display's inner square was composed of circular shape by width ratio. The reason why the prototype was embodied in the smartphone environment was that text information display domain and the relevant display ratio and font size are all visual variables. Therefore, the external design factors and the influencing factors by wearing the smartphone were excluded. Scrolling of the display was possible, when dragging up and down was conducted. To provide information in consideration of ergonomic judgment standard on text information, the text information was displayed in black on the white background in view of visibility. In consideration of legibility, Android's basic font, "droid sans" was used for the font of the background color. For the text information, a light essay by a writer, Pi Chun-deuk, "Connection" that did not offer burden in reading with light theme was offered. Each text information was acquired from normal reading distance of 14inch (35.5cm) (Sanders, 1993).

4. Result

4.1 WPM (Word per minute)

The result of ANOVA for WPM (word per minute) on the square frame ratio and font size is as follows as shown in Table 4. There were significant differences in display ratio (p-value < 0.00) and font size (p-value < 0.00), and reciprocal action (p-value = 0.030) was significant.

Figure 3 shows the reciprocal action graph of the display ratio and font size on the read WPM, where two-people reciprocal action occurred.

Table 4. ANOVA result of WPM

	DF	SS	MS	*F*-value	*P*-value
Display Ratio	3	440098.92	146699.64	13.527	0.000*
Font Size	4	158498.18	39624.545	8.208	0.000*
Display Ratio*Font Size	12	142375.58	11864.632	2.762	0.030*

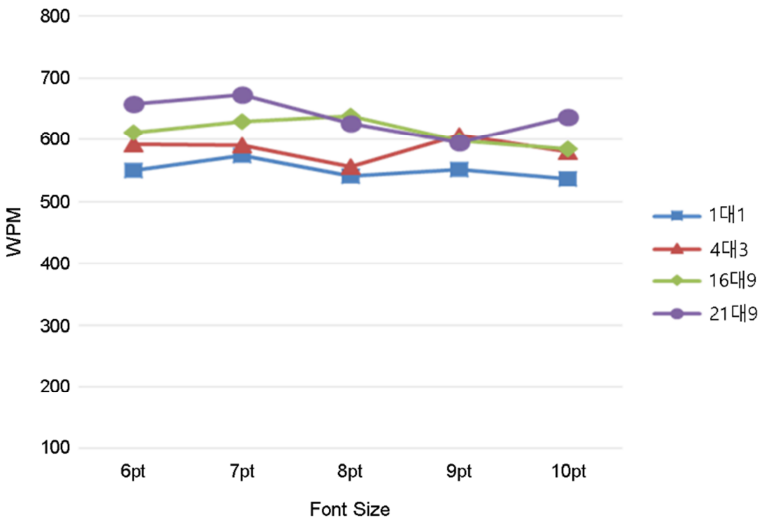

Figure 3. Interaction line plot of WPM

4.2 Reading preference

The result of ANOVA for reading preference on the square frame ratio and font size is as follows as shown in Table 5. There were significant differences in display ratio (p-value = 0.02) and font size (p-value = 0.01), and reciprocal action was judged not significant.

Table 5. ANOVA result of reading preference

	DF	SS	MS	*F*-value	*P*-value
Display Ratio	3	28.050	9.350	5.699	0.020*
Font Size	4	12.932	3.233	3.605	0.010*
Display Ratio*Font Size	12	12.332	1.028	1.685	0.720

The preference for display ratio was in the order of 16:9, 21:9 and 4:3 in terms of reading preference (See Figure 4). As a result of post LSD analysis (Least Significant Difference), 16:9, 21:9, and 4:3 were classified into A group with high ratio preference, and 1:1 was classified into B group with low ratio preference.

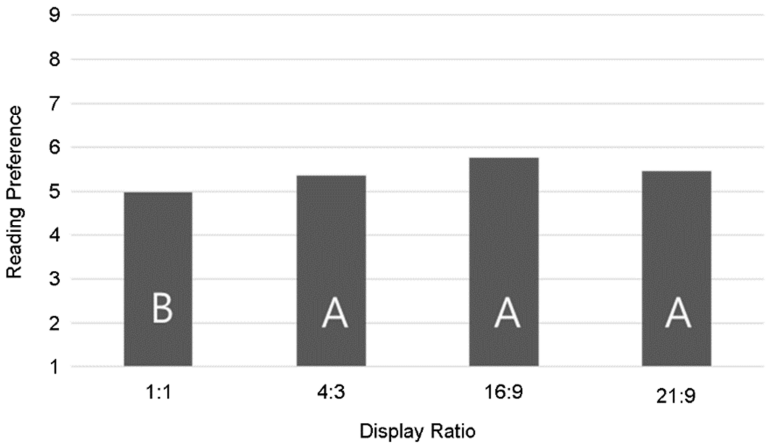

Figure 4. Identification of reading preference for display ratio

The preference for font size in reading preference was shown in the order of 7pt, 6pt, 9pt, 8pt and 10pt (See Figure 5). As a result of post LSD analysis, 7pt was classified into group A with high font size preference, and 6pt, 9p, 8pt, and 10p were classified into group B with low font size preference.

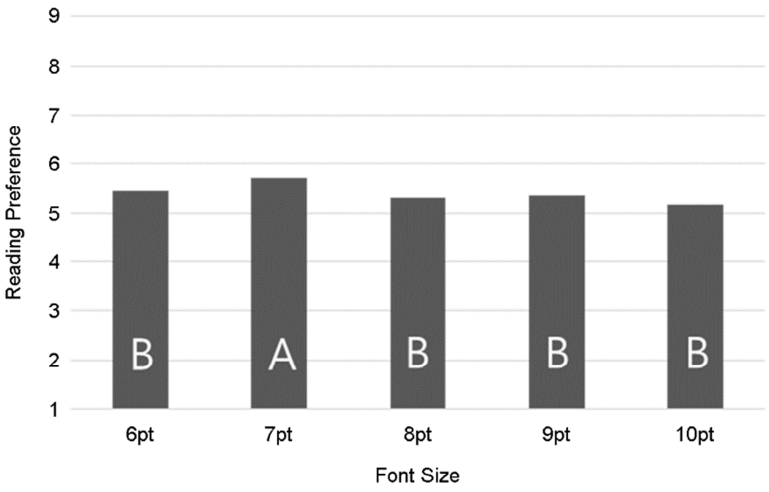

Figure 5. Identification of reading preference for font size

4.3 Design preference

The result of ANOVA for design preference on the square frame text information within the circle display is as follows as shown in Table 6. There were significant differences in display ratio (p-value = 0.040) and font size (p-value < 0.000), and reciprocal action was judged not significant.

The preference for display ratio in the design preference was shown in the order of 16:9, 21:9, 4:3 and 1:1 (See Figure 6). As a

Table 6. ANOVA result of design preference

	DF	SS	MS	*F*-value	*P*-value
Display Ratio	3	113.937	37.979	14.865	0.040*
Font Size	4	152.458	38.114	13.293	0.000*
Display Ratio* Font Size	12	17.879	1.490	1.538	0.112

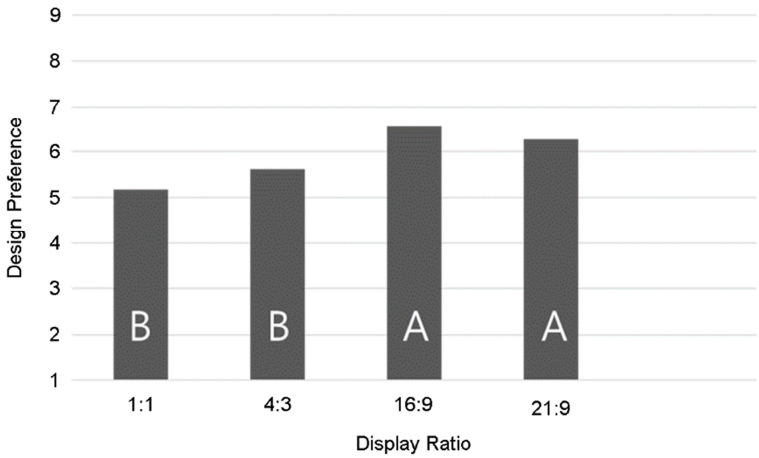

Figure 6. Identification of design preference for display ratio

result of post LSD analysis, 16:9 and 21:9 were in group A with high ratio preference, and 4:3 and 1:1 were in group B with low ratio preference.

The preference for font size in the design preference was shown in the order of 8pt, 9pt, 10pt, 7pt and 6pt (See Figure 7). As a result of post LSD analysis, 8pt, 9pt and 10pt were in group A with high font size preference, 10pt was in group B, and 6pt and

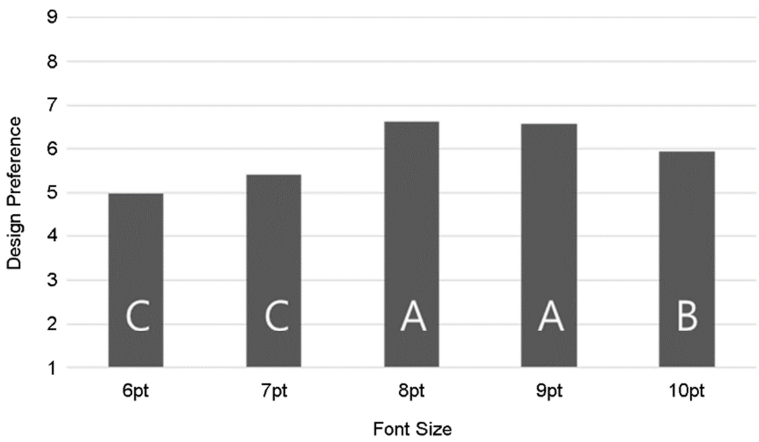

Figure 7. Identification of design preference for font size

7pt were in group C with the lowest font size preference.

4.4 Total preference

The result of ANOVA for total preference on the square frame text information within the circle display is presented below as shown in Table 7. There were significant differences in display ratio (p-value < 0.00) and font size (p-value < 0.00), and reciprocal action was judged not significant.

Table 7. ANOVA result of total preference

	DF	SS	MS	*F*-value	*P*-value
Display Ratio	3	108.829	36.276	14.715	0.000*
Font Size	4	203.595	50.899	17.426	0.000*
Display Ratio* Font Size	12	25.184	2.099	1.666	0.760

The preference for display ratio in the total preference was shown in the order of 16:9, 21:9, 1:1 and 4:3 (See Figure 8). As a result of post LSD analysis, 16:9 and 21:9 were in group A with high ratio preference, and 4:3 and 1:1 were in group B with low ratio preference.

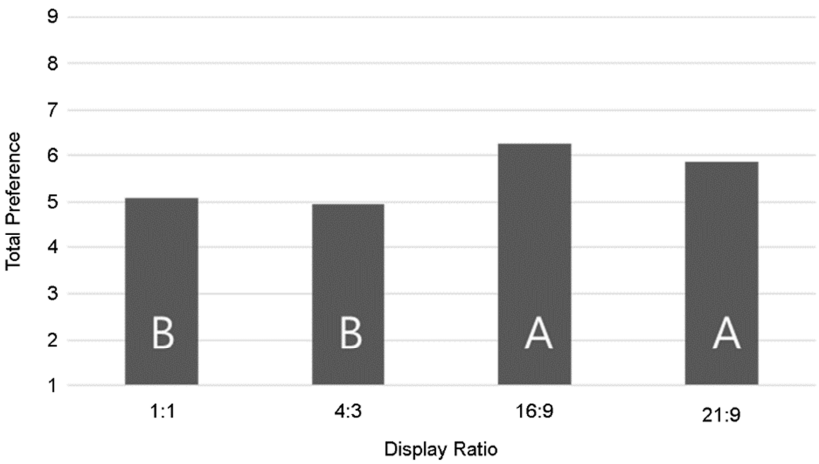

Figure 8. Identification of total preference for display ratio

The preference for font size in the total preference was shown in the order of 9pt, 8pt, 10pt, 7pt and 6pt (See Figure 9). As a result of post LSD analysis, 9pt was in group A with high font size preference, 8pt and 10pt were in group B, and 6pt was in group C with the lowest font size preference.

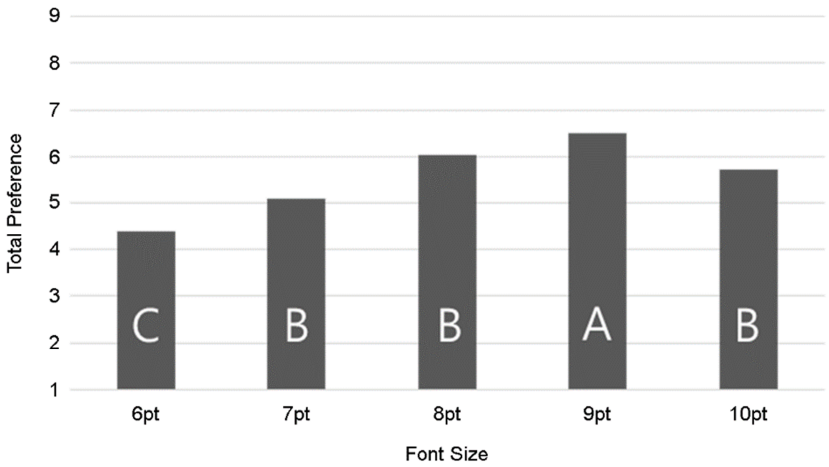

Figure 9. Identification of total preference for font size

5. Discussion

This study drew suitable display ratio and font size, when text information is presented in the square frame within the circle display of a smartwatch. Since the smartwatch is a smaller size than existing 3~6inch smartphones, this study researched the square display ratio and font size within the effective circle on user's information acquisition extent upon up and down scrolling in text information display. The reason is that studies on the performance and preference for the square frame ratio and font size displayed within the circle display in providing text information in a 1.3~2inch display lack, unlike the text information offering guideline studied previously. This study examined four dependent variables: WPM, reading preference, design preference and total preference.

To identify user's actual performance ability and visual satisfaction in acquiring text information in the circle display, not only an individual analysis, but an integrated analysis is necessary for realistic access to experiment results. As a result of ANOVA for WPM, there were differences in display ratio and font size, and reciprocal action took place between the two variables. Therefore, the average reciprocal action graph was drawn with an individual analysis (Figure 3). Reading performance ability tended to be high, irrelevant of font size in the 21:9 and 16:9 ratios, where width ratio is wide in the display. The reason is that comfort is felt in movements between lines as the width ratio becomes wider.

Concerning statistically significant reading preference, 16:9, 21:9 and 4:3 of display ratios were classified into an independent group with high preference through post LSD analysis, and 1:1 belonged to a group with low preference. As for font size preference, 7pt was in group A with high preference, and 6pt, 8pt, 9pt and 10pt belonged to group B with low preference in order.

As a result of ANOVA for design preference, there were significant differences in display ratio and font size, and reciprocal action did not occur. Therefore, 16:9 and 21:9 of display ratios were classified into A group, and 4:3 and 1:1 were classified into group B through the post LSD analysis. The font sizes, 8pt and 9pt were classified into group A with high preference, 10pt into group B and 6pt and 7pt into group C. In consideration of display ratio, the use of 7pt, 8pt and 9pt in the 16:9 display ratio can be appropriate. As a result of post analysis on font size, 9pt, 10pt and 8pt were classified into group A, and 7pt and 6pt into group B.

To find out from which dependent variable between reading preference and design preference, the subjects' preference is more affected in the circle display environment, this study used total preference, which is a subjective scale (Kim, 2011). In the total preference, the display ratio and font size showed significant differences, and no reciprocal action between the two variables occurred. As a result of post LSD analysis, 16:9, and 21:9 were classified into A group, and 4:3 and 1:1 were classified into B group. In the font size, 9pt was classified into A group, and 8pt, 10pt, and 7pt into B group, and 6pt into C group.

Through the post analysis, three rank points, two rank points and one rank point were awarded to A, B, and C groups, respectively, which were the alternatives classified as the statistically independent groups, on reading preference and design preference, respectively. Based on the rank points, the sum of the points on the two preference measurements was calculated, and then, the optimum alternative on the display ratio was drawn (See Table 8).

Because the influence of font size on total preference (F=17.426) is bigger than the influence of display ratio (F=14.715), this study conducted comparison on the font size in priority.

Table 8. Display ratio and font size rank

Rank point	Reading preference		Design preference	
	Display ratio	Font size	Display ratio	Font size
3	4:3, 16:9, 21:9	7pt	16:9, 21:9	8pt, 9pt
2	1:1	6pt, 8pt, 9pt, 10pt	1:1, 4:3	10pt
1				6pt, 7pt

Looking at the font size result, the rank points were three points for 6pt, four points for 7pt, five points for 8pt, five points for 9pt and four points for 10pt. In the total preference that considered even WPM, 9pt was classified into A group as a result of post analysis, and therefore, it can be the best alternative for font size.

Looking at the display ratio result, the rank points were four for 1:1, 5 for 4:3, 6 for 16:9 and 6 for 21:9. In the total preference that considered even WMP, 16:9 and 21:9 were classified into A group, but 16:9 was higher in average preference. Therefore, 16:9 can be the best alternative for display ratio.

As a result of this study, 16:9 display ratio and 9pt font size can be the best alternative in composting text information with the square frame within the circle display.

6. Conclusion

While a preceding study took into account small-sized display information structure to be inserted in a mobile device (Chae and Kim, 2004), this study considered display ratio and font size in terms of text information composition in the small circle display environment. In this manner, this study is discriminated from the previous study. Concerning the display ratio and font size, it was confirmed that the reading preference, which is cognitively comfortable and easy to acquire text information, and design preference, which is comfortable to see visually, statistically affect.

This study can be used as basic data, when the text information of a circle smartwatch to be launched is composed in the frame,

and is meaningful in that the study interpreted influences on preferences, according to information inference and exposed information volume in scrolling in the circle display. The limitation of this study is that additional analysis is required by equally composing the text information's width/height ratio of a character, ratio of between lines, and margin ratio by font size that affect readability, if ergonomic judgment standard is considered, because this study composed font size with 100% ratio by font size between the characters.

Further study, according to men and women's gender ratio and age difference, is judged to be necessary, because, this study conducted a limited experiment concerning subjects' gender ratio and age. This study conducted the experiment by embodying the prototype actualized in the smartphone as the experiment environment. Because, the independent variables considered in the experiment are all visual variables, there is no influence on the results; however, there needs some consideration on the fidelity aspect, because of different experiment environment from the smartwatch environment, viewed from the user's position.

The study results are expected to be used as a guideline of the frame composing user-oriented circle smartwatch's text information.

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Author listings

Seungtaek Park: tmdxor@korea.ac.kr
Highest degree: BS, Department of Industrial Information System Engineering, Seoul National University of Science Technology
Position title: Ms. Candidate, Department of Industrial Management Engineering, Korea University
Areas of interest: Product Development

Jaekyu Park: ergopark@gmail.com
Highest degree: MS, Department of Industrial Systems and Information Engineering, Korea University
Position title: PhD, Candidate, Department of Industrial Management Engineering, Korea University

Areas of interest: Product Development

Jaeho Choe: jhchoe@daejin.ac.kr
Highest degree: PhD, Department of Industrial Engineering, Pohang University of Science and Technology
Position title: Professor, Department of Industrial Management Engineering, Daejin University
Areas of interest: Product Development

Eui S Jung: ejung@korea.ac.kr
Highest degree: PhD, Department of Industrial Engineering, Pennsylvania State University
Position title: Professor, Department of Industrial Management Engineering, Korea University
Areas of interest: Product Development, Technology Management