

Effects of Viewing Distance and Local Illumination on Projection Screen Visual Performance

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Abstract: The main purpose of this study is to evaluate the viewing distance and local illumination effects on visual performance while working with a projection screen. Digital projectors have become more popular. However, studies on visual performance using a projection screen are rare. Viewing distance (3, 6, and 9 m) and local illumination (75 and 450 lux) were the independent variables. Each experimental trial took 40 min, including a 10-min proofreading task and a 30-min film watching task. The identification rate for the proofreading task and the attention rate for the film-watching task were collected. The results indicated that viewing distance had a significant effect on the identification rate ($p=0.04$). A reduced identification rate tendency was found with increasing viewing distance. A significantly higher attention rate ($p=0.032$) was found at the local illumination of 450 lux compared to that of the 75 lux. We suggest that (a) a shorter viewing distance (correspond to 25~50 min arc of visual angle) is suitable for performing text-reading on a projection screen; (b) if the visual tasks with a projection screen mostly contain video and voice, the viewing distance will have little effect on performance; and (c) the local illumination on the audience's work area should be around 450 lux while watching a film with a projection screen. Actual or potential applications for this research include recommendations for proper viewing distance and local illumination for projector users.

Keywords: Vision and lighting; information displays; office ergonomics; mental fatigue; attention and vigilance.

1. Introduction

The rapid development of digital science and technology has brought the digital projector to the forefront of teaching aids. Digital projector use has increased immensely – both in schools and companies. More people rely on a digital projector to brief plans, teach students, present papers, demonstrate prod-

ucts, see films or hold meetings and conferences.

A projection screen can be simultaneously watched by a large audience in a classroom or meeting room. The viewing distance from the eye to the projection screen (more than 2 m) is markedly longer than those suggested for a visual display terminal (VDT). As

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we know, the eyes assume a vergence resting position, approximately corresponding to a distance of 1 m, without a fixation stimulus or in a dark visual field [1-2]. When the target is closer (less than 1 m), the extra-ocular muscles must exert stronger ocular force to turn the visual axes toward each other. This is considered the reason why people perceive visual fatigue near computer screens [3-4]. Those who have a weak vergence system because of a smaller vergence gain tend to prefer viewing distances longer than 50 cm to avoid the visual fatigue induced by near screens [5-6]. Consequently, people who watch a projection screen may have little eyestrain induced by the screen proximity because of the obviously farther viewing distance.

Different viewing distances produce different subtended visual angles (in min arc) for a given target height presented on the screen. When the viewing distance is farther, the visual angle of a given text height is smaller, which makes the text appear smaller. Previous studies have indicated that the smaller visual angle of the character height produces lower legibility, resulting in worse reading performance with computer screens [7-10] and smaller electronic books [11-12]. In this near vision visual task condition the viewing distance is relevant as a stimulus for vergence and accommodation. This is not the case for the far vision condition (more than 2 m), where accommodation and vergence are more or less at rest. The question that remains is whether different sizes of text (in terms of visual angle) have an effect on reading performance in the far vision condition. The text size effect issue was investigated at a constant letter size in mm, while varying the viewing distance in this study. This was done because large screens are for large audiences who sit in different positions.

In addition to the viewing distance, ambient illumination has been confirmed to be relevant in VDT work performance. Although Human Factor Society [13] recommended that the ambient illumination of 200 to 500 lux

was suitable for VDT tasks, Shieh and Lin (2000) indicated that the subjects had significantly better visual identification performance under the 450 lx condition than at the 200 lx level, particularly for the liquid crystal display (LCD) [14]. Conversely, Xu and Zhu (1990) found that visual performance decreased as the ambient illumination increased during work with the cathode ray tube (CRT) display [15]. This is because of the differences in optical characteristics between CRTs and LCDs. In terms of the newly developed electronic paper (E-paper) displays, Shieh and Lee (2007) suggested that the acceptable lighting level was around 700 lux for E-paper because of its reflective characteristic, requiring higher ambient illumination to reflect the message on displays [16]. Furthermore, Lin, et al. (2009) studied the legibility and visual fatigue for simulated flexible E-paper under three ambient illumination conditions (200, 1500, and 8000 lux) and found that ambient lighting of 1500 lux was more appropriate than the other two conditions [17].

Although substantial literature exists concerning the ambient illumination effect on near-vision performance with VDTs and E-paper displays, there is still little research investigating the illumination effects on performance for watching from a projection screen. As we know, higher ambient illumination would deteriorate the luminance contrast ratio between the target and its background and thus reduce target visibility on the projection screen. For this reason, people usually turn off the lights or draw the curtains to decrease the ambient illumination to get a clear picture on a projection screen. However, it may be too dark to read or write on the table. A compromise solution to this problem is to adopt the localized general lighting method. The question that remains is whether the performance differs among different levels of local illumination.

The intent of this study was to investigate the effects of viewing distance and local illumination on visual performance with a

projection screen. Two hypotheses are proposed: (1) performance will be enhanced with a shorter viewing distance (i.e., greater viewing angle), and (2) performance will decrease when watching the projection screen using a higher level of local illumination. The experimental work included Chinese text proof-reading and film-watching tasks. The proof-reading task was aimed at collecting the text identification performance. The film-watching task was designed to obtain the viewer's attention performance.

2. Methods

2.1. Subjects

The 30 participants (15 men, 15 women) had a mean age of 22.4 years (range = 20 to 24 years) and normal or corrected-to-normal vision with a visual acuity of 1.0 or better (decimal units). Prior to participating in this study, the experimental process was explained in detail to all participants. They were then requested to fill out a written consent form to indicate their awareness of the experimental goals and their willingness to participate in this study. Each participant was paid \$ 4.00 (U.S.) per hour for performing the experimental trials.

2.2. Apparatus

The experimental stimuli were produced using a notebook computer (IBM X31), and presented using a digital projector (TOSHIBA TDP-T91) with a brightness of 2200 ANSI lumens and a resolution of 1024×768 pixels. The visual stimuli were projected onto a projection screen (178×137 cm). The CIE chromaticity coordinates for the screen color for the notebook computer were measured with a Minolta Color Analyzer CA-210 (Japan). The subjects' visual acuity was measured using the E type visual acuity test (CK-M-9). Six lamp stands were used to control the local illumination conditions in the

laboratory. Each lamp had an electricity-saving light bulb with a color temperature of about 6500 K. A palmtop illuminometer (YichangLM-81LX) was used to measure the illumination level on the worktable.

2.3. Experimental Design

The viewing distance and local illumination were the independent variables. The viewing distance was defined as the distance from the center of the projection screen to the subject's eyes. We used viewing distances of 3, 6, and 9 m. The Chinese character height was designed as 43.45 mm presented on the projection screen. Thus viewing distances of 3, 6, and 9 m corresponded to 50, 25, and 16.6 min arc of text size, respectively. Two seats were arranged for each viewing distance level. Figure 1 shows the workplace arrangement in the laboratory. The subjects were not allowed to adjust their seating positions to maintain constant viewing distance during the experiment.

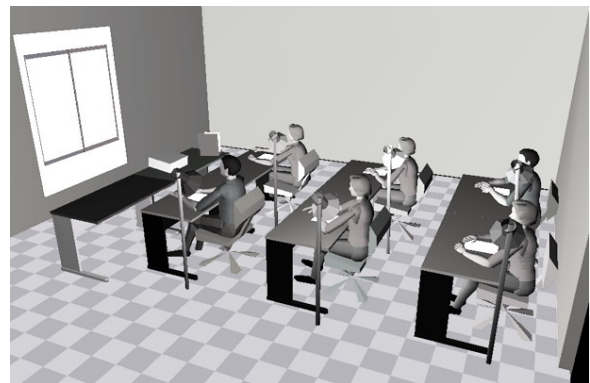


Figure 1. The workplace arrangement used in the experiment.

Two levels of local illumination were employed: 75 lux (which represent a dark environment) and 450 lux (which is the normal lighting level for ordinary office). The local illumination was defined as the illumination level on the working table for the subjects. Six lamp stands, placed beside the work tables, were carefully adjusted to control the table illumination according to the experi-

mental conditions. Lampshades were used to prevent the local illumination from producing glare and altering the contrast condition on the screen.

Six treatments (3×2) comprised the viewing distance and local illumination combinations. Thirty participants were randomly divided into three groups with each group having 10 persons, gender balanced. Each group was randomly assigned to each of the three viewing distance levels (between-subjects factor). Every subject randomly performed the two (75 and 450 lux) local illumination treatments (within-subject factor) on two different days.

2.4. Experimental Tasks and Setup

Each experimental trial took 40 minutes to perform two kinds of visual work with the projection screen. The experimental tasks contained a 10-min proofreading task and a 30-min film-watching task.

10-min proofreading task. 20 pages of Chinese text were sequentially presented on the projection screen one by one for 30 sec per page in the proofreading task. Each page was designed to have left and right regions, as shown in figure 2. These two regions presented approximately the same text, but the right region had eight errata within the text. The characters per region were arranged in eight lines, with about 12 characters per line. The subjects were asked to identify the errata presented on the projection screen as much as they could. They should write down the found errata on a given sheet. To maintain work motivation, subjects were paid an extra \$ 2.00 for individual performance above the average level for all participants.

Several understandable articles were selected as materials for the proofreading tasks. These articles were randomly assigned to different experimental trials. The characters were displayed with the font 'KaiU type' in 24 point. The actual height of the characters pro-

jected on the screen was 43.45 mm. The inter-character spacing was 12.82 mm and interline spacing was set at 65.98 mm, as shown in figure 2.

30-min film-watching task. Immediately following the 10-min proofreading task, subjects were required to continuously watch a film for 28 minutes. At the end of the film, an attention test about the scenario in the film was completed by the subjects within 2 minutes. Eight questions were presented simultaneously on the projection screen. Each subject answered them on a sheet provided.

In order to maintain work motivation, subjects were also paid an extra \$ 2.00 for individual performance above average level for the 30 participants. A who-dun-it serial was selected as the material for the film-watching task. These materials were divided into several short films, 28-min long each. These short films were randomly assigned to different experimental trials.

Experimental setup. The digital projector was positioned on a table 76 cm in height. The horizontal distance from the projection screen to the lens of the projector was 240 cm. The elevation angle of the projector base was 11 degrees with respect to the horizontal axis. The actual size of the outline border projected onto the screen was 950 mm high and 630 mm wide. The whole projection scope was 1020 mm high and 1350 mm wide. The work tables were 76 cm high, 50 cm wide and 199 cm long. The illumination on the projection screen was controlled at 50 lux when the digital projector was not turned on. Table 1 shows the measured CIE chromaticity coordinates (x , y) and black and white luminance on the screen of the notebook computer. The light output of the digital projector was measured using the ANSI Lumen standard. The projection screen was maintained at 1880 ± 10 ANSI Lumen. All of these set-up parameters were fixed in all of the experimental trials.

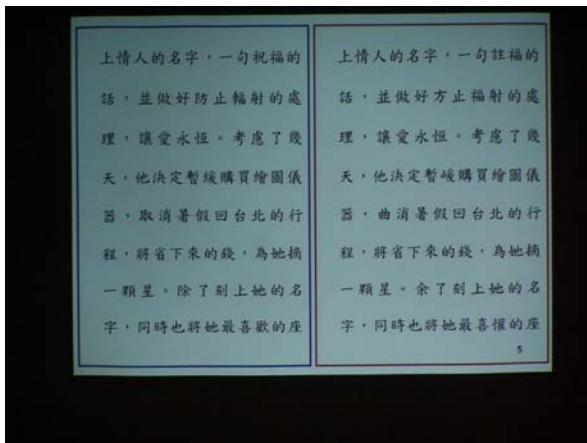


Figure 2. The layout of the slides projected on the screen for the proofreading task.

Table 1. The Measured CIE Chromaticity Coordinates (x, y) and Luminance of White and Black on the Notebook Computer Screen

Coordinate	White	Black
x	0.3181	0.2453
y	0.3312	0.2492
L(cd/m ²)	99.83	0.32

2.5. Dependent Measures

Each experimental trial collected two dependent variables, the proofreading performance and film-watching performance. The data collection approaches are described in the following:

Proofreading performance was collected in terms of the identification rate, which was the ratio of the number of correctly found errata to the total given errata in the proofreading task. Each proofreading task had 20-pages of text to be read. Each page contained about 180 Chinese words. Since each page was presented on the projection screen for only 30 seconds, the subjects had a little time pressure to proofread the entire text during the 10 minutes. In this way, we did not need to collect the completion time for the proofreading task.

Film-watching performance was collected in terms of the attention rate, which was defined as the ratio of the number of correctly answered questions to the total questions in the attention test. Each attention test included eight simple questions regarding with film scenario. These questions were designed to estimate the attention performance of the subjects, instead of measuring memory performance. For examples, 'Who dropped from the top of the hotel? (1) GARY, (2) TONY, (3) GIGI' and 'How much money did LANCHIN originally want to get? (1) 100,000, (2) 200,000, (3) 300,000'. If the subject did not miss the story in the film, he or she could easily answer the questions.

2.6. Experimental procedure

Preliminary phase. To evaluate the differences among the three subject groups (named A, B, and C), all of the subjects performed a preliminary test at the same viewing distance (6 m) and under the same local illumination condition (200 lux). After the participants had assumed a comfortable sitting posture, the Chinese text was presented on the projection screen for 30 seconds per page. Participants were asked to identify the errata in the text as much as they could and write down the errata found on a sheet provided. After 10 min of proofreading the film-watching task began. The subjects were asked to continuously watch the film for 28 min. At the end of the film, eight questions, simultaneously presented on the screen, were answered by the subjects in two minutes. After the preliminary test, the subjects made an appointment for the normal experimental trials on the other two days.

Normal experimental phase. Groups A, B, and C were assigned to viewing distances of 3, 6, and 9 m, respectively. Participants were seated with the assigned viewing distance to the projection screen during the normal experimental trials. The experimental procedure of the trials was the same with that

of the preliminary test. Every trial also included a 10-min proofreading task and a 30-min film watching task. Every subject should perform two 40-min experimental trials on separately two days under two different local illumination conditions (75 and 450 lux), respectively. The trial order was randomized.

2.7. Data analysis

SPSS 10.0 Statistical Software was used for the collected data analyses. Before conducting the analysis of variance (ANOVA), the normality assumptions for the data distribution were checked using Kolmogorov-Smirnov Goodness-of-Fit Test. The level of significance was set at $p < 0.05$. If the data distribution was normal, a mixed-factor ANOVA was used to determine the Viewing Distance effects (three levels, between-subjects) and Local Illumination (two levels, within-subject) on the performance data, with the Turkey's honestly significantly different (HSD) test for post-hoc pairwise comparisons. Effects were considered 'significant' when $p \leq 0.05$. If the responded data distribution was not normality, a proper non-parametric test should be used to evaluate the studied main effects.

3. Results

Table 2 shows the descriptive statistics (mean \pm standard deviation) of each dependent variable for the three subject groups in the preliminary test. The unpaired Student t test results showed that the subject group had no significant effect on the identification and attention rates. These results merely confirmed that the group effect would not confound the between-subject factor (viewing distance) in the following normal experiment.

For the normal experiment, mean and standard deviation values of the identification rate and attention rate for each independent

variable level are shown in table 3. The identification rates were 73.5%, 64.6%, and 57.8% for the viewing distances 3 m, 6 m, and 9 m, respectively. There was a tendency to a reduced identification rate in the proofreading task with increasing viewing distance. All p -values obtained from the Kolmogorov-Smirnov Z test exceeded 0.05, supporting the normality assumptions for the following analyses of variances (ANOVAs). Based on the ANOVA results, identification rate was significantly affected by viewing distance, $F(2, 27) = 3.630$, $p = 0.040$. The two local illuminations did not reveal significantly different identification rates, $F(1, 27) = 0.360$, $p = 0.553$. The interaction effect was not significant on identification rate, $F(2, 27) = 0.391$, $p = 0.680$, suggesting that the viewing distance and local illumination effects were independent.

Figure 3 illustrates the Turkey test results for the difference among the three viewing distance levels. These post-hoc test results showed a significant difference between two conditions: identification rate varied from the 3 m condition ($73.5\% \pm 12.2$) to the 9 m condition ($57.8\% \pm 15.9$), $p = 0.032$. No significant difference emerged between the 3 m and the 6 m conditions, $p = 0.299$, as well as between the 6 m and the 9 m conditions, $p = 0.481$.

The mean attention rate during film-watching tasks significantly increased from 72.5% at 75 lux to 81.7% at 450 lux. Based on the ANOVA results, local illumination had a significant effect on attention rate, $F(1, 27) = 5.198$, $p = 0.031$. However, viewing distance effect was not significant on attention rate, $F(2, 27) = 1.113$, $p = 0.343$. The interaction effect was also not significant for attention rate, $F(2, 27) = 0.333$, $p = 0.720$.

Table 2. Preliminary Test Results

Group	n	Identification rate (%)	Attention rate (%)
Group A	10	66.3 ± 11.7	73.0 ± 14.4
Group B	10	64.9 ± 13.3	74.4 ± 14.3
Group C	10	65.8 ± 10.9	72.1 ± 12.3

Table 3. Dependent Variable Results under Each Independent Variable Level

Independent variable	n	Identification rate (%)	Attention rate (%)
Viewing distance			
3 m	20	73.5 ± 12.2	79.4 ± 14.8
6 m	20	64.6 ± 11.3	78.1 ± 14.0
9 m	20	57.8 ± 15.9	73.8 ± 15.1
Local illumination			
75 lx	30	64.9 ± 15.2	72.5 ± 15.2
450 lx	30	65.7 ± 14.2	81.7 ± 12.6

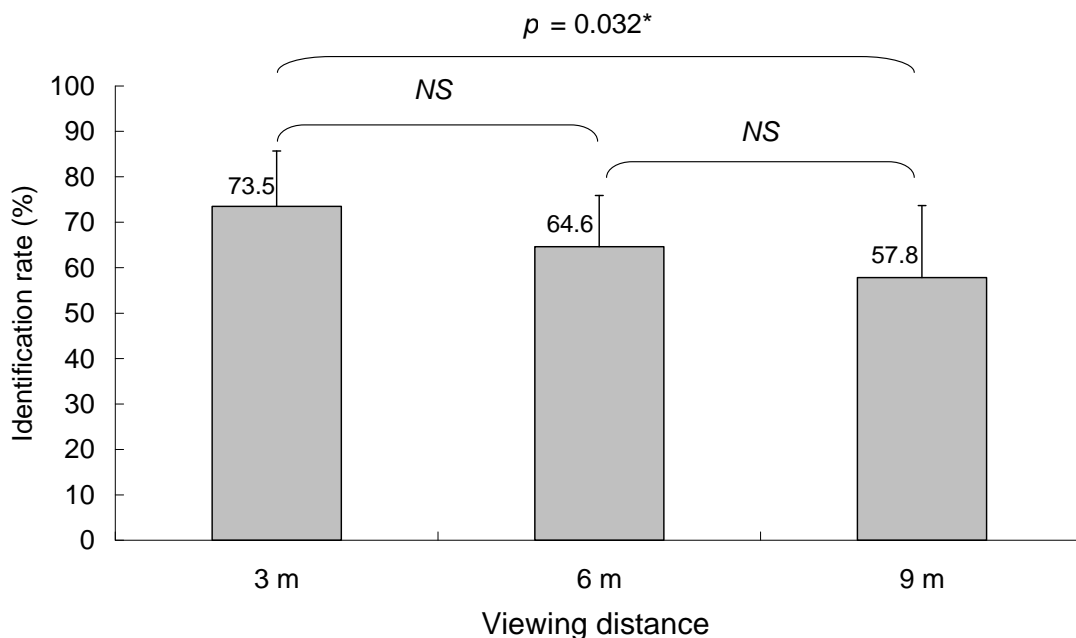


Figure 3. Identification rate results in the proofreading tasks under the three viewing distances. Comparison was made with standard post-hoc tests (Turkey method). * is significant at $\alpha = 0.05$; NS is not significant.

4. Discussion

Our participants were able to assume a normal sitting posture, the projection area has a dark illumination level (50 lux), and the projector produced clear text and images on a bright-background screen. Further, viewing distances and the local illuminations were within the usual range of those in classrooms or meeting rooms. Based on these conditions, our experimental tasks resemble typical viewing conditions for work or study with a projection screen. The following sections separately discuss the important factors that affected the proofreading and film-watching performance.

4.1. Proofreading Performance

The proofreading tasks were performed using a big projection screen. This is different from VDTs and computer screens. This study found that identification rate is a function of the viewing distance, but not a function of the local illumination. Based on the experimental design, the viewing distances 3, 6, and 9 m corresponded to 50, 25, and 16.6 min arc of text size, respectively. Therefore, these results strongly suggest that when the text size (in terms of visual angle) is larger, higher identification rate is made. However, the use of local lighting adds little to the probability of correct performance in proofreading tasks. In other words, the text size effect is significant on proofreading performance even in the case of far vision (3 to 9 m).

Therefore, if the text legibility is the most important for watching a projected context, shorter viewing distance (correspond to 25~50 min arc of visual angle) was proposed to be adopted. The post-hoc test results showed that a significant difference in proofreading performance between 3 and 9 m conditions was found, but no significant difference emerged between 3 and 6 m conditions, as well as between 6 and 9 m conditions. This result implies that differences between text

sizes are often not significantly apparent yet until the size differences become quite large. This result supports the previous findings [18-19] although their studies were regarding print. With regard to reading from computer-displayed text, the text size effect has also been confirmed to be significant on legibility or reading performance [8-10, 20]. Moreover, some recent studies concerning reading from Chinese electronic books (e-books) also have similar conclusions [11-12].

4.2. Film-Watching Performance

The attention rate for watching a film shows a trivial difference among the viewing distances. This can be explained by the task characteristics of watching a film. The visual stimuli of a film were mostly dynamic images instead of text. Participants could easily receive the story in the film by listening to the audio without reading the subtitles. These are the reasons why subjects had similar film-watching performance among different viewing distances. In summary, when using a projection screen to watch a video, the attention performance will be similar at different viewing distances within a large visible range.

The film-watching performance shows a large and significant increase when the local illumination is brighter. This result strongly suggests that adequate local illumination (e.g., 450 lux) results in increased performance compared to a dark environment (75 lux). This result was consistent with the findings of Shahnava and Hedman's study [21], which suggested keeping the ambient illumination levels in the range of 300 to 500 lux, rather than reducing them to lower levels. Based on the experimental settings, it seems that the lamps shown would be very unlikely to have any effect on screen viewing conditions. Therefore, the change in performance shall be mostly due to different local lighting sources. Subdued local lighting sources (75 lux condition), representing a darker ambient illumina-

tion, produced a higher luminance ratio between the screen and surroundings that could cause a transient adaptation problem, disability or a discomforting glare. Because the total dark adaptation process takes about 35 to 40 min; the attention performance during the trial may be affected by changes in eyes' sensitivity to the dark environment. These problems may be the reasons why the darker condition (75 lux) led to worse film-watching performance than the brighter condition (450 lux). We therefore suggest that it is not advantageous to maintain darkness throughout the room when watching videos from a projection screen.

4.3. Limitations and Future Research

This study confirmed that the text size effects are significant in proofreading performance in the far vision condition. Although this finding is consistent with those of the VDT-based studies, announcing that all of the suggestions for VDTs can completely be applied in using a projection screen is premature. Some other factors such as screen color, brightness, resolution and luminance contrast were not discussed in this study. These factors may result in different performance between a projection screen and a VDT. Furthermore, when watching a projection screen, the head elevation angle is usually upward, which is markedly different from using a VDT (head upright or downward). Therefore, further research is required to confirm whether previous study results on VDTs can be successfully applied in using a projection screen.

The text size effect was investigated at a constant letter size in mm, while varying the viewing distance in this study. This is because of a potentially variety of viewing distance for using a projection screen. However, the issue of optimal Chinese angular letter size could be better investigated at a constant viewing distance, while varying the letter size in mm. In this way, a previous study [20] suggested that the Chinese character height should be at least 20.39 min arc for 100% legibility while

reading from a VDT. Furthermore, in terms of using a Chinese e-book display, a larger visual angle of 33 min arc has been recommended [11], because the used e-book display has less luminance contrast than general VDTs. Consequently, further research is required to investigate the legibility threshold for reading from a projection screen, since the optical characteristics of a projection screen is much different from the VDT and e-book display.

5. Conclusions

This paper deals with ergonomic issues in using a projection screen that has not been given much recent attention. The significant effects of viewing distance and local illumination found in this study were similar to those discovered from VDT-based studies. The proofreading results suggested that a shorter viewing distance (correspond to 25~50 min arc of visual angle) is suitable for performing text-reading on a projection screen. However, if the visual tasks with a projection screen mostly contain video and voice, the viewing distance will have little effect on performance. Based on the film-watching results, it should be noted that the adequate local illumination (e.g., 450 lux) had a significantly higher performance than the lower condition (75 lux). Consequently, to enhance an audience's attention in watching a film with a projection screen, the local illumination on the audience's work area was strongly recommended to be around 450 lux.

The local lighting was well controlled in this study so as to prevent altering the luminance and contrast conditions on the projection screen. Therefore, it is reasonable that little difference in proofreading performance was found between the 75 lux local illumination and the 450 lux condition. However, the proofreading task lasted only 10 min in this study. We suggest that when the brightness and contrast ratio of the screen are adequate to produce good legibility, local illumination would have little effect on read-related per-

formance for a short period (10 min). However, further research is required to confirm this suggestion in the case of prolonged reading from a projection screen.

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