Letter

A Direct Way to Show the Relationship of Contrast Sensitivity and Adaptation Luminance

Yufang ZHANG, Warren G. JULIAN and Terry A. PURCELL

Faculty of Architecture, Design and Planning, The University of Sydney, Australia

Received November 24, 2009, Accepted April 28, 2010

This paper was presented at the 6th Lux Pacifica, Bangkok, Thailand, April, 2009.

ABSTRACT

Previous research has shown that contrast sensitivity improves progressively as adaptation luminance is increased. This paper proposed to use simulation as a direct way to show the effect of change of adaptation luminance upon contrast sensitivity. Matlab software was used in the simulation and 14 pictures were simulated. 10 pictures of the 14 pictures were processed to filter certain spatial frequencies of the luminance. 20 subjects answered word lists to evaluate the environment of the simulated pictures. The most important finding was that the effect of change of adaptation on contrast sensitivity can be simulated and shown in a direct way. It was concluded that in lighting research, an alternative approach for doing experiments can be doing experiments in a simulated environment. It implied that in interior lighting design, energy saving should not be an excuse to deprive people's well-being.

KEYWORDS: simulation, Matlab, contrast sensitivity, adaptation luminance

1. Adaptation luminance and contrast sensitivity

Previous research has suggested that adaptation was closely related to visual perception of a lighting environment¹⁾⁻⁴⁾. Adaptation in vision is the process which eyes' perception of light and colour changes, which allows visual system to operate throughout the vast range of luminances. It is the photoreceptors themselves, the light sensitive cells of the retina that make the adaptation⁵⁾. As an important light technical parameter, adaptation luminance has close correlations with another light technical parameter contrast⁴⁾⁶⁾⁷⁾.

Contrast is a measure of differences in luminances in parts of a scene (although there are contrasts other than luminance contrast, for example colour contrast and brightness contrast). Our study only examined luminance contrast. Luminance contrast is a luminance difference ratio. It can be defined as $C = (L_o - L_b) / L_b$, where L_o is luminance of an object and L_b is that of background⁴⁾.

Early in 1968, Blackwell H.R. and Blackwell O.M. put forward that contrast sensitivity (the inverse of the minimum contrast required for threshold detection) improved progressively as luminance was increased⁸⁾. In their experiments, the background luminance is the adaptation luminance. Later Yonemura⁹⁾ and Xu⁷⁾ agreed that smaller contrast differences could be detected at higher adaptation luminances.

2. Simulation

Matlab 7.0.1 was used in the simulation. Spatial

frequencies (SFs) of luminance of pictures were filtered in order to give range of contrasts. There were two colour pictures shown as follows. The two pictures were taken in an office at the University of Sydney. Figure 1 was called "light-on" and Figure 2 was called "light-off". In Figure 2 blinds were used in the office because of glare from windows during daytime. It was seen that with blinds, the office looked gloomy, so electric light was on when one was working.

The pictures were processed by Matlab 7.0.1. Picture "light-on" was divided into 20×20 small squares and average luminance value of each square was calculated and showed in Figure 3. The highest luminance was illustrated by dark red, followed by red, reddish orange, orange, yellowish orange, yellow, yellowish green, green, bluish green, blue and dark blue as luminance reduced.

Figure 1 An office with light on

Figure 2 The office with light off

Figure 3 Average luminance value of each square of Figure 1

The monitor used was capable of producing contrast ratio 750:1, with the maximum luminance 250 cd/m². So the luminance range should be [0.3 cd/m²; 250 cd/m²]. In Figure 3, the dark red squares had the highest luminance 250 cd/m², and the dark blue squares had the lowest luminance 0.3 cd/m². It is clear in Figure 3 that the window area (with blinds) had very high luminances which were illustrated by dark red and red. For all surfaces, the whiteboard had relatively higher luminances than those of the other surfaces. The corner areas had very low luminances, which were illustrated by blue and dark blue.

Then Matlab filtered out luminance spatial frequencies to produce the set of pictures shown in Table 1. The “ ≤ 0.013 ” means that Matlab retained SFs equal to and less than 0.013, etc. Colour information was removed. A similar process was done on the night-time “light-on” picture. Conditions 1, 2, 8 and 9 were pictures with full luminance special frequencies. Conditions 3-7 and 10-14 were pictures with certain luminance special frequencies filtered. Details of the 14 pictures are listed in Table 1.

Table 1 Details of 14 pictures (conditions) in the experiment

light	SFs of luminance	condition
electric light on, sky light from windows	no SFs filtered	1
electric light off, sky light from windows	no SFs filtered	2
electric light on, sky light from windows	≤ 0.02	3
electric light on, sky light from windows	≤ 0.017	4
electric light on, sky light from windows	≤ 0.015	5
electric light on, sky light from windows	≤ 0.013	6
electric light on, sky light from windows	≤ 0.01	7

light	SFs of luminance	condition
electric light on, no sky light	no SFs filtered	
electric light off, no sky light	no SFs filtered	
electric light on, no sky light	≤ 0.02	
electric light on, no sky light	≤ 0.017	
electric light on, no sky light	≤ 0.015	
electric light on, no sky light	≤ 0.013	
electric light on, no sky light	≤ 0.01	

3. Subjective evaluation

The sequences of the 14 pictures for different subjects were randomly selected in the experiment.

20 subjects were given a list of fifty-three words and were asked to respond on a “yes” or “no”, to indicate

whether they thought the word could describe the environment. The words were listed in random order. The fifty three words were selected from the work of Flynn et al⁽¹⁰⁻¹²⁾ and Shepherd⁽⁴⁾. They were applicable to many aspects of the room, not just the lighting. Having words applicable to many aspects of the room served to disguise the aim of the experiment⁽⁴⁾. The following table gives one permutation of the word lists used.

Table 2 One sample of word lists in the experiment

words	yes	no	words	yes	no
cold			uninviting		
negative			warm		
disturbing			noisy		
shaded			dim		
inviting			sterile		
even			sunny		
undisturbing			glaring		
cheerful			complex		
positive			interesting		
quiet			formal		
gloomy			spacious		
cosy			balanced		
stark			light		
pleasant			non-glaring		
comfortable			non-uniform		
mottled			sombre		
simple			enclosed		
dark			unpleasant		
glossy			uncomfortable		
uniform			depressing		
subdued			monotonous		
bright			unbalanced		
objects obscure			details distinct		
uneven			objects clear		
details indistinct			inadequately lit		
adequately lit			informal		
diffuse					

Each subject made judgments for all the 14 pictures. The order of presentation of 14 lighting conditions was randomized across subjects. Each subject was given a separate word list for each picture. Each subject spent about 40 minutes to finish the task.

4. Results

More than sixty percent of the subjects selected conditions 5, 6, 7, 9, 12, 13 and 14 as gloomy. Previous research maintained that gloom was a negative experience which was related to negative emotions, and which could be described as dim or dark⁽⁴⁾. Gloom has

occurred in the lighting literature from the late 1950s to describe rooms that appear to be “inadequately lit” or “dim” or “not bright”⁴⁾⁹⁾¹³⁾⁻¹⁶⁾. But from the questionnaires collected in this experiment, sometimes when subjects selected “gloomy”, they didn’t select “dim” or “dark”, which indicated that gloom is different from dim or dark.

In our experiment, which condition is gloomy and which is not? The K-Means Cluster Analysis (SPSS) was applied. There were two groups given by the cluster analysis. One contains conditions 2, 5, 6, 7, 9, 11, 12, 13 and 14. The other contains conditions 1, 3, 4, 8 and 10.

In conditions 6, 7, 9, 12, 13 and 14, no less than 80% of the subjects selected “gloomy”, indicating that those conditions were “gloomy” conditions. More than half of the subjects selected “gloomy” in conditions 2, 5 and 11. The three conditions were “slightly gloomy” conditions.

In the typical gloomy conditions (conditions 6, 7, 9, 12, 13, 14), words selected by no less than 60% of the subjects were: cold, dark, depressing, diffuse, dim, enclosed, inadequately lit, informal, monotonous, negative, non-glaring, quiet, shaded, sombre, subdued, uncomfortable, uneven, uninviting and unpleasant. Those words have indicated that the experience of gloom was a negative feeling. This experiment has produced similar results to Shepherd’s⁴⁾. The aforementioned experiment was done in a real environment.

In conditions 1, 3, 4, 8 and 10, more than 55% of the subjects selected “adequately lit” and “light”, indicating that those conditions were lit conditions. In conditions 1, 3, 8 and 10, no less than 60% of the subjects selected “bright”.

More subjects judged condition 1 as bright compared with condition 7, and more subjects judged condition 2 as bright compared with condition 8. It can be seen that no matter during daytime or at night, an office with electric light on was judged brighter than that with light off. Subjects judged objects clearer, details more distinct, and environment more inviting with light on than with light off.

It was also shown that the less SFs of luminance retained in pictures, the more obscure and more indistinct subjects felt, meaning that contrast sensitivity improved progressively as adaptation luminance was increased.

When electric lights were off, no matter during daytime or at night, subjects judged conditions as gloomy. With light on, if SFs of luminance retained were no more than 0.015, conditions were judged as gloomy. If SFs of luminance retained were more than 0.017, conditions were judged as non-gloomy.

5. Conclusion

Our experiment showed a direct way of simulating effect of change of adaptation on contrast sensitivity: contrast sensitivity increased with increasing adaptation luminance. It also showed that smaller contrast

differences can be detected at higher adaptation luminances.

Since this simulation experiment has produced similar results to the aforementioned experiment done in a real environment⁴⁾, in lighting research, an alternative approach for doing experiments can be doing experiments in a simulated environment.

6. Discussion

Ultimately, what we want to discuss is lighting design based on the issue of an understanding of gloom. Gloom is a negative experience related to inadequate light¹⁷⁾. The results of our experiment have some implications in a practical life. One result was that when lights were off, no matter during daytime or at night, subjects judged conditions as gloomy. When designing lighting for interiors, undue emphasis is sometimes placed on satisfying a sufficient illuminance on the working plane. The “energetic” approach to sustainability reinforces that emphasis, often to the detriment of the quality aspects of the design¹⁸⁾. This might be fashionable nowadays caters to the mantra of energy saving. Some lighting designers have taken up the idea of “less is more” and use as little electric light as possible during the daytime. There is a considerable risk that interiors will be judged to be inadequately lit.¹⁸⁾ In our experiment, though there were big windows in the office, electric lights were still needed in order to meet the satisfaction and comfortability of people. Saving energy should not result in a detriment the well-being of people. It is a balancing issue that needs further debate and research.

References

- (1) Waldram, J.M.: Studies in Interior Lighting, Transaction of the Illuminating Engineering Society, Vol. 19, pp. 95-133 (1954).
- (2) Bellchambers, H.E., Lambert, G.K. and Walsingham, R.J.: Measurement of Visual Adaptation - Preliminary Experiments, Lighting Research and Technology, Vol. 1, pp. 104-106 (1969).
- (3) Rothwell, S. and Campbell, F.: The Physiological Basis for the Sensation of Gloom: Quantitative and Qualitative Aspects, Ophthal. Physiol. Opt., Vol. 7, pp. 161-163 (1987).
- (4) Shepherd, A.J.: Gloom in Buildings, The University of Sydney, Sydney (1990).
- (5) Tregenza, P. and Loe, D.: The Design of Lighting (1 ed.), E & FN Spon, New York (1998).
- (6) Dember, W.N.: The Psychology of Perception, Holt, Rinehart and Winston, Toronto and London (1960).
- (7) Xu, H.: Communication Theory Approach to Measuring the Goodness of Seeing, Lighting Research and Technology, Vol. 16, pp. 98-103 (1984).

- (8) Blackwell, H.R. and Blackwell O.M.: The Effect of Illumination Quantity upon the Performance of Different Visual Tasks, Transactions of the Illuminating Engineering Society, Vol. 33, pp. 143-152 (1968).
- (9) Yonemura, G. T.: Criteria for Recommending Lighting Levels, Lighting Research and Technology, Vol. 13, pp. 113-129 (1981).
- (10) Flynn, J.E., Hendrick, C., Spencer, T.J. and Martyniuk, O.: A Guide to the Methodology Procedures for Measuring Subjective Impressions in Lighting, J. Illum. Eng. Soc., Vol. 8, pp. 95-110 (1979).
- (11) Flynn, J.E., Spencer, T.J., Martyniuk, O. and Hendrick, C.: Interim Study of Procedures for Investigating the Effect of Light on Impression and Behaviour, J. Illum. Eng. Soc., Vol. 3, pp. 87-94 (1973).
- (12) Flynn, J.E. and Subisak, G.J.: A Procedure for the Qualitative Study of Light Level Variations and System Performance, J. Illum. Eng. Soc., Vol. 3, pp. 28-35 (1978).
- (13) Lynes, J.A.: Lightness, Colour and Constancy in Lighting Design, Lighting Research and Technology, Vol. 1, pp. 171-181 (1971).
- (14) Julian, W.G.: Lighting: an Urgent Case for Major Research Effort in Architectural Science, Building and Environment, Vol. 22, pp. 155-161 (1987).
- (15) Julian, W. G.: Considerations in Modern Lighting Design, Lighting in Australia, August, pp.14-23 (1988).
- (16) Lam, W.M.C.: Perception and Lighting as Formgivers for Architecture, New York, Van Nostrand Reinhold, (1992).
- (17) Zhang, Y., Julian, W. G. and Purcell, A.T.: Visual Perception of Gloom, 31st ECVP, Utrecht (2008).
- (18) Julian, W. G., Zhang, Y. and Purcell, A.T.: The Risk of Gloomy but Sustainable Future, 51st IESANZ (2008).

---

*Figure 1 to 3 appear in color on J-STAGE; <http://www.jstage.jst.go.jp/browse/jlve/>