JESK
J Ergon Soc Korea 2017; 36(3): 213-219
http://dx.doi.org/10.5143/JESK.2017.36.3.213
http://jesk.or.kr eISSN:2093-8462

Identification of the Minimum Legible Text Size for Group-View Display of the Main Control Room in Radioactive Waste Facility

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Received : April 04, 2017
Revised : April 18, 2017
Accepted : June 09, 2017

Objective: The present study identified the minimum legible text size by an experiment for eight combinations of background and text colors, which will be used in designing visual information on group-view display (GVD).

Background: Information on minimum legible text size is needed to design the visual information presented on GVD in a radioactive waste control room.

Method: The experiment was conducted for 22 male participants (age: mean = 37, SD = 6.7; visual acuity: over 0.8) who were recruited by considering demographic characteristics of current control room operators. Eight combinations of background and text colors were considered and the minimum legible text size was determined for each combination by applying the method of limits, one of psychophysical methods.

Results: The minimum legible text size was significantly different in accordance with the combination of background and text colors. Statistical analysis results showed that luminance contrast and color contrast between background and text influenced the minimum legible text sizes.

Conclusion: This study concluded that the minimum legible text size is 8 minute of arc for various combinations of background and text colors.

Application: The minimum legible text size identified in the present study can be utilized in designing visual information on GVD at the main control room in a radioactive waste facility.

Keywords: Minimum legible text size, Group-view display, Main control room, Radioactive waste facility

1. Introduction

Visual information displayed on group-view display (hereafter, GVD) in the main control room of radioactive waste facility should be adequately visible to all operators. GVD is a large display which provides the operating information of radioactive waste facility to operators. The operators in the main control room must safely operate the radioactive waste facility by monitoring the visual information displayed on GVD

(Corcoran et al., 1981). Therefore, the visual information is properly visible to all operators in order for the effective recognition of status about the radioactive waste facility (Yamamori et al., 2000).

The nuclear power plant design guideline of NUREG-0700 (O'Hara et al., 2002) provides the minimum and optimal text size in minute of arc (symbol: ') for design of visual information. The NUREG-0700 suggests 16' as the minimum text size for GVD. It indicates that the height of text should be at least 2.3cm (text height in cm = 6.283 × distance in cm × 16 ÷ 216) to be seen by all operators who are 5m away from GVD. In addition, the NUREG-0700 specifies 20'~22' as the range of optimal text size.

The NUREG-0700 has been usefully utilized in design of visual information since its publication in 2002; however, the visual design guideline needs to be modified due to improvement of display technology. New display technology improves the resolution and image quality of displays and facilitates to recognize a smaller text. Therefore, the minimum text size recommended in the NUREG-0700 is conservatively large and can unnecessarily limit the amount of visual information displayed on GVD (Carvalho et al., 2008).

The present study identified a minimum legible text size by an experiment for the design of visual information. The experiment was conducted in an experimental room where its environmental condition (e.g., illumination) is similar to the main control room in radioactive control facility. The participants having similar demographic characteristics (e.g., age and gender) of current operators in the main control room were participated. The experiment was conducted for various combinations of background and text colors which will be used in visual information design for the main control room. The present study determined the minimum legible text size by applying method of limit which is one of psychological approaches.

2. Experimental Methods

2.1 Participants

Twenty two males in their 30s and 40s were participated in this experiment. The present study considered demographic characteristics (age group and gender) of control room operators in recruitment. The participants' average age was 37 (SD = 6.7) and their corrected visual acuity was over 0.8.

2.2 Experimental design

Eight combinations of background and text colors which will be used in a radioactive waste control room were considered in the experiment as shown in Table 1. The background color consists of six (white, light gray, gray, dark gray, yellow, and blue); the text color includes three (white, black, and red). All colors considered in this experiment were defined by the Munsell color system, which specifies a color in terms of three dimensions (hue, lightness, and color purity).

A minimum legible text size was determined by applying *method of limits*, one of psychological approaches. The method of limits investigates a perceptual sensory threshold by presenting different intensity of stimuli in ascending and descending orders (Fechner, 1860). In the method of limits, the perceptual sensory threshold is determined as average of two threshold values identified in both ascending and descending experiments. The range of text sizes (1'~20') presented to each participant was defined by a pilot study.

Intensity of illumination in the experimental room and viewing distance from GVD to each participant were controlled by referring to the environment and layout of a main control room. The intensity of illumination was set to 500lux by considering the illumination recommendation (O'Hara et al., 2002) for the main control room in radioactive waste facility. A LCD monitor (FLATRON L1954T,

Table 1. Conditions of background and text colors

No.	Color		Luminosity contrast*	Color contrast**	Example
	Background	Text			
1	White	Black	21.0	-	hot
	0.46Y	10.00YR			
2	Light gray	Black	14.0	-	hot
	7.51GY	10.00YR			
3	Gray	Black	11.5	-	hot
	5.84RP	10.00YR			
4	Dark gray	Black	9.0	-	hot
	8.30GY	10.00YR			
5	Dark gray	White	2.3	-	hot
	8.30GY	0.46Y			
6	Yellow	Red	-	255	hot
	0.80GY	7.63R			
7	Yellow	Black	-	510	hot
	0.80GY	10.00YR			
8	Blue	White	-	510	hot
	5.54PB	0.46Y			

*In order to exclude color effects, luminosity contrast was calculated for achromatic colors such as white, gray, and black by W3C's method (W3, 2013; Juicystudio, 2013).
**Color contrast was calculated for chromatic colors such as yellow, red, and blue by W3C's method (W3, 2013; Juicystudio, 2013).

LG Display, South Korea) was placed 5m away from the participant by considering the layout of main control room (Lee et al., 2010).

The experiment was conducted by an experimental program developed using Visual Basic 6.0. The experimental program randomly selected the eight combinations of background and text colors. In addition, the experimental program randomly displayed one of 50 three-letter lowercase English words in Arial font, which is one of the most popular typeface (Bernard et al., 2003; Myung, 2003).

2.3 Experimental procedure

The present study was conducted by four steps (introduction, acuity test, pilot test, and main test). In the introduction step, a participant was instructed the experimental method and signed a written consent. In the acuity test step, a corrected visual acuity of each participant was measured using a visual acuity chart. In the pilot test step, an enough exercise was allowed to be accustomed the experiment. In the main test step, four trials (two ascending trials and two descending trials) of main experiment for each participant were conducted in a random order.

2.4 Statistical testing

The present study conducted statistical testing using MINITAB (Minitab Inc., USA) at 0.05 significance level (α). Two single-factor within-subject ANOVAs were carried out for the factors of color combination (8 levels) and age group (2 levels). One single-factor between-subjects ANOVA was done for the factor of presentation order of text size (2 levels). Least significant difference (LSD) test was used in post hoc analysis.

3. Results

The minimum legible text size was significantly different in accordance with the combination of background and text colors ($F(7, 140) = 7.17$, $p < 0.001$). Post-doc analysis revealed that the combinations were statistically divided into two groups: small size group vs. large size group (Figure 1). In the small size group, blue (background)-white (text) ($\bar{x} \pm SE$; 4.49 ± 0.13), white-black (4.58 ± 0.13), yellow-black (4.59 ± 0.14), and light gray-black (4.69 ± 0.13) were included. In the large size group, light gray-black (4.69 ± 0.13), medium gray-black (4.80 ± 0.13), dark gray-black (4.85 ± 0.13), dark gray-black (4.83 ± 0.13), and yellow-red (4.95 ± 0.14) were included.

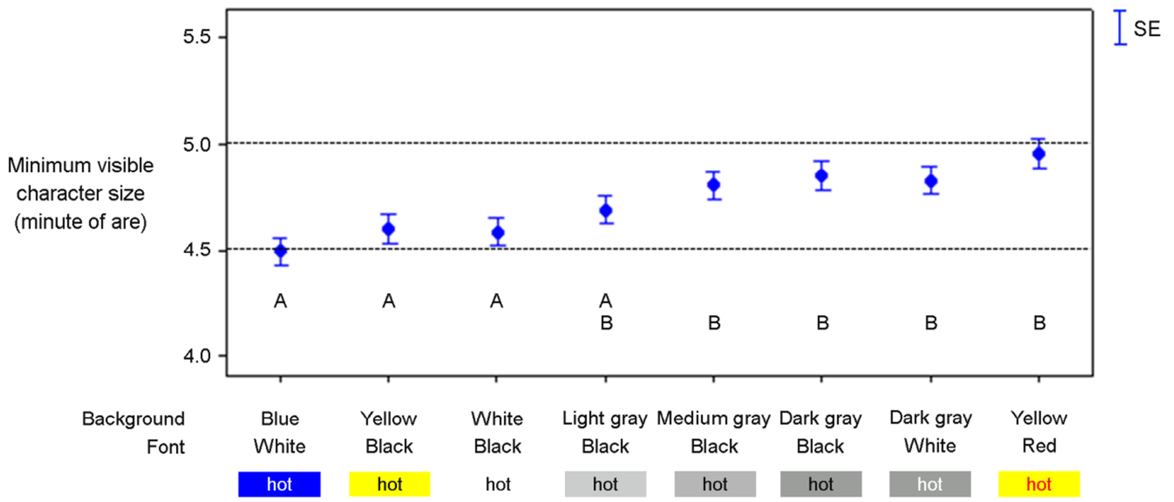

Figure 1. Minimum legible text size for the combinations of background and text colors (Alphabet letter indicates statistical significant at $\alpha = 0.05$)

The minimum text size significantly increased as luminosity contrast (hereafter, LC) between background and text colors decreased ($F(1, 2) = 36.61$, $p = 0.026$). A regression analysis between minimum text size and LC was conducted for four combinations (white-black, light gray-black, medium gray-black, and dark gray-black) of achromatic colors. Analysis results showed that the minimum text size negatively correlated with LC (minimum text size = 5.04 - 0.0227 × LC; adj. $R^2 = 0.922$).

The minimum text size tended to increase as color contrast (hereafter, CC) between background and text colors decreased ($F(1, 2) = 20.58$, $p = 0.140$). A regression analysis between minimum text size and CC was conducted for three conditions (blue-white, yellow-black, and yellow-red) which include at least one chromatic color in both background and text. Analysis results showed that the minimum text size negatively related to CC (minimum text size = 5.37 - 0.002 × CC; adj. $R^2 = 0.907$).

Age group (30's vs. 40's) did not significantly affect to the minimum text size ($F(1, 21) = 0.11$, $p = 0.75$). The minimum text size for 30's (4.70 ± 0.06) was similar to that for 40's (4.76 ± 0.07). In contrast, the order (ascending vs. descending) of text size provided to each participant in the experiment significantly affected to the minimum text size ($F(1, 21) = 10.41$, $p = 0.004$). The minimum text size for the descending order (4.64 ± 0.07) was smaller than that for the ascending order (4.80 ± 0.07).

The minimum text size adequately visible to all participants was 8' (Table 2). The minimum text size visible to all participants was slightly varied from 7' to 8' in accordance with the combinations of background and text colors. For example, the minimum text size visible to all participants was 7' for blue-white; but, 8' for yellow-red. These results indicate that the text over 8' can be seen by all participants in all combinations of the background and text colors considered in the present study.

Table 2. Minimum text size for various combinations of background and text colors (unit: minute of arc)

No.	Color condition		Minimum legible text size				
	Background	Text	Mean	SD	SE	Min	Max
1	Blue	White	4.488	1.215	0.131	2	7
2	Yellow	Black	4.593	1.278	0.138	2	7
3	White	Black	4.581	1.222	0.132	3	7
4	Light gray	Black	4.686	1.171	0.126	3	7
5	Medium gray	Black	4.802	1.235	0.133	3	7
6	Dark gray	Black	4.849	1.223	0.132	2	7
7	Dark gray	White	4.826	1.229	0.133	3	7
8	Yellow	Red	4.953	1.273	0.137	2	8

4. Discussion

The present study found the minimum legible text size for visual information design of GVD in the main control room. In the present study, the minimum legible text size was investigated for the various combinations of background and text colors by applying the method of limits. The minimum legible text size identified in the present study can be of help in visual information design for GVD.

The minimum legible text size (8') identified in the present study was different from the minimum text size (16') recommended in the NUREG-0700. The reason cannot clearly understand because the NUREG-0700 does not provide technical and scientific grounds (O'Hara et al., 2002) in relation to the recommendation. However, there are two possible reasons (display resolution and safety margin), which cause this difference. First, the resolution of the display studied in the NUREG-0700 (published in 2002) would be lower than the resolution of the display used in the study; therefore, the minimum legible text size of the NUREG-0700 could be bigger than that of this study. Second, it is anticipated that the NUREG-0700 would provide a conservative recommendation by considering a safety margin.

The minimum legible text size found in this study would be recommended to apply with consideration of a safety margin in the design of visual information. For safe operation of a radioactive waste facility, operators in the main control room need to easily recognize all information displayed in GVD (Lee and Seong, 2009). In addition, the visual information should be properly perceived under high cognitive workload which can be caused by emergent or unexpected events.

The minimum legible text size identified in the present study related with luminosity contrast and color contrast between background and text colors as stated in existing studies (Kong et al., 2011; Shieh and Lin, 2000; Legge et al., 1990). The minimum legible text size for achromatic colors decreased as luminosity contrast increased. For example, the minimum size for white-black (luminosity contrast: 21.0) was 4.58'; however, the minimum size for gray-black (luminosity contrast: 11.5) was 4.80'. Furthermore, the minimum legible text size for chromatic colors decreased as color contrast increased. For example, the minimum size for blue-white (color contrast: 510.0) was 4.49; however, the minimum size for yellow-red (color contrast: 210.0) was 4.95.

To improve applicability of the results identified in this study, two further studies would be needed. First, a proper safety margin to the minimum legible text size identified in the present study needs to be scientifically studied in order to secure enough safety under emergent situations. Second, male participants in their 30s and 40s were recruited in this study by considering demographic characteristics of current operators at a radioactive waste control room; however, in order for generalization of the results identified in the present study, an experiment for older age (e.g., 50s) and female would be needed.

Acknowledgements

This research was jointly supported by Korea Electric Power Company (KEPCO), the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science, and Technology under Mid-career Research Program (NRF-2015R1A2A2A03005486), the Biomedical Research Institute Fund, Chonbuk National University Hospital, and the Ministry of Trade, Industry Energy under Industrial Technology Innovation Program (No. 10063384).

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