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Research article

Permissible viewing times of educational projector and TV

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ABSTRACT

Projectors have become one major medium in modern teaching, with large area-size displays emerging as an alternative. What concerns the general public is whether such eLearning would impose threat on eyes, by noting blue enriched white light to be hazardous to retina and else. Especially, little was known about their permissible viewing time under a certain viewing clarity. We had hence carried out a quantitative study with the use of a blue-hazard quantification spectrometer to determine the permissible viewing time when using a projector and a large size TV screen for displaying. Surprisingly, the large TV screen could permit a much longer viewing time, meaning which is more eye-friendly. It is plausibly because its resolution is much higher than that of the projector. Two dilemmas were observed in such eLearning; those sitting in the front would suffer a much higher illuminance, leading to a much shorter viewing time, while those sitting in the back would need a far much larger font size to see clearly. To ensure both viewing clarity and a sufficiently long permissible viewing time, orange text on black background is suggested to replace the defaulted black text on white background. The permissible viewing time could hence drastically increase from 1.3 to 83 h at 2 m by viewing a 30 pt font for the TV and from 0.4 to 54 h for the projection. At 6 m, the permissible viewing time was increased from 12 to 236 h for the TV and from 3 to 160 h for the projection, based on a viewable 94 pt font. These results may help educators and other e-display users to wisely apply the display tools with safety.

1. Introduction

Projectors have become one major medium in modern teaching, making teaching and learning more convenient than using blackboard [1–4]. Whilst, the use of large area-size displays has also become increasingly prevalent and emerges as an alternative [5–7].

Given the gradual shift in teaching media, what concerns the general public is whether such eLearning would impose threats on eyes, by noting blue enriched white light to be hazardous to retina and macula etc [8–23]. Taking retinal damage for example, Ham et al. revealed the photochemical sensitivity of retina to light to increase with the decrease of wavelength, explaining why retina is more vulnerable to the short wavelength blue light [8]. Jaadane et al. investigated the effect of white light-emitting diodes (LEDs) on

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retinal pigment epithelium and found that exposure to excessive blue light can increase oxidative stress, leading to retinal cell death [20]. The threats might become more severe in such an eLearning era, unless we take proper cautions.

To explore if some of the threats can be quantified, a few studies were carried out about the effect of wavelength on photoretinitis [8–23]. The threat was quantified via the use of a permissible exposure-limit [24–38]. For examples, Okuno et al. used the permissible exposure-limit to evaluate the blue-light hazard of various light sources [24]. Bonner et al. applied the permissible exposure-limit to assess the risk arising from exposure to luminaires and video screens in two large entertainment venues [26]. Sliney et al. employed a threshold limit value to quantify the ocular hazards from various projection systems and classified them into different risk groups [27]. O'Hagan et al. had assessed systematically the blue-hazard of a range of lamps, computer screens, tablet computers, laptops, and smartphones, by comparing their maximum exposure limit [28]. Dain had investigated the amount of blue light in various computer screens, lamps and outdoor environment and revealed their corresponding maximum exposure limits [29]. Wong et al. reported a review regarding the current research state on blue light safety in using digital devices. It covered the detection of blue-hazard as well as the influences of blue light on eye and circadian rhythms [30]. Besides the maximum permissible exposure limit (MPE), Jou et al. also applied a new index, melatonin suppression sensitivity (MSS), to quantify the threat of light at night on melatonin secretion [35]. They also applied MPE and MSS to demonstrate a fabricated candlelight-style OLED to be eye- and physiologically-more friendly than the blue enriched counterparts [32–37]. Furthermore, Jou et al. reported an easy-to-apply formula and a ready-to-use table derived therefrom to enable a quick determination of the maximum permissible exposure limit (MPE) of any given desk lamp by knowing its labelled color temperature and luminous flux [38]. However, little was known about the permissible viewing time of projectors and large area size displays for eLearning.

To understand the effects of viewing displays or projections on eyes, Kim et al. had investigated the suitable luminance range for subjects to read on LCD display under several conditions of ambient lighting through a psychophysical experiment [39]. Liu et al. had discussed the effect of the vertical plane luminance on projection screens and human visual clarity in the classroom to understand the visual satisfaction of students upon viewing the projection [40]. Nevertheless, little is known regarding the potential threats of those displays on eyes. Especially, there is no knowledge about whether projector or large TV screen is more friendly based on the same viewing clarity.

We had hence carried out a quantitative study with the use of a blue-hazard quantification spectrometer (SRI-100) to determine the MPEs when using a projector and a large size TV screen for displaying in the current teaching environment of Shu-Guang Girls Senior High School, which is also a direct reflection of the common teaching environment at least in Taiwan. Surprisingly, the large TV screen could permit a much longer viewing time, meaning which is more eye-friendly. It is plausibly because its resolution is much higher than that of the projector. The MPE was 1.3 h for the subjects to view the TV screen with a 30 pt font with a 20 lx illuminance at the first row, i.e. 2 m away from the screen. Whilst, it permitted only 0.4 h to view the projection, because a much higher illuminance (80 lx) was required to the view the same 30 pt font with clarity at the same viewing distance. The TV screen permitted a much longer viewing time, which was plausibly because it has a per area resolution 8 times that of the projector.

Two dilemmas were observed in such eLearning. Those sitting in the front would suffer a much higher illuminance, leading to a much shorter viewing time. Whilst, those sitting in the back need a far much larger font size in order to see clearly. To ensure both viewing clarity and a sufficiently long permissible viewing time, an orange text on dark background is recommended. The time permitted by viewing a 30 pt font at 2 m could increase from 1.3 to 83 h for the TV and 0.4–54 h for the projection. It could respectively increase from 12 to 236 h and 3–160 h at 6 m, based on a viewable 94 pt font.

2. Experimental

2.1. Maximum permissible exposure limit (MPE)

The maximum permissible exposure limit (MPE) was calculated by the formula reported by International Commission on Non-Ionizing Radiation Protection (ICNIRP) [41]. It estimated how long one can view a screen before retina permanent damage occurs, and was given as following:

$$\mathrm{MPE} = 100/\mathrm{E_B} \tag{1}$$

Where E_B is the blue light hazard weighted radiation with a unit of W m^{-2}. The magnitude of E_B can in turn be calculated as following:

$$\mathrm{E_B} = \sum_{\lambda=300}^{700} \mathrm{E_\lambda} \bullet \mathrm{B}(\lambda) \tag{2}$$

where E_λ is the spectral irradiance (W m^{-2}), and B(λ) is the photoretinitis (blue-light hazard) function (Wm^{-2}sr^{-1}), and λ (nm) is the wavelength.

2.2. Subjects

The subjects of this study were 5 students from Shu-Guang Girls Senior High School, aged 16–17 years. Those subjects with a diopter ranging from 5 to 5.5 have average decimal acuity of 0.1, which was determined by Snellen-type chart. According to formula (3) from "Visual acuity measurements" [42], which was shown below, an average decimal acuity of 0.1 corresponded to a logMAR

Table 1
Technical specifications of the used projector and TV.

	Projector[a]	TV[b]
Size (cm^2)	273 × 161	189 × 106
Resolution (pixels)	1920 × 1080	3840 × 2160

[a] Epson EB-2250U.
[b] JECTOR FM-S86.

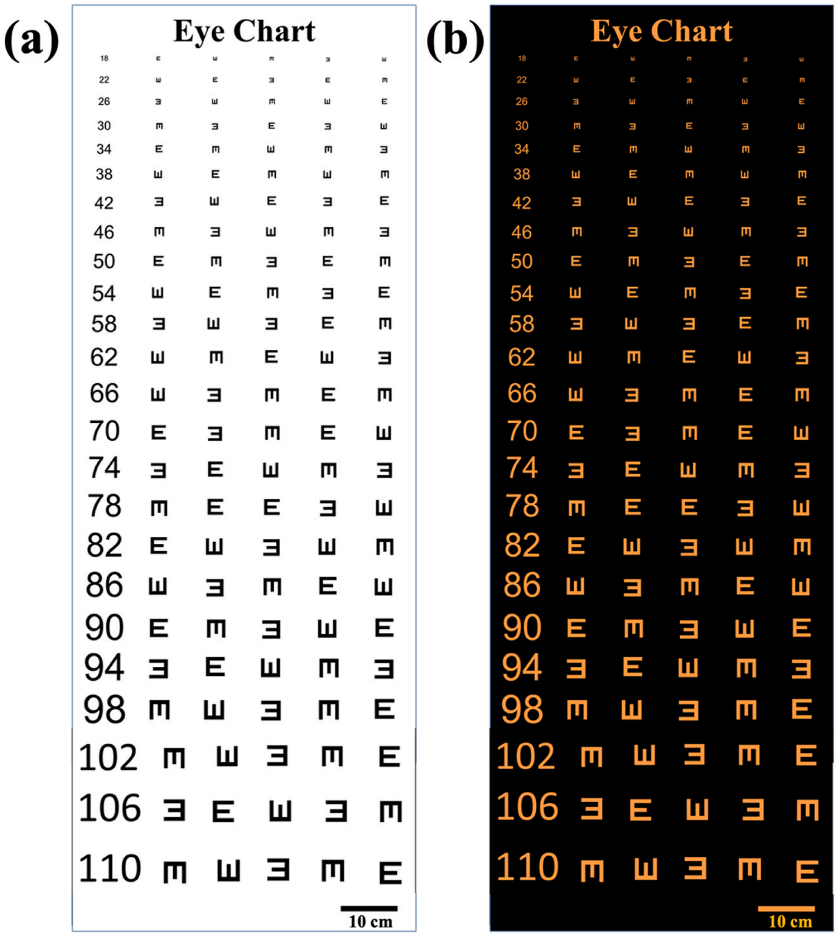

Fig. 1. Eye chart images for measuring the viewing clarity on the studied media with the setting of (a) black text on white background and (b) orange text on dark background.

value of 1.0. All subjects were asked to view the eye charts on the projection and TV screen without wearing eye-glasses or contact lenses.

$$\text{logMAR} = -\log(\text{decimal acuity}) \quad (3)$$

2.3. Displaying apparatus

Table 1 shows the technical specifications of a projector produced by Epson and a large size TV from JECTOR. The TV had screen area 2.2 times smaller than the projector but 4 times higher for resolution, which meaning that it has a per area resolution 8.8 times that of the projector.

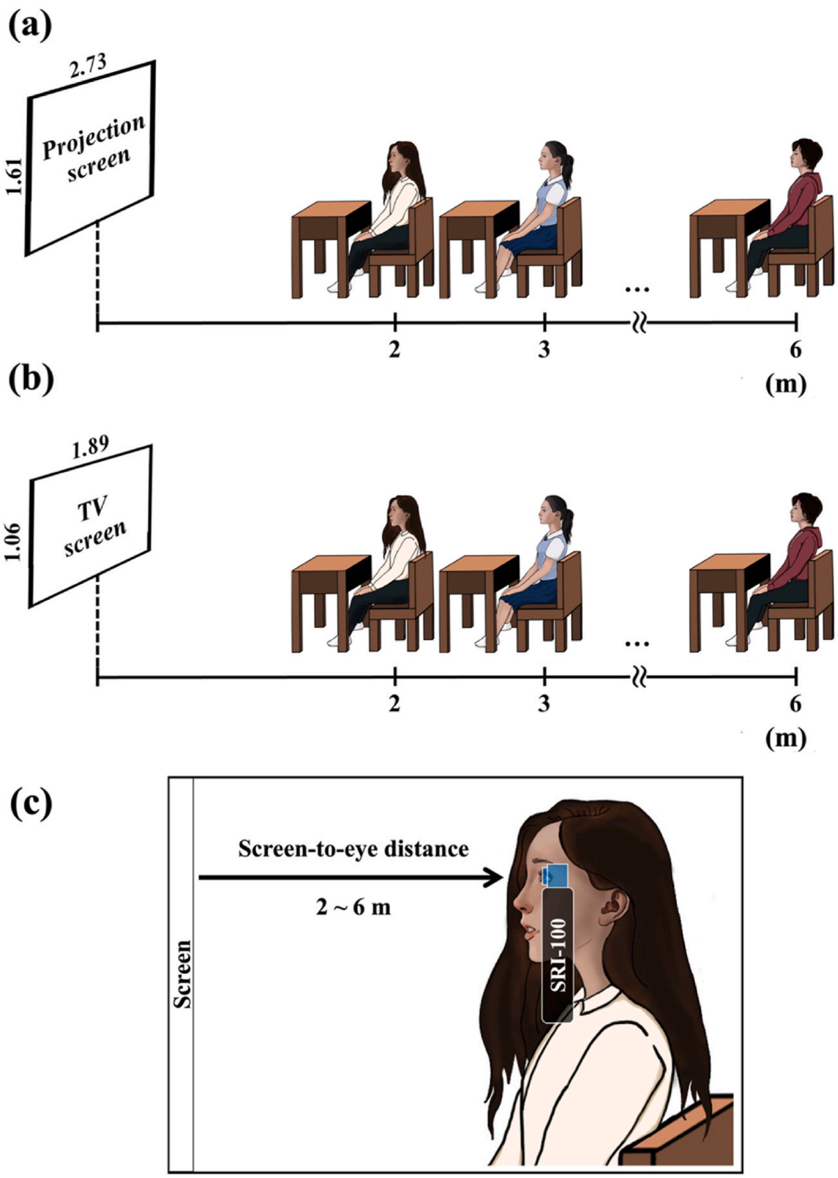

Fig. 2. Schematic illustration of the experimental setup. (a) A projection screen and (b) a TV screen was viewed under 2–6 m of screen-to-viewer distance. (c) The blue-hazard quantification spectrometer (SRI-100) was placed nearby the eye of a presumed subject.

2.4. Eye charts

Fig. 1 shows the eye charts showing on the studied media for measuring the viewing clarity. The sizes of eye charts are both 1.66×0.62 m^2, using either a defaulted black text on white background (Fig. 1a) or an orange text on dark background (Fig. 1b). The font-sizes of 18–110 pt, having text density of 117 text per square meter, were employed with a typeface of Optician Sans. To ensure the font-sizes to be the same on the two different media, a 10 cm scale bar was applied in both eye charts.

2.5. Method

Fig. 2a and b shows the setups of subjects viewing a 2.73×1.61 m^2 projection and a 1.89×1.06 m^2 TV screen respectively. Subjects were asked to view the eye-charts on the studied screens in a classroom without illumination and ambient light. To evaluate the viewing clarity, each individual was asked to report the minimum font size they could clearly view on the eye charts. The procedure was repeated at distances varying from 2 to 6 m.

Fig. 2c illustrates the setup measuring the permissible viewing time, MPE, by using a blue-hazard quantification spectrometer (SRI-100) from Iboson Co., Ltd. It was placed beside subject's eye with the shutter facing the studied projection and TV to determine the

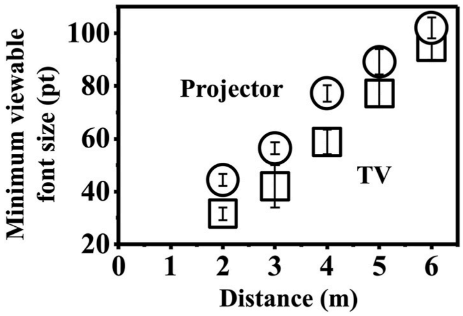

Fig. 3. Minimum viewable font-size for subjects to view a projector and a TV at different distances, wherein a default screen setting was used, which was black text on white background. The error bars represent standard deviation of the mean.

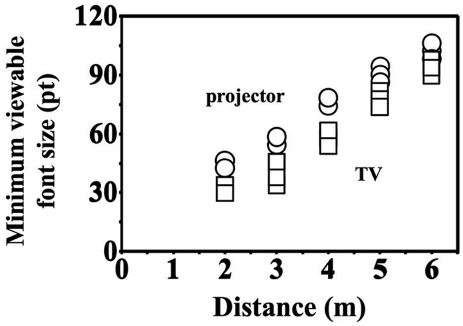

Fig. 4. Scatter plot of minimum viewable font size of 5 subjects upon viewing projection and TV with the default setting.

Table 2
Statistical analysis regarding the impact of the minimum viewable font-size on different settings for subjects viewing on projection and TV with respect to viewing distance, whereby $P < 0.01$ stand for "statistically significant".

P value		
Setting	Media	
	Projection	TV
Default	0.0004	0.001
Orange text on black background	0.007	0.008

corresponding MPEs at varying viewing distance.

Within-subject design was employed. Each subject participated the two experiments in two different days. Each session took a duration of 20 min.

The participants were informed the procedure of the experiments, and the informed written consents were obtained. Ethical approval was obtained from the Research Ethics Committee, National Taiwan University Hospital Hsin-Chu Branch (approval number: 110-136-F, dated: December 07, 2021).

3. Results and discussion

3.1. Viewing clarity

Fig. 3 shows the minimum viewable font-sizes for subjects to view a projector and a TV from the first to last row (2–6 m), wherein a default screen setting was used, which was black text on white background. The minimum viewable font-size was 46 pt at 2 m for the projector. As the distance increased to 6 m, a 102 pt font-size was required with viewing clarity. As to the TV, it was 30 pt at 2 m, and 94 pt at 6 m.

Fig. 4 shows the minimum viewable font sizes of the five subjects in viewing the projection and TV screen with the default setting, i.e., a black text on white background. Overall speaking, the TV screen could provide a better viewing clarity that is to allow subjects to see clearly a much smaller font-size.

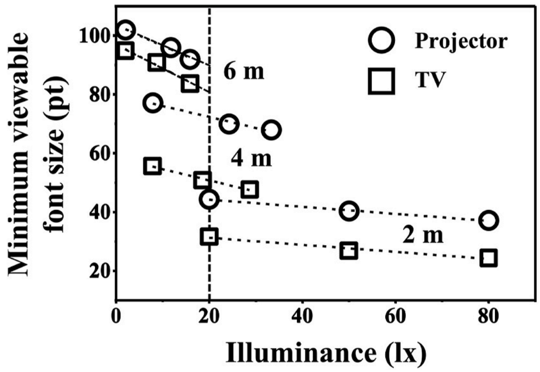

Fig. 5. Minimum viewable font-sizes for subjects to view a projector and a TV at different illuminances. They sensitively varied with the variation of viewing distance.

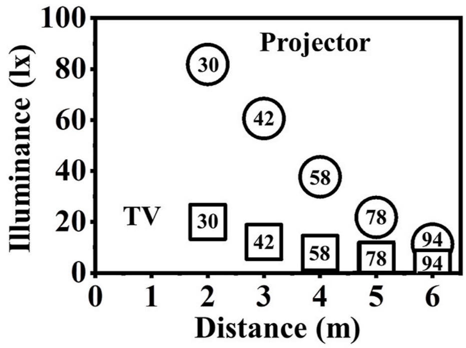

Fig. 6. Illuminances required for subjects to view the projector at different distances, on basis of the same minimum viewable font-sizes in viewing a TV with the default setting.

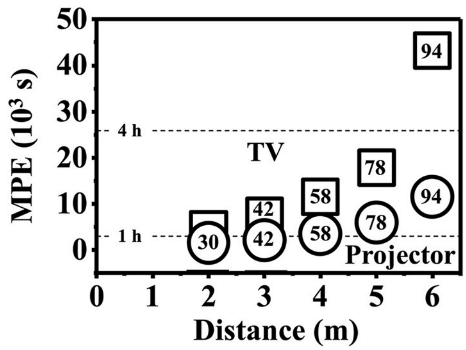

Fig. 7. The times permitted for subjects (MPE) to view the projector and the TV at different distances. Although a longer viewing distance could permit a longer viewing time, a comparatively larger font-size would be needed.

One-way analysis of variance (ANOVA) was used as the statistical analysis, which was performed with OriginPro 2018. *P*-values were obtained to determine whether viewing distance was correlated, significantly or not, with minimum viewable font size.

The minimum viewable font-size strongly depends on the viewing distance, with a P value of 0.001 for TV and 0.0004 for projection (Table 2). As the P values were smaller than 0.01 (statistically significant), which means minimum viewable font-size has correlation with viewing distance.

3.2. *Effect of illuminance on viewing clarity*

Fig. 5 shows the minimum viewable font-sizes for subjects to view the projector and TV under different illuminances. The illuminance required was 20 lx to view the projection of a 44 pt font at 2 m. It required 80 lx to view the 38 pt font. As to the TV screen, the

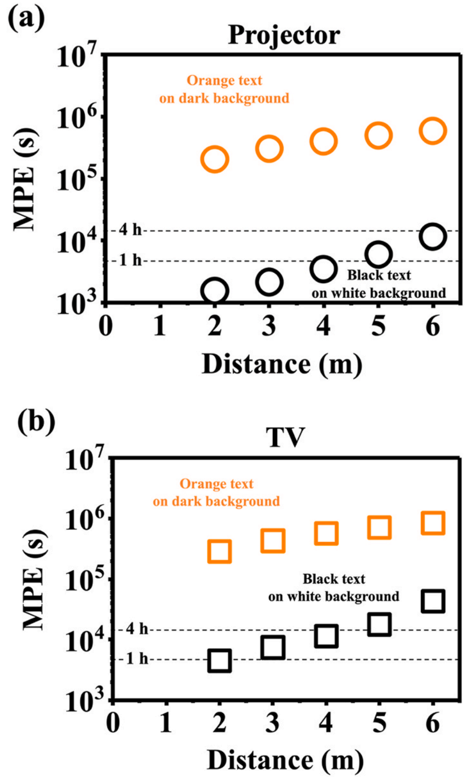

Fig. 8. Screen setting effects on the times permitted for subjects (MPE) to view the (a) projector and (b) TV at the different distances.

same 20 lx enabled to view a 30 pt font and the same 80 lx enabled to view a 24 pt font.

Much larger font-sizes were required as the viewing distance was increased. At 20 lx for example, the minimum viewable font-size required was increased from 44 to 90 pt for viewing the projection at from 2 to 6 m. For the TV screen, the corresponding font-size required was increased from 30 to 81 pt.

Fig. 6 shows the illuminances required for subjects to view the projection at different distances, based on the same font-size viewable by using the TV screen. The illuminance required was 82 lx in order to view the 30 pt font viewable by using the projection at 2 m.

The font-size must increase to 94 pt for viewing the TV screen at 6 m. Based on the same 94 pt font-size and same 6 m viewing distance, the illuminance required was 11 lx to view the projection, while 2 lx for TV. The TV required a much lower illuminance to view the same font. This should be due to its higher resolution. As seen in Table 1, the TV has a per area resolution 8 times that of the projector.

3.3. Permissible viewing time

Fig. 7 shows the times permitted, MPE, for subjects to view the projection and TV at different distances. The MPE was 0.4 h to view the projection with a 30 pt font at 2 m with a required illuminance of 82 lx. Whilst, it was 1.3 h in viewing the TV screen with the same font-size at the same distance (2 m). The longer permitted time is due to a lower required illuminance.

At a longer distance, a much longer viewing time is permitted since the resultant reaching-eye illuminance drops markedly with the increase of viewing distance. As a result, the permitted time at 6 m was 3 h for the projection and 12 h for the TV screen. However, a much larger font-size, i.e., 94 pt, was demanded.

As seen in the figure, the TV screen that possesses an advantageous high resolution could enable a viewing time longer than an hour throughout the entire distance. That would presumably warrant the completion of a whole class without causing photoretinitis. In contrast, the projector could only permit a more than 1 h viewing time at distances longer than 3 m. In other words, those sitting at front rows might encounter photoretinitis or other oxidative stress related issues.

The null hypothesis states that viewing the image from a projector is safer than from a TV screen, since the former is an indirect light and the required illuminance for viewing clarity might be lower and hence be more friendly to retina. Whilst, the alternative hypothesis states that projector/display resolution is more crucial than direct or indirect lighting in affecting the required illuminance. Higher resolution would enable better viewing clarity at a lower illuminance.

The results showed that the TV screen provided a better viewing clarity at a lower required illuminance at all the studied viewing distances for having a higher resolution. The higher resolution also enabled subjects to view clearly the eye chart with a much smaller

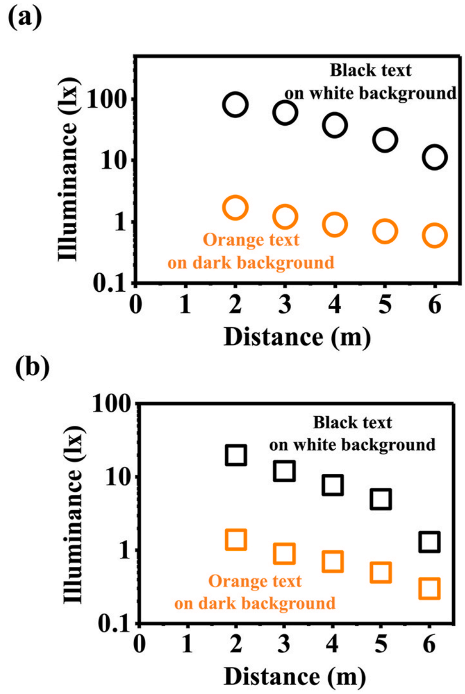

Fig. 9. Screen setting effects on illuminances required for subjects to view the (a) projector and (b) TV at different distances, on basis of the same minimum viewable font-sizes.

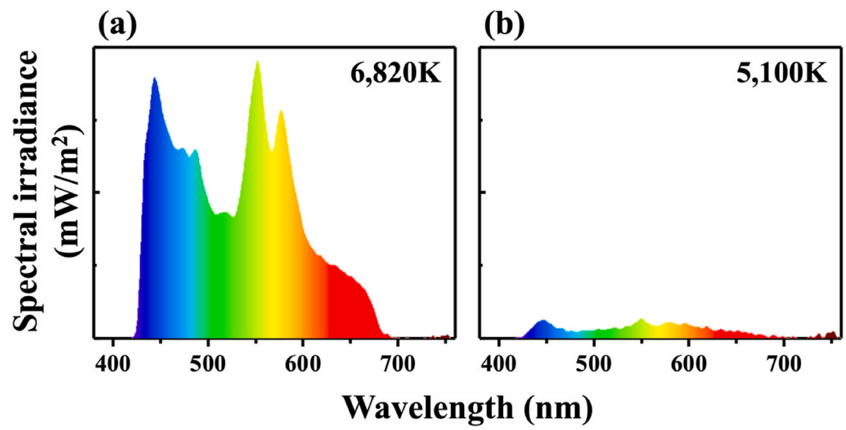

Fig. 10. Spectral irradiances of the projection with the (a) default setting, i.e. a black text on white background, and (b) an orange text on dark background.

font-size on the TV screen, based on the same illuminance. In order to have the same viewing clarity, a much higher illuminance was required for projection. This in turn lead to a shorter permissible time in viewing projection, although which is an indirect light. The null hypothesis could hence be rejected, and the alternative hypothesis was supported.

However, one dilemma revealed herein is that although a lower illuminance at a longer distance could permit a longer viewing time, a much larger font-size would hence be required inevitably. This would require the lecturers to have their power points prepared with sufficiently large fonts.

3.4. Dilemmas and effective intervention I

Fig. 8 shows the screen setting effect on the time permitted for subjects (MPE) to view the projection and TV screen at the different distances. As the setting was switched from the defaulted black text on white background to an orange text on dark background, the MPE was skyrocketed from 0.4 to 54 h upon viewing the same 30 pt font at 2 m for the projection (Fig. 8a). As for the TV screen, it was

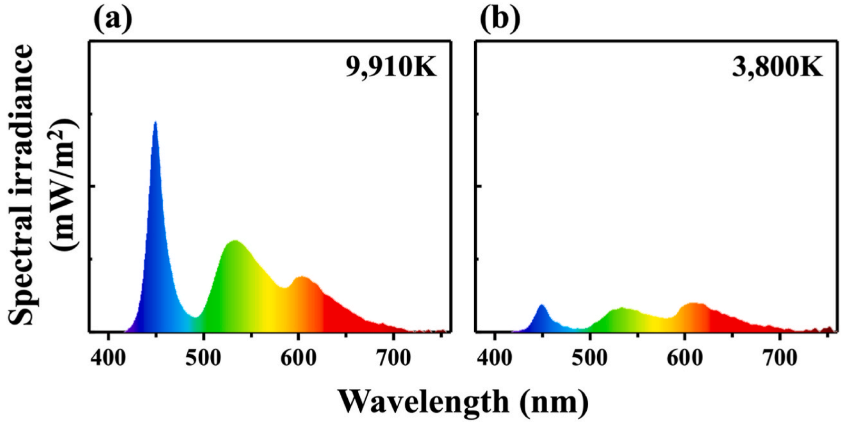

Fig. 11. Spectral irradiances of the TV screen with the (a) default setting, i.e. a black text on white background, and (b) an orange text on dark background.

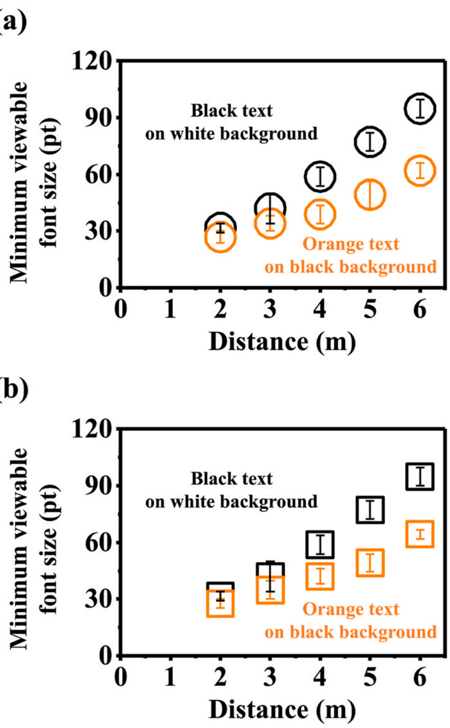

Fig. 12. Screen setting effects on the minimum viewable font size for subjects to view the (a) projection and (b) TV screen at the different distances. The error bars represent standard deviation of the mean.

increased from 1.3 to 83 h (Fig. 8b).

At 6 m, the new setting also helped increase the permitted time drastically. It was increased from 3 to 160 h for the projection upon viewing the minimum viewable 90 pt font (Fig. 8a). It was increased from 12 to 236 h for the TV screen (Fig. 8b).

The marked increase in the permitted viewing time (MPE) should mainly be attributed to the drastic reduction in the illuminance required. For example, it was decreased from 82 to 1.7 lx in viewing the projected 30 pt font at 2 m (Fig. 9a). As viewing the same size font on the TV screen, it was decreased from 20 to 1.4 lx (Fig. 9b). At 6 m, the required illuminance was decreased from 11 to 0.6 lx for the projection and 1.3 to 0.3 lx for the TV screen, based on the same 94 pt font.

The second reason why the permitted viewing time (MPE) was markedly increased can be attributed to a significant decrease in color temperature of the projection and screen. The color temperature was decreased from 6820 (Fig. 10a) to 5100 K (Fig. 10b) for the projection, while from 9910 (Fig. 11a) to 3800 K (Fig. 11b) for the TV screen.

The MPE was improved by 134 folds as the projection viewed at 2 m was changed to orange text on dark background in lieu of the

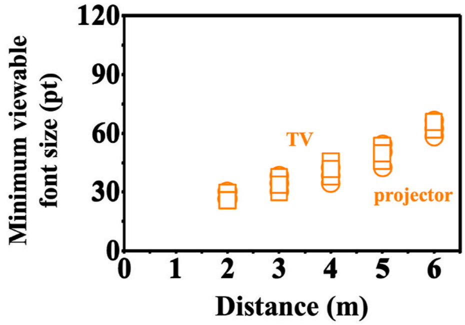

Fig. 13. Scatter plot of minimum viewable font size of 5 subjects upon viewing projection and TV with orange text on dark background.

defaulted black text on white background. Amongst, an improvement of 48 folds was originated from illuminance reduction. Whilst, a minor improvement of 2.8 folds was due to the decrease in color temperature.

At 6 m, the MPE was improved by 53 folds, with 19 folds contributed by the illuminance reduction and 2.8 folds by the decrease in color temperature.

As to the TV, the use of orange text on dark background permitted at 2 m an MPE of 64 folds longer. The illuminance reduction contributed about 14 folds, while 4.5 folds from a lower color temperature.

At 6 m, the improvement was 20 folds, with 4.3 folds contributed by the illuminance reduction and 4.5 folds by the decrease in color temperature.

3.5. Dilemmas and effective intervention II

Fig. 12 shows the screen setting effect on the minimum viewable font size for subjects to view the projection and TV screen at the different distances. As an orange text on dark background was employed on projection, the minimum viewable font-size at 2 m was reduced from 30 to 26 pt, indicating this setting to be capable of providing higher viewing clarity.

At a much longer viewing distance, such as 6 m for example, the viewable font-size could be reduced from 94 to 62 pt as the default setting was changed to that with an orange text on dark background (Fig. 12a).

As to the TV, the use of orange text on dark background could also improve the viewing clarity. The required font-size could be reduced from 30 to 26 pt at 2 m and 94 to 66 pt at 6 m (Fig. 12b).

Fig. 13 shows the minimum viewable font sizes as the default setting was changed to the orange text on dark background. Unlike viewing under the default setting, this eye-friendly setting enabled the subjects to view a much smaller font either the TV or projection. Their smallest viewable sizes are close to each other with a corresponding P value of 0.008 for TV and 0.007 for projection (Table 2).

Indeed, switching the conventional setting, that with a black text on white background, to the highly eye-friendly modes, such as the orange text on dark background studied herein, could help provide better viewing clarity for those sitting at the back rows of a classroom without the use of an oversize fonts.

4. Conclusion

To conclude, we had carried out a quantitative study concerning the time permitted for subjects to view the educational projection and TV screen at varying distance.

It was somewhat surprising to learn the TV screen, that emits a direct light, to permit a longer permissible viewing time than the projector, that emits an indirect light.

Display resolution apparently had played a crucial role in enabling viewing clarity. To view with clarity, a brighter light or larger font is demanded especially for subjects sitting at the back rows. This would hence create an overbrightness issue for those sitting at the front.

Our study suggests that switching from the default setting to a highly friendly mode, such as an orange text on a dark background, would be an effective intervention.

To gain in-depth understanding in further studies, a few more factors are needed to be taken into consideration. They include the effects from the ambient lights with different luminances and color temperatures, display resolution, subject sampling, and subject satisfaction etc.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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