The Effect of Surround on Perceived Lightness Contrast of Pictorial Images

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Abstract

Two experiments were conducted to obtain a predictive function for the effect of surround on perceived lightness contrast of pictorial images. Observers matched appearance in lightness contrast reproduction for images with an average surround and a light surround compared to images with a dark surround. Images with a light surround were compared to images with a dark surround under two room lighting conditions: light and dark. The surround effect appears to be overpredicted by currently used color-appearance model parameter values. These parameter values may be more on the order of 1.00:1.16 for lightness contrast reproduction between light-surround and dark-surround viewing conditions and 1.00:1.06 for lightness contrast reproduction between average-surround and dark-surround viewing conditions.

Introduction

Because of increased development activity in desktop digital imaging, there has been renewed interest in understanding the effect of surround on perceived lightness contrast of pictorial images. On the desktop, a user may want to reproduce the appearance of an image across a variety of media, e.g., print to slide, print to soft display, and slide to soft display. Each medium type has a different typical viewing environment that alters the relative luminance of the surround. In turn, the surround has an effect on the color appearance of an image. A print is typically viewed in a light surround and a slide is usually viewed in a darkened room with a dark surround. Likewise, a television or a computer display can be viewed with surrounds ranging in relative luminance from light to dark, but are typically viewed in a dim surround.

Previous research on the effect of surround has been detailed by Fairchild.[1] Therefore, only a few key points will be reviewed here. Breneman[2] and Bartleson and Breneman[3] examined the need for different optimum tone reproduction curves across medium types and requisite viewing conditions. To determine a scale of perceived lightnesses, observers matched elements of a pictorial image in dark and light surrounds to a series of patches. The luminance of the surround had a large effect on the relationship between perceived lightness and relative luminance. To formalize these results, Bartleson[4] proposed power functions to predict relative brightnesses in complex images. The form of the functions is similar to CIELAB L^* and RLAB L^R. He indicated that reflection prints viewed in a light surround are optimal when their gamma is about 1.00, slides viewed in a dark surround are optimal when their gamma is about 1.50, and images viewed in a dim-surround are optimal when their gamma is at an intermediate level of 1.25. Following Bartleson's predictions, the gamma of an image in a dark surround is expected to be 1.50 times lower than the gamma of an image in a light surround. Therefore, the lightness contrast (on log-log coordinates) of an image in a dark surround could be increased by a “gamma factor” of 1.50.

Hunt,[5] Fairchild and Berns,[6] and Fairchild[7] include parameters in their color-appearance models to transform image lightness contrast based on the relative luminance of the surround. The parameter values are specified in the ratio of 1.00:1.25:1.50 for light-surround, dim-surround, and dark-surround viewing conditions, respectively. Recent work has indicated that when these color-appearance model parameters are applied to images, the surround effect may be overpredicted.[8] Thus, there is a need to further explore the effect of surround on overall image lightness contrast to determine the appropriate model parameter values.

The flexibility of digital image processing has provided an opportunity to revisit the surround effect for multiple surround conditions and extend previous research to pictorial images that vary in gamma. Two experiments were conducted to obtain a predictive function for the effect of surround on perceived lightness contrast of pictorial images. The first experiment probes appearance matches in lightness contrast reproduction for images with an average surround compared to images with a dark surround. The second experiment examines appearance matches in lightness contrast reproduction for images with a light surround compared to images with a dark surround under light- and dark-room lighting conditions. Black-and-white image stimuli were used to isolate lightness contrast; however, it is expected that the results are also applicable to the lightness contrast of color images.

Method

Participants

Sixteen Eastman Kodak Company employees, who were experienced in judging images, participated in both experiments. All observers were previously screened to ensure that they had normal or corrected-to-normal visual acuity as well as normal color vision.

Experimental Design

For the first experiment, an image with a gamma factor of 1.00 in an average surround (20% scene white reflectance) was compared to a series of images in a dark surround with gamma factors ranging from 0.77 to 1.71 in approximately 0.05 increments. The range and increment differed slightly by scene. Gamma factors were calculated as the ratio of each image gamma in the series to the image gamma in the average or light surround. A subset of the image series was used for Experiment 2. For this experiment, an image with a gamma factor of 1.00 in a light surround (100% scene white reflectance) was compared to a series of images in a dark surround with gamma factors ranging from 0.93 to 1.43. All images were viewed under two room lighting conditions. The light-room condition was completed first so that the results could be compared to Experiment 1. For both experiments, this procedure was repeated for four different scenes. Scene order was counterbalanced with a Latin square design, and gamma factor variations were randomized within scene.

Image Stimuli

Four different scenes were used in this experiment: Bdress, Brightpeople, Fisherman, and Pigeons (Figure 1). The images were 3.50 x 2.80 inches in size at 1270 pixels / inch (4428 pixels by 3528 lines) and landscape in orientation.

For Experiment 1, black-and-white data were scaled with factors ranging from 0.80 to 1.70 in 0.05 increments to create a series of gamma levels. A family of tone reproduction curves that represent the aim series is shown in Figure 2. Tone reproduction curves pivot on D-min for all levels of gamma. Gamma was calculated by measuring the straight line slope of the tone reproduction curve. The slope is the ratio of differences in density and relative log exposure between relative log exposures of 1.3 and 2.9.

The images were exposed onto black-and-white photographic film with a Cymbolics Fire 1000 Printer. The image tone reproduction curves were verified by measuring a 25-step gray scale positioned at the top of the image montage. Images were spaced approximately at a 0.05 gamma multiplier of the average- or light-surround image curve shapes. One of the series images was determined to be a densitometric match to the average- and light-surround curve shapes.

a) Bdress Scene

b) Brightpeople Scene

c) Fisherman Scene

d) Pigeons Scene

Figure 1. Gray scale representations of scenes.

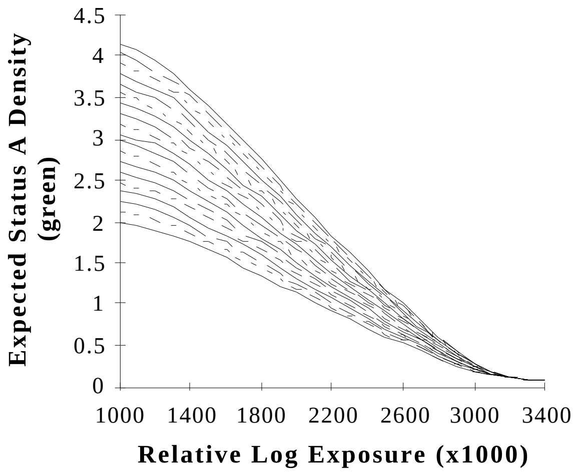


Figure 2. Aim series of tone reproduction curves ranging in gamma from 0.80 to 1.70 in 0.05 increments.

Viewing Apparatus

The viewing apparatus consisted of two black "foamcore" viewing boxes mounted to a Just Normlich Color Control 5000 transparency flat viewer (Figure 3). Separate boxes were used to view the average / light- and dark-surround images. To approximate the light levels found in a typical office, the luminance of the viewer was decreased to approximately 170 cd/m^2 with a 0.70 silver filter mounted to the inside of the viewer diffuser. The viewer had an approximate color temperature of 5033 K.

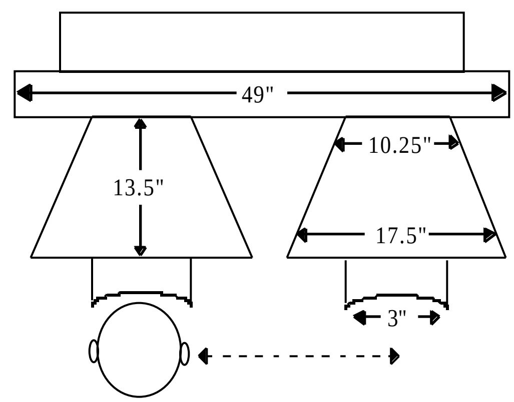
Viewing flare was minimized by the pyramid-like box design. The inside of both boxes was sprayed with flat black spray paint. The viewing ports were lined with black velvet. To equalize flare between the viewing boxes, the inside of the front face of the dark-surround box was sprayed with flat white spray paint. For Experiment 1, the image flare was controlled to a maximum of 0.30% of scene white reflectance. In Experiment 2, flare due to the light surround was difficult to correct with modifications to the apparatus. Therefore, the tone reproduction curve for the light-surround images was corrected for flare.

Viewing Environment

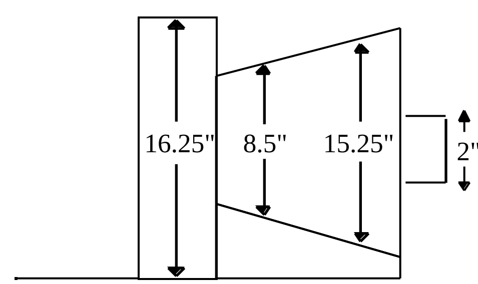
For Experiment 1 and the light-room condition in Experiment 2, the experiment room was illuminated with D5000 lighting at approximately 16 lux. The room was quite dark in the dark room condition and the meter was unable to provide a reading. The reduction in illumination of the room did not have an effect on image flare.

The dark surrounds were created by mounting the images in black matte Crescent board. The average and light surrounds were self-luminous and written with the image as part of a digital montage. The density aim for the average surround was 0.70 green Status A density (20% scene white reflectance). The density aim for the light surround was 0.114 Status A green density (approximately 100% scene white reflectance). The light-surround condition was intended to provide a close comparison to the work of Breneman[2] and Bartleson and Breneman.[3] The dark surround was estimated at 2% scene white reflectance. Percent scene white reflectance was calculated by setting scene white to 3.2 relative log exposure. Using the tone reproduction curve, relative log exposure was found for a given density value. The difference between surround log exposure and scene white was exponentiated to obtain relative reflectance and multiplied by 100 to obtain percent reflectance.

The average and light surrounds measured 7.50 x 6.75 inches. The dark surround measured 7.00 x 9.00 inches at the back of the box. The images were located in the center of the surround area. The viewing distance was approximately 13.50 inches or 4.8 picture heights (edge of the port to the image plane). The images subtended visual angles of 15 x 12 degrees. The average and light surrounds subtended visual angles of 28 x 30 degrees and the dark surrounds filled the entire visual field. An adjustable chair was used to maintain the proper viewing geometry.



a) Top View



b) Side View

Figure 3. Viewing apparatus.

Procedure

A similar procedure was used for both experiments. An image with a gamma factor of 1.00 in an average surround for Experiment 1 or a light surround for Experiment 2 was compared to images of various gamma factors in a dark surround. Following Breneman,[2] average- or light-surround and dark-surround images were binocularly viewed in alternation. Observers were asked if the image on the right (dark surround) was higher or lower in contrast than the image on the left (average or light surround). For Experiment 2, the observers first saw all scenes under the light-room condition and then under the dark-room condition.

Results

Data Analysis

Binary responses of "higher" were assigned to "1" and converted to observed probabilities. The observed probability data were analyzed with both probit and logit models using weighted and non-weighted maximum likelihood estimation.[9-11] A modification was made to extreme observed probability values of 0 and 1 so that weights would not be equal to 0. Although it is sometimes recommended to replace extreme probability values of 0 and 1 in the data set with modified values, this replacement did not provide a significantly better fit to the data and in a few cases, a significantly worse fit resulted. Also, it is commonly suggested that any X^2 approximation is not adequate if 20% of the cells have expected values of less than 5 or any cells have expected values of 0.[11] All of the data sets reported here violate this rule. To derive a measure of goodness of fit, expected and observed values in cells were collapsed until the minimum expected value of 5 was met. Collapsing the cells does have the effect of decreasing the sensitivity of the test at small levels of gamma factor. This result is of concern and therefore, the X^2 tests should be interpreted with caution. In addition, the Pearson X^2 statistic was used instead of the log likelihood ratio X^2 statistic as a measure of goodness-of-fit because it appears to be more accurate for small sample sizes.[9] The reader should also refer to the 95% fiducial limits (Table 1). The 95% fiducial limits were calculated with a t-value of 1.96.

Experiment 1 and 2 Combined Results

The logistic distribution with weighted estimates and a base 10 log transformation of gamma factor provided the best, statistically good fit for all scenes for both experiments ($p > 0.9900$ for all Pearson X^2 statistics). Weighted estimates improved the fit to the data through reducing the variability in the parameter estimates and decreasing the degree of non-constant variance. However, the residuals indicate some lack of fit at the inflection points of the curves for all scenes.

Overall, the pattern of results for scenes is similar across both surround conditions. The Bdress scene is least sensitive to the effect of surround and the Fisherman scene is most sensitive to the effect of surround (Table 1 and Figure 4).

For Experiment 1, a four-scene average of gamma factor at the point of subjective equality indicates that the contrast of an image in a dark surround should be increased by 6% to match the contrast of an image in an average surround. This result demonstrates that the dark surround has only a small contrast-reducing effect on an image that is compared to an image in an average surround.

For Experiment 2, a four-scene average indicates that the contrast of an image in a dark surround must be increased 16% for the light-room condition and 16.5% for the dark-room condition to match the contrast of an image in a light surround (see Table 1). There were few differences between results for light- and dark-room lighting conditions.

Discussion and Conclusion

Through the experiments detailed in this paper, additional support has been garnered for the results of Braun and Fairchild.[8] The surround effect seems to be overpredicted by current color-appearance model parameter values and may be more on the order of 1.00:1.16 for accurate lightness contrast reproduction between light-surround and dark-surround viewing conditions and 1.00:1.06 for accurate lightness contrast reproduction between average-surround and dark-surround viewing conditions. The experimental results differ slightly by scene. Therefore, these values should serve as a general guideline.

Acknowledgments

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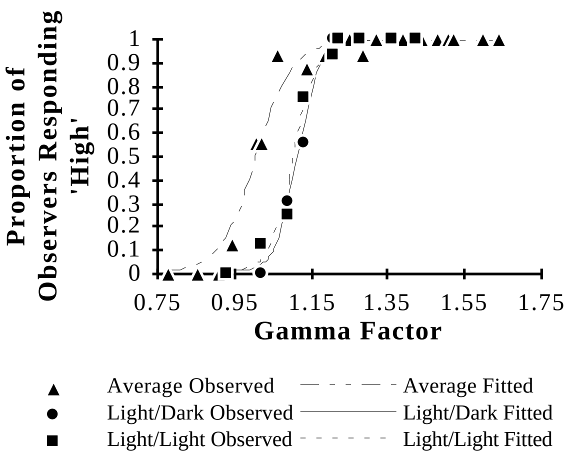
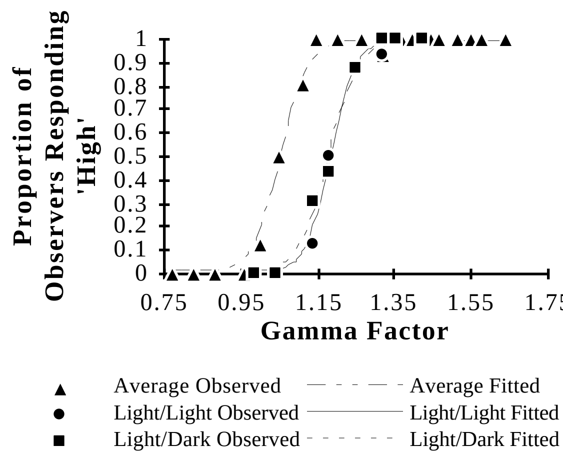
Table 1. Gamma factors for the point of subjective equality (0.50) and the interval of uncertainty (0.25 to 0.75) for light- and average-surround image comparisons. Ninety-five percent fiducial limits for each probability value are in parentheses.

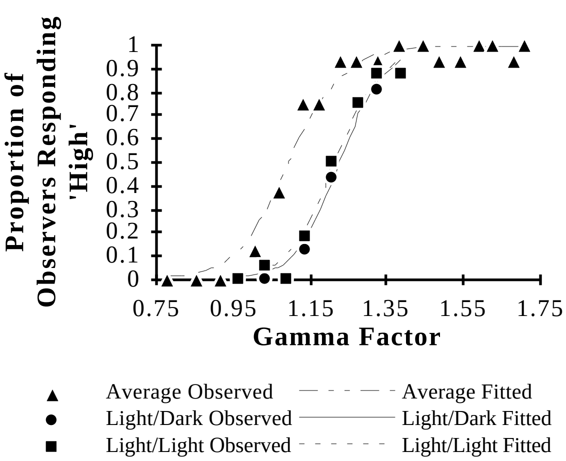
			Scene			
Test-Surround	***Room Lighting***	***Probability***	*Bdress*	*Brightpeople*	*Fisherman*	*Pigeons*
Average	*Light*	*0.25*	0.96 (0.93-0.98)	1.02 (0.96-1.04)	1.02 (0.91-1.07)	1.00 (0.94-1.03)
		0.50	1.01 (0.99-1.02)	1.05 (1.03-1.08)	1.10 (1.04-1.15)	1.07 (1.04-1.09)
		0.75	1.06 (1.05-1.09)	1.10 (1.07-1.15)	1.18 (1.13-1.28)	1.14 (1.11-1.20)
Light	*Light*	*0.25*	1.07 (1.05-1.09)	1.15 (1.13-1.16)	1.15 (1.12-1.17)	1.07 (1.04-1.09)
		0.50	1.11 (1.09-1.12)	1.19 (1.17-1.20)	1.22 (1.20-1.24)	1.13 (1.11-1.15)
		0.75	1.14 (1.13-1.17)	1.22 (1.21-1.25)	1.29 (1.26-1.32)	1.20 (1.18-1.23)
	Dark	*0.25*	1.09 (1.06-1.10)	1.14 (1.11-1.15)	1.17 (1.14-1.19)	1.07 (1.04-1.09)
		0.50	1.12 (1.11-1.13)	1.18 (1.17-1.20)	1.23 (1.21-1.25)	1.13 (1.12-1.15)
		0.75	1.15 (1.14-1.18)	1.22 (1.20-1.26)	1.30 (1.27-1.33)	1.20 (1.18-1.23)



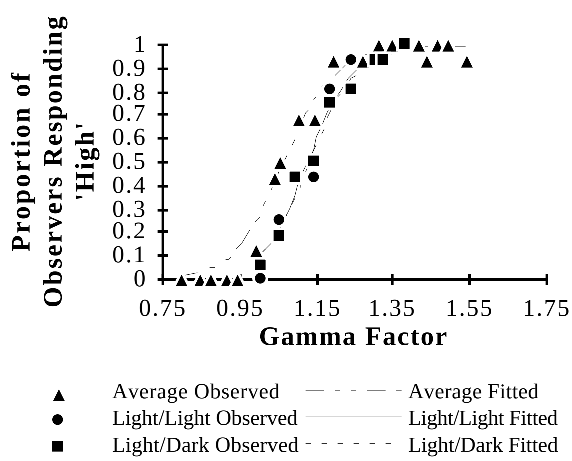
a) Bdress



b) Brightpeople



c) Fisherman



d) Pigeons

Figure 4. Observations and fitted curves for Experiments 1 and 2.