Effects of illumination conditions on preferred viewing distance of portable liquid-crystal television

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Abstract — This study explored the effect of TV size, light source, and ambient illumination on the preferred viewing distance of portable liquid-crystal-display televisions. Results showed that the mean preferred viewing distance was 1389 mm. TV size had significant effects on preferred viewing distance. The larger the screen size, the greater the preferred viewing distance, at around 6.7–14.7 times the width of the screen (W). Light sources revealed no significant effect on preferred viewing distance. The effect of ambient illumination on preferred viewing distance was significant. The higher the ambient illumination was, the longer the preferred viewing distance.

Keywords — Portable liquid-crystal-display television, preferred viewing distance, light source, illumination, TV size.

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1 Introduction

Watching TV is an indispensable part of modern daily life. Cathode-ray-tube television (CRT-TV) had been the mainstream in the past. During the past few years, due to technological development, global environmental awareness, and the requirement for smaller product design, the flat-panel-display television (FPD-TV) featuring energy-savings and a lighter and thinner design with no radiation, has gradually replaced the giant and high-energy-consuming CRT TV. Among all FPD TVs, the liquid-crystal-display television (LCD-TV), with its technological maturity and lower price, has taken the lead to become the main stream in the market. Jarenski estimated the global production of LCD TV will rise to US $193,900,000 in 2012 from US $100,100,000 in 2008 with a 67% annual compound growth rate.

In extensive multimedia, the rise of portable TV also caused the digital audio-visual revolution. Pablo pointed out that portable televisions are regarded as the next trend that is gaining momentum in the market nowadays. Portable TV can be enjoyed anywhere or any time; in your home or away, it is ideal for a desk, kitchen, kids’ room, or car.

Viewing distance is one critical factor affecting viewing performance and viewing fatigue. A longer viewing distance makes images of visual stimuli on the retina smaller and less clear. However, it is generally accepted that shorter viewing distances increase the tension of the ciliary and extraocular muscles and produce greater visual strain (Weston and Fisher). Ankrum pointed out the resting point of vergence averages about 1143 mm when looking straight ahead and comes in at about 889 mm with a 30° downward gaze angle, and 150 mm in front of your nose you are going to experience discomfort – this can contribute to eyestrain (Owens and Wolfe-Kelly). Some studies (Jaschinski-Kruza, Shieh and Chen, and Shieh and Lee) showed VDT viewing distance to be correlated with visual strain; there were fewer reports of visual fatigue at a longer viewing distance. Research for proper viewing distance has been an important topic in human-factors engineering. Until now, studies mostly focused on computer displays.

There are not many studies available regarding optimal TV viewing distance, and the results are inconclusive. Enoch found 6.25W (W is the width of screen) to be the best viewing distance. The University (Wisconsin) Facilities Research Center suggested 5W and 14W would be the minimum and maximum viewing distance. Wadsworth suggested 2W and 6W would be the minimum and maximum viewing distance. McVey found the minimum viewing distance to be 4W. When watching high-resolution TV (800 or more pixel scanning lines), the minimum viewing distance could be dropped to as low as 2W; while the maximum viewing distance was 8W.

The Office of Technology Assessment reported that the preferred viewing distance (PVD) was found to be about 3.5H (H is the height of screen) for the typical HDTV system. Ardito, Gunetti, and Visca found in their research that the preferred viewing distance was 3W or 5.2H in general. Narita et al. pointed out the recommended viewing distance was 2H or 3H for HDTV. Sakamoto et al. revealed that the viewing fatigue was the lowest when viewing distance was between 3H and 4H.

Lee explored the effect of TV size, illumination, and viewing angle on preferred viewing distance in HDTV. TV size and illumination significantly affected preferred viewing distance. The larger the screen size, the greater the preferred viewing distance, at around 3–4 times the width of the screen (W). The greater the illumination, the greater the
preferred viewing distance. Viewing angle also correlated significantly with preferred viewing distance.

All the above literature reveals that the size of the TV screen plays an important role on viewing distance. However, the available data are mostly for family-sized TV with screen size around 20–40 in. Portable TVs have screen sizes of about 10 in. or less. Can the preferred viewing distance for family-sized TV apply to smaller portable TV deserves study. Moreover, portable TVs are supposed to be used in various of illuminating conditions, under various light sources such as daylight and artificial light, or under various ambient illuminations such as bright outdoors and dim indoors.

For ambient illumination, Lee found that for family-sized TV (20–40-in. TV) PVD increased with an increase in ambient illumination from 250 to 650 lx and then leveled off for greater illuminations. However, the above results may not apply to portable TV because portable TV has a much smaller screen and the image on it will also be much smaller that watching it may need greater ambient illumination than ordinary family-sized TV. Furthermore, portable TV is convenient to carry around and can be enjoyed at home where fluorescent light is the main light source or outdoors illuminated by the sun. Thus, there is a need to investigate the effect of light source and ambient illumination on PVDs of portable TV.

In summary, there were very few human-factor evaluations of PVD of portable LCD TVs. Many factors have effects on viewing distance, including TV characteristics such as size, environmental factors such as ambient illumination, as well as various light sources. Therefore, it is necessary to perform a more practical analyses to understand the PVD in watching television and, at the same time, to provide users and manufacturers with guidance and suggestions. This study explored the effect of light source, TV size, and ambient illumination on PVD when watching portable LCD TVs.

2 Method

2.1 Experimental design

This study evaluated three independent variables:

1. **TV size**: at three levels, 2.8, 9.0, and 12.3 in., measured diagonally in inches; i.e., TV size = \( \sqrt{(TV \text{ height})^2 + (TV \text{ width})^2} \).

2. **Light source**: at two levels, daylight D65 (6500K) and fluorescent TL84 (4000K). They are the generic light sources in a human-living environment.

3. **Ambient illumination**: at four levels: 200, 600, 1000, and 1400 lx.

The factor of light source was treated as a between-participants’ factor, and TV size and illumination were treated as within-participants’ factors in the experiment. There were 30 subjects in the experiment. The participants were randomly divided into a daylight D65 group and a fluorescent TL84 group, each having 15 subjects. Each participant randomly completed the 4 (illumination) × 3 (TV size) = 12 treatment combinations.

2.2 Participants

The participants were 30 college students with ages ranging between 18 and 24 (M = 20.7, SD = 1.3). All had corrected 0.8 or better visual acuity with normal color vision. They were recruited by an announcement posted on the school Internet Web site and bulletin board. There was an institutional review board (IRB) approved by the Oriental Institute of Technology and all the participants gave written informed consent in the study. Each participant was paid NT $200 (about $US 7).

2.3 Apparatus

The three portable LCD TVs were the Visao X20 (FunTwist Technology Inc., Taiwan) 2.8-in. TFT LCD (display size: 57 mm (W) × 43 mm (H); resolution: 320 × 240 pixels); the EMMAS (Xin-Yi Corp., Taiwan) PD-6800 9.0-in. TFT LCD wide-VIEW screen (16:9) (display size: 198 mm (W) × 114 mm (H); resolution: 640 × 254 pixels); and the EMMAS AB-980 12.3-in. TFT LCD wide-VIEW screen (16:9) (display size: 262 mm (W) × 164 mm (H); resolution: 800 × 480 pixels). A Topcon screenscope (Topcon, Japan) and standard pseudo-isochromatic charts (Ishihara, Japan) were used to examine the participants’ visual acuity and color vision. Ambient illumination levels were measured with an LT Lutron Lx-103 illumination meter. The light source and illumination were controlled in a color-assessment cabinet (VeriVide CAC 120-5).

2.4 VDT conditions of workplace

The experiment was conducted in the Human Factor Laboratory of the Department of Industrial Management, Oriental Institute of Technology. The portable TVs were placed inside a color-assessment cabinet with no interference from any external light source during the experiment. The portable TV set was placed 320 mm from the edge of the table and 730 mm from the height of the table. The inclination angle of each portable TV screen was 90° with respect to the horizontal axis. The participants sat on a chair 460 mm high with a chin supporter to fix their head. The laboratory room temperature was controlled at 26°C. The audio volume of the TV program was set at 55–60 db (measured 1000 mm away from the TV set). The illuminations were measured within ±1% of the designated levels. Neither glare nor reflection appeared on the TV screen. The screen luminances for the three TVs were set at scale 50 during the experiment. The scale range was from 0 to 100 with greater value indicating greater image brightness. The maximum luminances for the three TVs were the same at 270 cd/m² (scale 100). The luminance contrasts were also set at scale 50; i.e., the lumi-
nance ratio of the brightest and darkest images was 50 in this study. A metering line was drawn on the floor of the laboratory to help the data-collection process.

### 2.5 Task and procedure

The TV program (stimuli material) presented during the experiment was a DVD film titled IP Man. Each participant was required to proceed with the following:

1. Sit on a plastic, movable chair 460 mm high and watch the program on the TV;
2. Adjust the PVD and then allow the experimenter to measure and record the data. The participants were instructed to adjust the PVD to their best visual comfort and legibility after watching TV for 3 minutes. They adjusted PVD by moving the chair along the metering line drawn on the floor. After completing PVD, the participants were required to adjust the minimum and maximum acceptable viewing distances;
3. Repeat steps 1 and 2 for all 12 (4 illuminations × 3 TV sizes) treatment combinations. There was a 1-minute break between treatments.

Each participant proceeded for PVD data collection. It took about 1 hour to complete the entire experiment.

### 2.6 Dependent measures and data analysis

The dependent variable of this study was PVD, the perpendicular distance from the eyes of the participant to the center of LCD screen. Analysis of variance (ANOVA) and least significant difference (LSD) were performed to evaluate the effect of the independent variables on PVD. All calculations were processed with SAS software. All significance levels were set at $\alpha = 0.05$.

### 3 Results

The means and standard deviations of PVD under each level of the independent variables are shown in Table 1. Figures 1 and 2 are the bargraphs with LSD results indicating the PVDs under TV sizes, light sources, and illuminations. What follows are the results of the analysis of variance of the PVD.

The data in Table 1 shows that the PVDs for TV size 2.8, 9.0, and 12.3 in. were 839, 1581, and 1746 mm, respectively. The smaller the TV size, the shorter the PVD seemed to be. ANOVA results as shown in Table 2 indicated that TV size had significant effect on PVD ($F(2,56) = 170.85, p < 0.01$). The critical difference of paired comparison as determined by using the LSD method was 104.8 mm, and the results are shown in Table 3. PVDs were significantly different among the TV sizes. Based on the width and height of the TV screen, the PVDs (perpendicular to the screen center) were 14.7$W$, 19.5$H$ (2.8-in. TV); 8.0$W$, 13.9$H$ (9.0-in. TV); and

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![FIGURE 1 — LSD bars at TV sizes.](image)
As shown in Table 1, the mean preferred viewing distances were 1436 and 1342 mm under daylight (D65) and fluorescent light (TL84), respectively. The light source had no significant effect on PVD ($F_{(1,28)} = 1.31, p > 0.05$).

PVDs for illumination 200, 600, 1000, and 1400 lx were 1300, 1355, 1441, and 1460 mm, respectively. As ambient illumination increased, the longer the preferred viewing distance became. The results of the analysis of variance (Table 2) showed that illumination had a significant effect on PVD ($F_{(3,84)} = 18.94, p < 0.01$). The critical difference of paired comparison as determined by the LSD method was 48.6 mm. As shown in Table 3, PVD was significantly shorter under 200 lx (816 mm), 600 lx (822 mm), 1000 lx (855 mm), and 1400 lx (863 mm) ambient illumination, while the difference between 1000 lx (1441 mm) and 1400 lx (1460 mm) was not statistically different.

The interaction between TV size and ambient illumination was significant ($F_{(6,168)} = 4.88, p < 0.01$). As shown in Fig. 3, the PVDs for 200 lx (816 mm), 600 lx (822 mm), 1000 lx (855 mm), and 1400 lx (863 mm) were similar for 2.8-in. TV. However, the PVDs for 9.0-in. TV (1439, 1526, 1618, and 1742 mm) and 12.3-in. TV (1644, 1717, 1849, and 1775 mm) lengthened with an increase in ambient illumination from 200, 600, 1000, to 1400 lx, i.e., the ambient illumination had little effect on PVDs for 2.8-in. TV, whereas for 9.0- and 12.3-in. TVs, PVD increased significantly as ambient illumination increased.

Moreover, light source and ambient illumination had a significant interaction effect ($F_{(3,84)} = 7.58, p < 0.01$). As shown in Fig. 4, under 200-, 600-, and 1000-lx ambient illuminations, the PVDs of TL84 (1217, 1267, and 1410 mm) were lower than that of D65 (1382, 1443, and 1472 mm). However, under 1400-lx ambient illumination, the PVD of TL84 (1473 mm) was greater than that of D65 (1448 mm).
A regression model was used to predict the PVD using TV size, light source, and ambient illumination as the predicting variables. Because the relationship of the predicting variables and PVD was not linear, a quadratic model was constructed and stepwise regression applied to build the equation. The estimated equation is

\[ \hat{y} = 319 + 192x_1 + 0.02x_1x_2 - 7.34x_1^2, \]

where \( \hat{y} \) is the predicted PVD, mm; \( x_1 \) is the TV sizes (inches, diagonal measure); and \( x_2 \) is the ambient illumination, lx.

The coefficient of determination of the equation was \( R^2 = 0.62 \). The regression coefficient indicated that for a 1-in. increase in TV size, the PVD increased by 192 mm. However, the increase leveled off and showed a second-degree curvilinear effect (coefficient \( x_1^2 \) was \(-7.34\)). TV size and illumination had an interaction effect on PVD (coefficient of \( x_1x_2 \) was 0.02). Based on this regression equation, if a man watches a 5-in. TV and the illumination is 500 lx, the estimated direct front PVD is 1146 mm.

The minimum acceptable viewing distance was shortest (800 mm) at 200 lx. Ambient illumination had significant effect on minimum acceptable viewing distance. As illumination increased, the minimum acceptable viewing distance tended to increase.

TV size had significant effect on maximum acceptable viewing distance. The maximum acceptable viewing distance increased as TV size increased. The maximum acceptable viewing distances were 1047, 2390, and 2732 mm, or 18.4W, 12.1W, and 10.4W for TV sizes 2.8, 9.0, and 12.3 in., respectively. The maximum acceptable viewing distance for daylight (D65) was 2157 mm, longer than that (1957 mm) for fluorescent light (TLS84). Ambient illumination had significant effect on maximum acceptable viewing distance. The maximum acceptable viewing distance increased as ambient illumination increased. For ambient illuminations of 200, 600, 1000, and 1400 lx, the maximum acceptable viewing distances were 1903, 2103, and 2202 mm, respectively.

The minimum and maximum acceptable viewing distances are shown in Table 1. The effect of TV size on minimum acceptable viewing distance was significant. The minimum acceptable viewing distance increased as TV size increased. The minimum acceptable viewing distances were 612, 923, and 1029 mm, or 10.7W, 4.7W, and 3.9W for 2.8-, 9.0-, and 12.3-in. TVs, respectively. The minimum and maximum acceptable viewing distances are shown in Table 1. The minimum acceptable viewing distances were similar for daylight (D65) and fluorescent light (TLS84). Light source had no effect on the minimum acceptable viewing distances. The minimum acceptable viewing distance was the shortest (800 mm) at 200 lx. Ambient illumination had significant effect on minimum acceptable viewing distance. As illumination increased, the minimum acceptable viewing distance tended to increase.

4 Discussion

The major goal of this study is to investigate the effect of TV size, light source, and ambient illumination on PVD of portable LCD TV.

The PVDs were about 840–1750 mm with a grand mean of 1389 mm. The figures are shorter than those (about 2500–3500 mm) found in various experimental studies (e.g., Lee) and survey studies (e.g., Nathan et al.). TV size is the key factor that makes the difference. This study used portable TVs with screen sizes at 2.8–12.3 in., while the TVs in other studies were family TVs with screen size around 20–40-in. Images on portable TV screens are smaller and people have to sit closer to watch and thus have shorter PVDs than ordinary family TVs.

For portable TVs, as expected, PVD increased significantly with an increase in TV size. The PVD (839 mm) for the smallest 2.8-in. TV was about a hand length (around 600–800 mm). This figure is greater than the viewing distances (about 350–500 mm) for various mobile devices (e.g., notebook, electronic-paper display) found in many studies (Kato et al., Cesar et al., and Shieh and Lee9). A possible reason is that the experimental task in the present study was TV watching, while the other studies employed a text-reading task. Text reading usually demands a shorter viewing dis-
tance because alphanumeric information is smaller and less discriminable. The PVD increased from 839 mm for the smallest 2.8-in. TV to 1581 mm for 9.0-in. TV, and to 1746 mm for the largest 12.3-in. TV. The PVD for 2.8-in. TV was about 1/2 of that for 9-in. and 12.3-in. TVs. However, the screen size for 2.8-in. TV was less than 1/3 of the other two TVs; i.e., PVD for the smallest 2.8-in. TV was relatively longer than that predicted by TV size in itself. This may be have something to do with the resolution of the TV screen. Even though the resolution of the 2.8-in. TV (320 × 240 pixels) was less than that of 9.0-in. TV (640 × 234 pixels) and 12.3-in. TV (800 × 480 pixels); taking the screen size into account, pixels per inch for 2.8-in. TV was much greater than the other two larger TVs. Hence, the space between pixels would be smaller and the image quality better (Snyder and Maddox\textsuperscript{22}) for the 2.8-in. TV. Thus, the PVD for 2.8-in. TV was relative longer than that predicted by TV size in itself. In terms of TV width or height (W/H), the PVDs were around 14.7W/19.5H for 2.8-in. TV; 8.0W/13.9H for 9.0-in. TV; and 6.7W/10.6H for 12.3-in. TV. The ratio between the PVD and TV W/H increased with a decrease of TV size. The ratio is also much greater than that (about 3–4W/5–7H) found for family-size TV (e.g., Lee\textsuperscript{18}). Ardito \textit{et al.}\textsuperscript{13} had similar findings that the ratio between PVD and TV W/H was greater for small-sized TV and it decreased to about 3H for very-large-sized TV. It is improper to predict the PVD of portable TV by the relationship of PVD to screen W/H of ordinary family-sized TV.

Light source had no statistically significant effect on PVD. PVD for daylight (D65) was 1436 mm, slightly but not significantly greater than that (1342 mm) for fluorescent light (TL84). However, the significant Light Source × Ambient Illumination interaction (Fig. 4) indicated that for illumination lower than 1000 lx, PVD under daylight (D65) was greater than that under fluorescent light (TL84). With an increase in ambient illumination over 1000 lx, the PVDs for the two light sources got closer. One possible reason is that the color temperature of light source TL84 is about 4000K, which looks reddish than daylight (D65). People are less sensitive to red color and thus may have to move closer to watch TV when the light source is fluorescent light (TL84), especially when the illumination is not sufficient (600 lx or less). But this conjecture needs further study.

For the effect of ambient illumination, lower ambient illuminations (200 and 600 lx) resulted in significantly shorter PVD in this study. It is likely that under lower illumination, the eye’s pupil dilates. This causes higher accommodation and poor depth of field (Westheimer\textsuperscript{23}). Hence, visual acuity deteriorates under dim illumination and people have to move closer to the TV screen to watch the image clearly, thus resulting in a shorter PVD. The result of this study also revealed that illuminations of 1000 and 1400 lx had similar PVDs of 1441 and 1460 mm, respectively. In other words, an illumination about 1000 lx seems appropriate for watching portable TV, especially for indoor portable TV watching when the light source is fluorescent light. This figure is greater than that (650 lx) found by Lee\textsuperscript{18} for family-sized TV. One possible explanation is that images on portable TV screens are small and hence more illumination is needed to clearly watch portable TV.

Despite these findings, whether the results are also valid for other situations requires further study because there are some limitations in the design of this study. For instance, the participants watched a TV program for about 3 minutes, which might not have been long enough to produce visual fatigue and to reach stability of preferred viewing distance. Further, the TV screens in this study were small-sized 2.8–12.3 in. and the results may not be applicable to larger screens (e.g., TV in household living rooms and video-conferencing displays).

5 Conclusion

This study revealed that PVD for watching portable TV is about 840–1750 mm or about 6.7–14.7 times the width of the TV screen. The smaller the TV size, the shorter the PVD and the PVD for the smallest TV could be about hands length (600–1000 mm). However, the ratio between PVD and screen W/H increases with a decrease of TV size. Light source has little effect on PVD. PVD increases with an increase in ambient illumination up to 1000 lx. An ambient illumination at around 1000 lx seems to be proper for watching portable TV.

References


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