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Relationship Between Ambient Illumination and Psychological Effects for Television Viewing

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Abstract. *In the present article we analyze the relationship between ambient illuminations and psychological effects while viewing still images displayed on a liquid crystal display (LCD). In two experiments, six kinds of images were displayed on the LCD under different brightness of illumination conditions and were rated by 15 observers, and four kinds of images were displayed under different colors of illumination conditions and were rated by 27 observers. The semantic differential method and factor analysis method are introduced to analyze the subjective evaluation. It is shown that comfort in viewing is enhanced according to the increase in brightness of the ambient illumination. Particularly, realistic sensation and dynamism are enhanced while retaining comfort with the illumination behind the LCD. It is also shown that realistic sensation and dynamism and comfort are enhanced under the illumination of average chromaticity of displayed images. © 2011 Society for Imaging Science and Technology.*
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INTRODUCTION

Recently, technological progress and different lifestyles have led to changes in the everyday television (TV) viewing environment. On the technical side, flat panel displays (FPDs), such as liquid crystal displays (LCDs) and plasma display panels, are significantly larger and thinner than before and have become widely used instead of traditional CRT displays. Their popularity justifies investigations of the psychological effect of large-sized FPDs and viewing conditions. Masaoka et al. reported that realistic sensation and dynamism increase with the increasing size of an FPD and the number of pixels.[1] Furthermore, The ITU-R has studied evaluation methods for many years and published recommendations of the standards of viewing television in a room environment.[2,3] These recommendations describe methods for the subjective image quality of a display device under constant viewing conditions, such as the room illumination and chromaticity behind the display device in the home environment.

At the present time, new dimensions such as the colors of ambient illumination have been added to displays to further enhance the viewing experience. Improved spatial and temporal resolution, more saturated primaries and lower power consumption, and light emitting diode (LED) based lighting systems can be used to design more attractive lighting atmospheres. Consequently, this has generated a rise in

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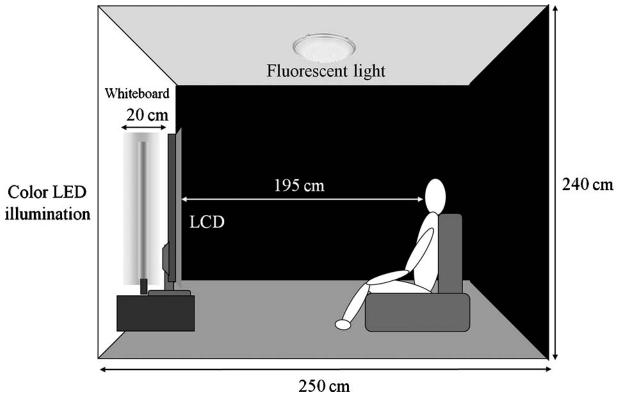

Figure 1. Experimental setup.

commercial products and proposals to actively control the lighting environment around a display.[4,5] For example, the color of the light surrounding a TV that changes in accordance with the color of the content shown on the display may enhance the experience of watching TV. For improving the realistic sensation while viewing FPDs, some studies have changed ambient illumination using attributes of displayed images, such as color and contrast.[6,7]

Changes in ambient illuminations while viewing a display significantly affect human impressions. In general, we experience highly realistic sensation and fatigue in a dark room and less realistic sensation and low fatigue in a bright room. Thus, it is important to analyze the availability of ambient illumination conditions while keeping high realistic sensation, high dynamism, and low fatigue. However, psychological impressions caused by the combination of displayed images and ambient illuminations have not been previously clarified. In this article, we analyze the relationship between ambient illuminations and psychological effects while viewing a display. In our psychological experiments, observers watched the displayed images under different ambient illumination conditions. The observers selected various adjective pairs from those prepared based on the semantic differential (SD) method.[8,9] By applying factor analysis to the data, we clarified the psychological effects caused by ambient illumination.

SUBJECTIVE EVALUATION

In the psychological experiments, we used the SD method to analyze the psychological effects caused by changing the ambient illumination conditions. Observers rated the impression of the displayed images under the following two different illumination conditions:

(1) Experiment 1: changing the brightness of ambient illumination around a display.
(2) Experiment 2: changing the colors of ambient illumination around a display.

Experimental Setup

Figure 1 shows the experimental setup in a living room of approximately $2.5 \times 3\ \mathrm{m}^2$. Two kinds of illuminations were employed in our experiment. One was a color LED illumination mounted behind the display. Since the light source was not directly visible, only the light reflected from a whiteboard was visible. Each LED illumination contains three primary LEDs: red, green, and blue. Its illuminance and colors can be controlled by adjusting the mixing ratio of RGB components. The other illumination was a fluorescent light on the ceiling whose illuminance was modulated by a controller. The entire environment was illuminated in daylight color (color temperature: 5000 K). The display device employed was a 52 in. wide screen LCD-TV (Sharp LC-52RX1W) which was positioned at a distance of 20 cm in front of the whiteboard. This LCD-TV has 1920×1080 resolution. The video screen was set at “standard mode.” The viewing distance was 195 cm, which corresponded with the distance of three times the screen height (3*H*) of the LCD.[3]

		Neither nor			
Prefer					Dislike
Sober					Colorful
Realistic					Non-realistic
Uncomfortable to watch					Easy to watch
Soft					Hard
Brilliant					Cloudy
Comfortable					Tiring
Quiet					Noisy
Bright					Dark
Beautiful					Dirty
Light					Heavy
Warm					Cool
Loose					Tight
Cheerful					Depressing
Stereoscopic					Planar
Tense					Relaxed
Dynamic					Static
Sharp					Mild
Bustling					Desolate
Good					Bad

Figure 2. Adjective pairs for psychological experiments.

Evaluation Method

In our experiment, the SD method[8,9] was employed to analyze the subjective evaluation. Figure 2 shows 20 adjective pairs (20 bipolar word pairs) for analyzing the psychological effects caused by the ambient illuminations. Initially, a pilot study was performed to collect adjective pairs that people use to describe the impressions of a displayed image. In total, approximately 100 different adjective pairs used for image quality evaluation and visual perception evaluation were collected. To reduce the large list of words, words that were mentioned only once were removed. Next, words with similar meaning were grouped and from each group few words were selected to generate a practical list of words. Finally, 20 suitable adjective pairs for our experiment were selected. All experiments including the pilot study were conducted using Japanese adjective pairs for convenience in conducting the experiments.

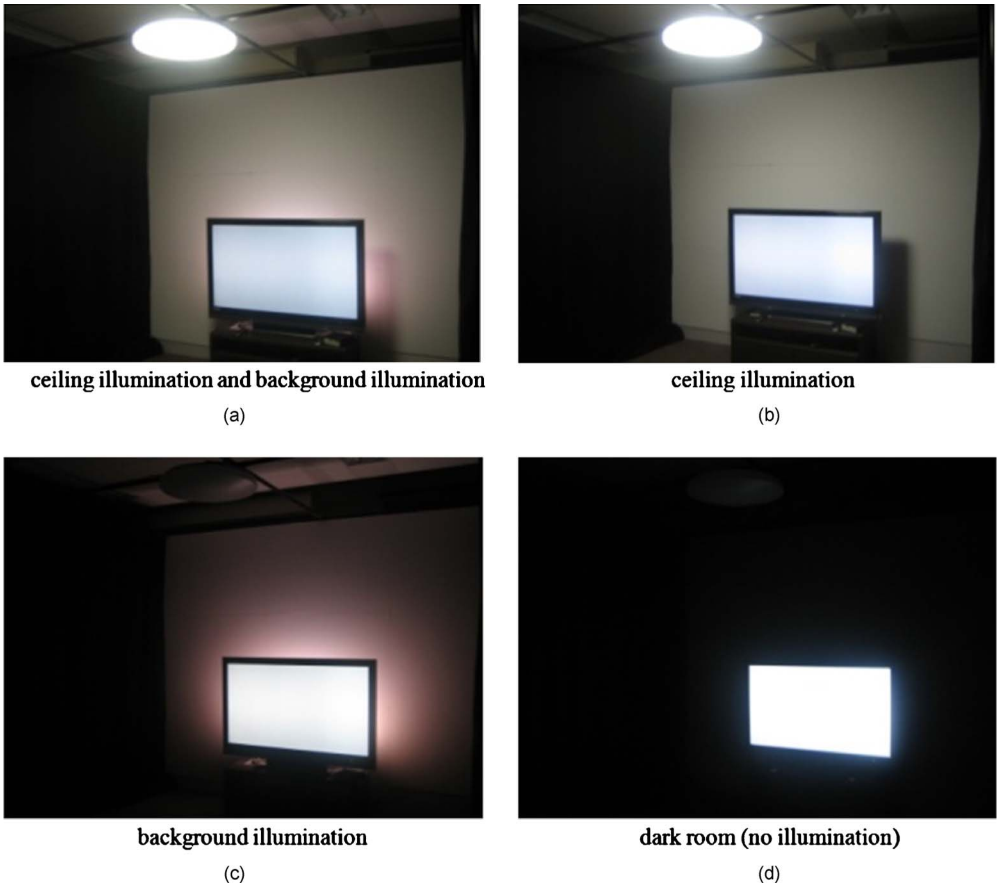

Figure 3. Ambient illumination conditions in experiment 1: (a) ceiling illumination and background illumination, (b) ceiling illumination, (c) background illumination, and (d) dark room (no illumination).

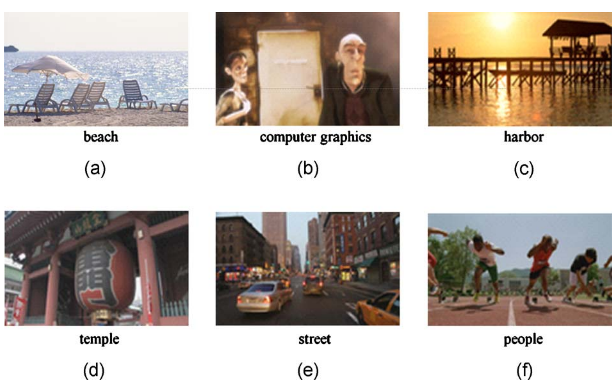

Figure 4. Displayed still images in experiment 1: (a) beach, (b) computer graphics, (c) harbor, (d) temple, (e) street, and (f) people.

The 20 adjective pairs were used to develop a questionnaire. The questionnaire contained a list of the words. Each observer rated the impressions of a displayed image under various ambient illumination conditions. The experimental results were transformed into the values from 5 (positive) to 1 (negative) to apply factor analysis.

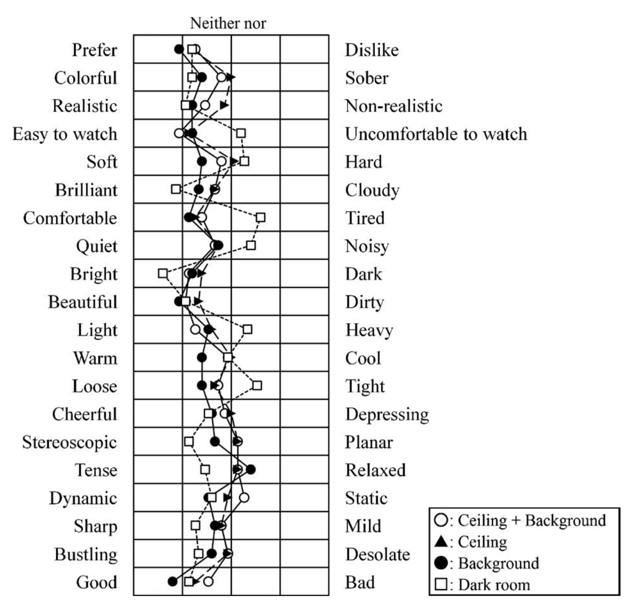

Figure 5. SD profiles of experiment 1.

EXPERIMENT 1: CHANGING THE BRIGHTNESS AROUND A DISPLAY

Experimental Methodology

Figures 3 and 4 show the ambient illumination conditions and still images displayed in experiment 1, respectively. The horizontal illuminance under the fluorescent ceiling light was approximately 300 lx, measured 85 cm above the floor, and the illuminance on the whiteboard under the back-

Table I. Factor loadings for experiment 1.

		First factor	Second factor	
Adjective pairs		Realistic sensation and dynamism	Comfort	Independent factor
Realistic	Non-realistic	0.883	0	0.217
Beautiful	Dirty	0.839	0.127	0.28
Stereoscopic	Planar	0.838	−0.182	0.265
Colorful	Sober	0.796	−0.253	0.302
Brilliant	Cloudy	0.794	−0.227	0.318
Good	Bad	0.769	0.166	0.38
Prefer	Dislike	0.765	0.234	0.36
Bustling	Desolate	0.761	−0.191	0.384
Cheerful	Depressing	0.629	−0.275	0.529
Dynamic	Static	0.604	0	0.631
Warm	Cool	0.48	0.202	0.729
Relaxed	Tense	0	0.727	0.471
Easy to watch	Uncomfortable to watch	0.224	0.71	0.446
Comfortable	Tired	0	0.679	0.539
Loose	Tight	0	0.614	0.616
Sharp	Mild	0.18	−0.556	0.658
Quiet	Noisy	−0.383	0.531	0.572
Light	Heavy	−0.205	0.492	0.716
Soft	Hard	0.136	0.465	0.765
Bright	Dark	0.355	−0.401	0.713
Contribution ratio		33.1%	17.5%	
Cumulative contribution ratio (%)		33.1%	50.6%	

ground illumination was approximately 60 lx. Color temperatures of both illuminations were set to 5000 K. The illuminance on the screen of the LCD was less than 3 lx in a dark room (no illumination). The illumination conditions changed in two ways [Fig. 3: (a)→(b)→(c)→(d) and (d)→(c)→(b)→(a)].

Fig. 4 shows the displayed still images. We used six stimuli consisting of a beach, computer graphics image, harbor, temple, street, and people. They were presented in random order for one minute under each illumination condition (each image was displayed for 10 s). After showing all images, observers rated the impressions and filled in the SD evaluation sheet (see Fig. 2) while the stimuli were repeatedly shown for another 1 min. The observers rated the images under the four illumination conditions shown in Fig. 4. An 18% gray image was displayed for approximately 30 s after each illumination condition.

Experimental Observers

Eleven males and four females participated in experiment 1. Their ages ranged from 22 to 33 years old. They were students of imaging science at the university and had no prior knowledge of the experimental setup. All participants reported normal or corrected to normal vision. They had filled in an SD evaluation sheet for practice before the experiment.

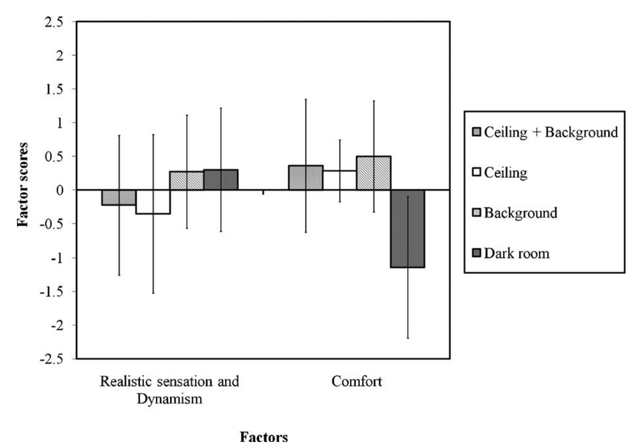

Figure 6. Factor scores of experiment 1. The error bars correspond to 1 standard deviation of the mean.

Results and Discussion

Figure 5 shows the SD profiles of the experimental results after changing the brightness of the ambient illuminations. Each profile of the illumination condition represents the average values of the rated value for each adjective pair. The highly rated values include “easy to watch,” “comfortable,” “quiet,” and “relaxed” under the ambient illuminations, and

Table II. Background illumination conditions in Experiment 2: (a) illumination conditions for four images, (b) additional illumination conditions for beach image.

(a)

Illuminance of white board (xy chromaticity value)	Illumination color of the background of display: White	R: Low chroma	G: Low chroma	B: Low chroma	Average color of image	Dark room
(a) Beach	58.2 lx (0.310, 0.279)	57.6 lx (0.484,0.273)	75.1 lx (0.276,0.442)	36.5 lx (0.203,0.171)	58.2 lx (0.310,0.279)	
(b) Blue sky					45.5 lx (0.217,0.202)	
(c) Greenery					12.5 lx (0.380,0.540)	
(d) Sunset					27.4 lx (0.544,0.384)	

(b)

Illuminance of white board (xy chromaticity value)	Illumination color of the background of display: R: High chroma	G: High chroma	B: High chroma	C: Low chroma	M: Low chroma	Y: Low chroma
(a) Beach	43.7 lx (0.702,0.298)	79.4 lx (0.184,0.709)	19.4 lx (0.140,0.032)	35.1 lx (0.202,0.211)	57.7 lx (0.295,0.194)	85.6 lx (0.395,0.402)

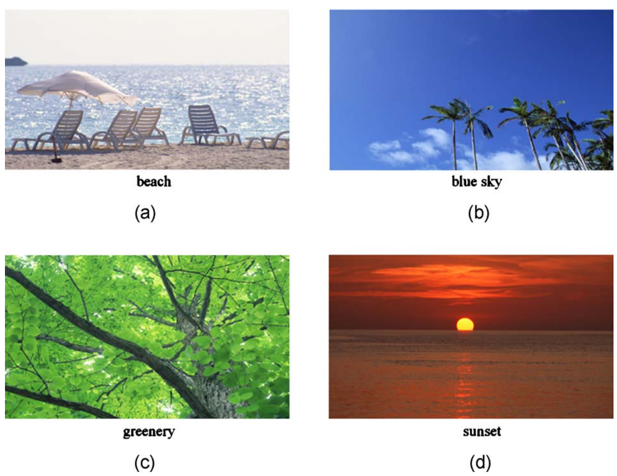

Figure 7. Displayed still images in experiment 2: (a) beach, (b) blue sky, (c) greenery, and (d) sunset.

"brilliant," "tired," "bright," "stereoscopic," and "tense" in the dark room (no illumination).

Table I shows the factor loadings of each adjective pair by factor analysis with the varimax rotation and maximum likelihood methods. The cumulative contribution ratio of the first and second factors is 50.6%. We call the first factor "realistic sensation and dynamism," derived from the evaluation words "realistic," "beautiful," and stereoscopic. The second factor is called "comfort," derived from the evaluation words relaxed, easy to watch, and comfortable.

Figure 6 shows the factor scores for realistic sensation and dynamism and comfort. The factor score of comfort for the ambient illumination condition is higher than the score for the dark room condition. Therefore, comfort is considered to be a factor depending on the illumination around the display. The factor score of realistic sensation and dyna-

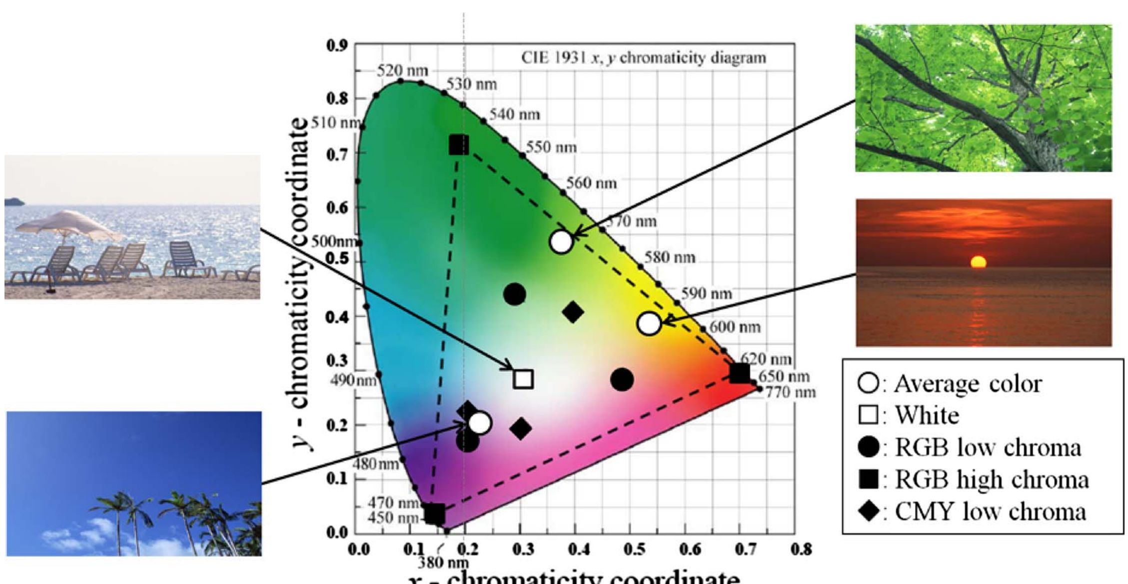

Figure 8. Chromaticity coordinates of illumination conditions and displayed images in experiment 2.

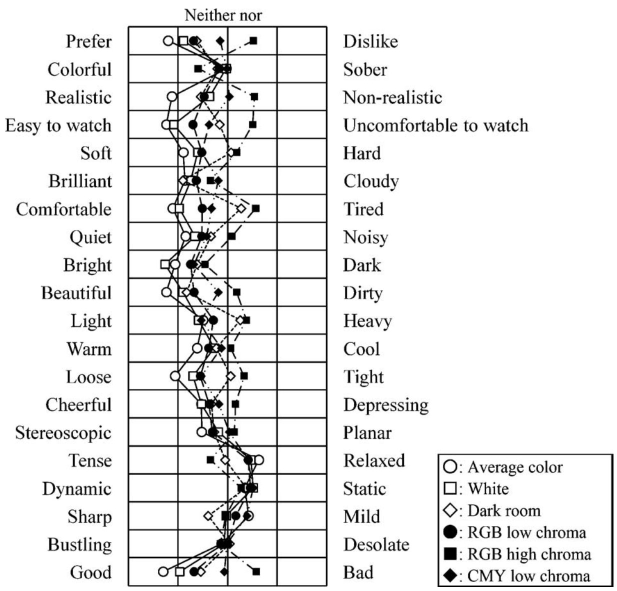

Figure 9. SD profiles of experiment 2.

mism is almost the same for the background illumination and dark room conditions. In particular, the background illumination condition increases the factor score of realistic sensation and dynamism but still maintains comfort.

EXPERIMENT 2: CHANGING COLORS AROUND A DISPLAY

Experimental Methodology

Table II shows the displayed still images and illumination conditions in experiment 2. Figures 7 and 8 show the images and chromaticity coordinates of the illumination conditions, respectively.

The stimuli were four images with natural scenes (beach, blue sky, greenery, and sunset). The experiment presented these images under each illumination condition. Only background illumination of the five conditions were used for each image [Table II, (a)]. The white illumination condition corresponds to the background illumination condition in Fig. 3(c). In addition, six illumination conditions were used

Table III. Factor loadings for experiment 2.

		First factor	Second factor	Third factor	
Adjective pairs		Realistic sensation and dynamism	Comfort	Activity	Independent factor
Good	Bad	0.89	0.27	0	0.135
Prefer	Dislike	0.856	0.262	0	0.198
Beautiful	Dirty	0.832	0.231	0	0.246
Realistic	Non-realistic	0.711	0.167	0.137	0.448
Easy to watch	Uncomfortable to watch	0.699	0.448	−0.162	0.285
Comfortable	Tired	0.592	0.583	−0.149	0.288
Brilliant	Cloudy	0.527	0	0.44	0.526
Stereoscopic	Planar	0.505	0	0.271	0.67
Loose	Tight	0.421	0.683	0	0.352
Soft	Hard	0.293	0.678	0.145	0.434
Relaxed	Tense	0.286	0.669	0	0.47
Light	Heavy	0.29	0.569	0	0.591
Sharp	Mild	0.102	−0.513	0.108	0.715
Quiet	Noisy	0.426	0.427	−0.366	0.502
Bustling	Desolate	0	0	0.645	0.579
Colorful	Sober	−0.116	−0.192	0.632	0.55
Cheerful	Depressing	0.371	0.262	0.509	0.535
Warm	Cool	0.124	0.299	0.425	0.715
Bright	Dark	0.392	0.246	0.411	0.617
Dynamic	Static	0	0	0.337	0.877
Contribution ratio		25.2%	15.9%	10.3%	
Cumulative contribution ratio		25.2%	41.1%	51.3%	

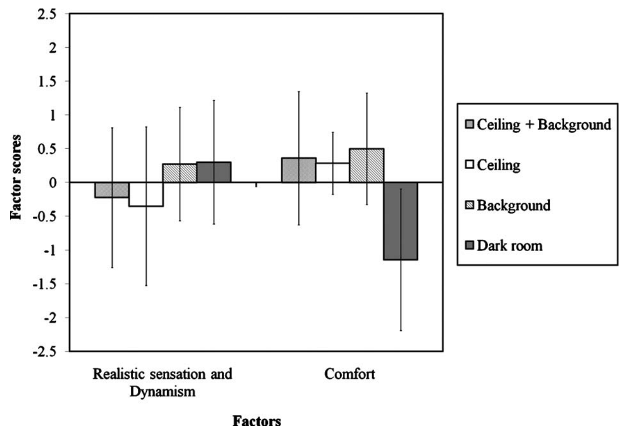

Figure 10. Factor scores of experiment 2. The error bars correspond to 1 standard deviation of the mean.

for the experiment with the beach image [Table II, (b)]. Since the conditions of "white" and "average color" of an image while viewing the beach image were approximately the same, only the illumination condition of white was used.

Each image was shown for 30 s under one illumination condition. After showing the image, the observers rated their impressions and filled in the SD evaluation sheet (see Fig. 2) while the stimuli were shown for another one minute. The observers rated a total of 29 (=4×6+6−1) kinds of the images and illumination conditions in experiment 2. An 18% gray image was displayed for approximately 30 s after each illumination condition.

Experimental Observers

Twenty-three males and four females participated in experiment 2. Their ages ranged from 22 to 26 years old, and they were studying imaging science at the university and had no prior knowledge of the experimental setup. All participants reported normal or corrected to normal vision. They had filled in a SD evaluation sheet for practice before the experiment.

Results and Discussion

Figure 9 shows the SD profiles of the experimental results for the changing colors of the illumination behind the display. Each profile of the illumination condition represents the average values of the rated value for each adjective pair. Highly rated values, such as "prefer," easy to watch, comfortable, and "good" were noted under illumination with the average

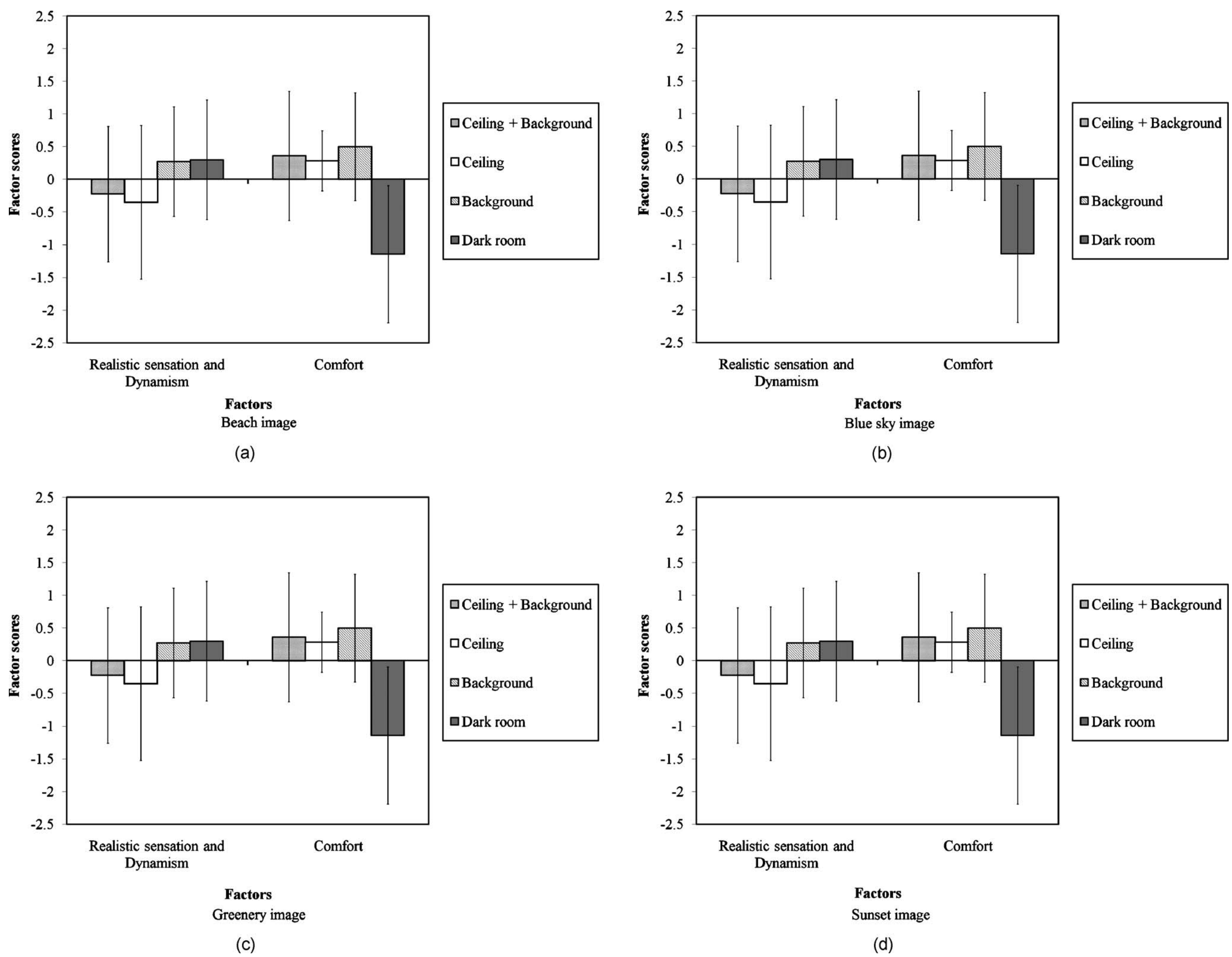

Figure 11. Factor scores of each image of experiment 2: (a) beach image, (b) blue sky image, (c) greenery image, and (d) sunset image. The error bars correspond to 1 standard deviation of the mean.

color of a displayed image and with white illumination condition, as compared to the other illumination conditions. In contrast, the dark room condition had a negative effect on the observers' impressions, resulting in "uncomfortable to watch," "tired," and "heavy." The results show the RGB high chroma illumination condition also produced poor impressions such as "dislikable," "nonrealistic," "uncomfortable to watch," "noisy," "dirty," and "bad" when displaying the beach image.

Table III shows the factor loadings of each adjective pair by factor analysis with the varimax rotation and maximum likelihood methods. The cumulative contribution ratio from the first to third factors is 51.3%. We call the first factor realistic sensation and dynamism, derived from the evaluation words good, prefer, and beautiful. The second factor is called comfort, derived from the evaluation words "loose," "soft," and relaxed. Moreover, the third factor is called "activity," derived from the evaluation words "bustling," "colorful," and "cheerful."

Figure 10 shows the factor scores of realistic sensation and dynamism, comfort, and "activity, " which are calculated by using the overall combinations of the stimuli and six illumination conditions [Table II(a)]. It is shown that realistic sensation and dynamism and comfort are enhanced with activity under the illumination with the average color of the displayed images. Fig. 10 also shows that the factor scores of realistic sensation and dynamism and comfort are rated highly under the white illumination. However, the factor scores of comfort are rated low under the dark room condition, which shows a similar trend to the factor score of comfort in the dark room of experiment 1. In contrast, the factor scores of realistic sensation and dynamism and comfort for the high chroma illumination are rated lower than those with the low chroma illuminations.

Figure 11 shows the factor scores of each stimulus. In general, the results have a similar tendency between (a) beach image, (b) blue sky image, (c) greenery image, and (d) sunset image. In Fig. 11(c), green (low chroma) illumination does not show a poor impression on the realistic sensation and dynamism factor. In Fig. 11(d), red (low chroma) illumination does not show a poor impression on the comfort factor. These results occur because the average color of the greenery image is similar to green illumination and the average color of the sunset image is similar to red illumination. However, as in the results of Fig. 11(c), red (low chroma) illumination does not show a good score for the realistic sensation and dynamism factor. Similarly, as in the results of Fig. 11(d), green (low chroma) illumination does not show a good score for the realistic sensation and dynamism factor. These results might be related to the observation that two colors in opposing color categories are viewed at the same time. Moreover, in the beach image [Fig. 11(a)], the scores for realistic sensation and dynamism and comfort for the high chroma illumination are rated lower than those with the low chroma illuminations.

CONCLUSIONS

In this article, we conducted experiments to analyze the ambient illumination conditions for keeping highly realistic sensation and comfort, and clarified four types of relationships between ambient illuminations and psychological effects while viewing a still image displayed on an LCD. First, it was shown that comfort in viewing was enhanced according to the increase in brightness of the ambient illumination. Therefore, comfort was considered to be a factor reflecting the feature of illumination around an LCD while viewing a displayed image. Second, realistic sensation and dynamism were enhanced while keeping the comfort under the illumination behind the LCD. Third, realistic sensation and dynamism as well as comfort were enhanced while maintaining the activity response, under illumination consistent with average chromaticity of the displayed images. Finally, high chromaticity illuminations decreased realistic sensation and dynamism as well as comfort.

The results of this study suggest that the presence of illumination behind the LCD with a color of average chromaticity of the displayed image appears to provide a benefit with respect to visual comfort and activity while keeping a realistic sensation, especially in comparison with conventional television viewing without this feature. However, the experiments of this study were performed under ambient illuminations with limited layouts. Actually, there are many types of illuminations such as pendant lights and table lights in the viewing environment of living rooms. In the future, we plan to analyze the psychological effects by changing the layouts of ambient illuminations while viewing video images.

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