International Commission on Illumination
Commission Internationale de l'Eclairage
Internationale Beleuchtungskommission

PP14

IMPACT OF LUMINANCE DISTRIBUTION ON PERCEPTION OF THE SHAPE OF ARCHITECTURAL SPACES

Joelene Elliott et al.

DOI 10.25039/x46.2019.PP14

from

CIE x046:2019

**Proceedings
of the
29th CIE SESSION**

Washington D.C., USA, June 14 – 22, 2019

(DOI 10.25039/x46.2019)

The paper has been presented at the 29th CIE Session, Washington D.C., USA, June 14-22, 2019. It has not been peer-reviewed by CIE.

© CIE 2019

All rights reserved. Unless otherwise specified, no part of this publication may be reproduced or utilized in any form or by any means, electronic or mechanical, including photocopying and microfilm, without permission in writing from CIE Central Bureau at the address below. Any mention of organizations or products does not imply endorsement by the CIE.

This paper is made available open access for individual use. However, in all other cases all rights are reserved unless explicit permission is sought from and given by the CIE.

CIE Central Bureau
Babenbergerstrasse 9
A-1010 Vienna
Austria
Tel.: +43 1 714 3187
e-mail: ciecb@cie.co.at
www.cie.co.at

IMPACT OF LUMINANCE DISTRIBUTION ON PERCEPTION OF THE SHAPE OF ARCHITECTURAL SPACES

Elliott, J., Davis, W.
The University of Sydney, Sydney, AUSTRALIA
joelene.elliott@sydney.edu.au

DOI 10.25039/x46.2019.PP14

Abstract

This research investigates the applicability of theatrical lighting techniques that manipulate the appearance of the shape of an environment to architectural spaces. Two temporal two-alternative forced choice experiments were conducted. Participants viewed the interior of a white room when illuminated by one of four test lighting conditions, in which the luminance differences between the vertical and horizontal surfaces varied, as well as a reference uniform luminance condition. In the first experiment, participants were asked to report which of the two randomly-presented lighting conditions made the space appear wider. In the second experiment, they were asked to indicate which made the space appear taller. In both experiments, participants reported that the space appeared smaller (narrower and shorter) when it was illuminated by all of the non-uniform lighting conditions than the reference uniform lighting condition.

Keywords: spatial perception, luminance, lighting design, interior lighting techniques

1 Introduction

The perception of the lightness of an object can appear to change depending on the lightness of the background. In artistic fields, such as the theatre, the use of light to present illusions is common. Theatrical lighting design texts describe the use of variations of luminance to manipulate perception of the environment. The contrast of light and dark enables the items on a stage to be viewed accurately or misinterpreted, and profiles and textures to be omitted or exposed (Pilbrow, 2002). The designers that implement these techniques learn their craft through a process of observation. Architectural lighting designers practice similar reasoning. Lighting design handbooks describe illusory spatial observations such as the 'cave effect'. (Cuttle, 2015).

Advances in lighting technologies provide the opportunity to re-think architectural lighting design practices and allow techniques that have been iteratively developed and passed on through tradition to be empirically investigated.

1.1 Spatial perception

It is well-known that visual perception arises not purely from the output of visual receptors, but also the surrounding context and knowledge of the environment. Spatial illusions are discrepancies between the apparent and physical characteristics of a stimulus, such as size, shape, orientation or movement (Day, 1972). Wandell (1995) demonstrates the importance of the spatial distribution of luminance on shape perception with crater images. The image on the left of figure 1 shows a large crater and the image on the right shows the same image rotated 180 degrees. The rotated image appears as a mound. This difference in perception occurs because the human visual system assumes that the light is coming from above.

Figure 1 – Wandell (1995) demonstrates the importance of luminance distribution on shape perception. The image on the left shows a large crater. The image on the right is same image rotated 180 degrees. Image source: Roddy (1999)

The human visual system also uses atmospheric perspective, or haze lightness, as a depth cue. Wardle (1995) notes “distant objects are viewed through more atmosphere than nearer objects and hence have a lower contrast.”

Empirical studies of the effect of lighting on the perception spaciousness of interior environments are sparse. Flynn concluded that the lighting of a space could affect people’s reports of mood, impressions of spatial complexity, perceptual clarity, spaciousness and formality (Manav, 1999). Experiments of room spaciousness and luminance distribution have been conducted using such presentation methods as changing the lighting conditions within a room and the viewing of images. There are, however, no known studies in which observers viewed lighting conditions within a real architectural space without visual cues such as furniture and luminaires. Although there is a lack of research in this area, techniques such as emitting light directly onto a ceiling so that it is perceived to be as high as possible, or the illumination of walls to ensure the space does not feel cave-like or enclosed, are commonly used by architectural lighting design professionals (Meek, 2014). Interestingly, the Australian Interior and Workplace Lighting Standards (2006) support these claims with the following unreferenced statement, “The sense of space and of form can be influenced by appropriate lighting design. Since the eye is involuntarily drawn towards light, the apparent proportions of a room can be influenced by the direction of lighting and the differences in luminance of the defining surfaces. Thus, a long room can appear to be shortened by transverse lines of light or by lightening the end walls and darkening the side walls. Similar treatment will give a square” (Standards Australia, 2006).

1.2 Hypotheses

The experiments conducted here were designed to test the following hypotheses:

- When the ceiling and floor have a higher luminance than the walls, the space will appear taller than it does with uniform illumination.
- When the walls have a higher luminance than the floor and the ceiling, the space will appear wider than it does with uniform illumination.

2 Methods

2.1 Experimental set-up

An interior space (3.6 m x 3.2 m x 3.2 m) was erected using theatrical scenery flats. One vertical face was omitted to enable the projection of lighting into the environment and the participant to enter the space. The internal walls were painted with a white matte finish, with 0.4 m of the walls along the open edge painted in matte black (to ensure the observer viewed a symmetrical space). Each surface was illuminated by one theatrical luminaire (ETC S4 Lustr Series 2, 50-degree ELDT lens). The luminaires lighting the walls were located on a 3.0 m piece of vertical concert truss. The luminaire illuminating the ceiling was mounted on the floor, slightly to the right side of the observer. The luminaire illuminating the floor was fixed to the ceiling (of the laboratory) at the height of 3.0 m, flush against one side of the space’s vertical

opening. All lights were positioned and focused such that the surfaces were lit without casting shadows from the observer. The observer was located on the middle of the open edge, 3.2 m from the rear wall. The observer's visual axis was similar to that of a seated office worker (Standards Australia, 1994). Figure 3 shows an image of an observer viewing the constructed space.

Figure 3 – Experimental structure and observer in viewing position.

2.2 Lighting conditions

All luminaires were thermally stabilised and tested for consistent output. The dimming characteristics of the luminaires were quantified, and the relationships between the input signals (dmx) and surface luminance were modelled.

A luminance meter was placed on a tripod at the position of the eyes of the participant. The tripod's pan and tilt control was used to measure the luminance of each surface of the room at 10 ° increments along the horizontal and vertical axes. To quantify the light reflected between surfaces, the luminance of each surface was measured five times, when each of the five luminaires was on. Measurements were not taken on the 0.4 m black portion along the open edge wall and corner locations. Measurements were used to quantify the relationships between luminaire input signal and surface luminance and mathematically account for light reflected between surfaces.

Because of light reflected between surfaces, the difference in luminance between surfaces was limited. Table 1 shows the luminance ratios between the vertical (walls) and horizontal (ceiling and floor) surfaces achieved. Table 2 shows the average luminance values of the surfaces. In four of five test conditions, the luminance of the walls and the luminance of the floor and ceiling were different. In the most extreme conditions, the walls' (condition 1) luminance was 1.8 times higher than the floor and ceiling. At the opposite extreme (condition 5) the ratio is reversed.

Table 1 – Luminance ratios for each lighting condition.

Lighting condition	1	2	3	4	5
Ceiling and floor	1	1	1	1.4	1.8
Walls	1.8	1.4	1	1	1

Table 2 – Luminance of surfaces for each lighting condition.

Lighting condition	1	2	3	4	5
Ceiling and floor	25 cd/m ²	29 cd/m ²	35 cd/m ²	41 cd/m ²	45 cd/m ²
Walls	45 cd/m ²	41 cd/m ²	35 cd/m ²	29 cd/m ²	25 cd/m ²

2.3 Procedure

Two experiments were conducted using the same test conditions. These experiments used a temporal two-alternative forced choice method. The participants were 20-50 years of age. Each participant's stereoscopic vision was tested using The Butterfly Test and their stereoacuity was less than or equal to 200 seconds of arc. Participants were initially exposed to dark conditions for three minutes.

Randomised comparisons were always made between a test condition and the uniform reference condition (identical to test condition 3). Each trial began with the presentation of one lighting condition held constant for three seconds. A short audible tone was then played as the illumination condition was changed. The second lighting condition was then held static for three seconds. All lights were turned off and subjects were asked to report their judgment.

For the first experiment, participants were asked to report which of the two lighting conditions made the space appear wider. In the second experiment, they indicated which of the two conditions made the space appear taller.

3 Results

As shown in figure 4, the data from the first experiment, in which participants compared the perceived width of the space, shows that participants found the space to appear narrower when illuminated by all non-uniform lighting conditions than the uniform reference condition. The dashed line shows the trend predicted by the hypothesis, which is clearly not supported by the data.

Figure 4 – The percentage of trials in which participants reported that the test condition appeared wider than the reference condition as a function of test condition number. The luminance ratios for each condition are shown below the x-axis. The dashed line shows the trend predicted by the hypothesis.

The result of the second experiment, in which participants compared the perceived height of the space, has a similar trend to the first experiment. Figure 5 shows that the participants found the space to appear shorter when illuminated by all of the non-uniform lighting conditions than the uniform reference condition. The dashed line shows the trend predicted by the hypothesis, which is not supported by the data.

Figure 5 – The percentage of trials in which participants reported that the test condition appeared taller than the reference condition as a function of test condition number. The luminance ratios for each condition are shown below the x-axis. The dashed line shows the trend predicted by the hypothesis.

6. Discussion

The spatial perception of architectural environments and the luminance of surfaces will be the subject of further investigation. The luminance ratios used in these experiments compare the luminance of one horizontal surface and one vertical surface. Consequently, the total amount of light is greater when the three vertical surfaces are brighter (the walls) than when the two horizontal surfaces (the floor and ceiling) are brighter. In order to eliminate this confound, the wall directly opposite the observer has been painted black, and the luminaire that illuminates this wall has been removed. A third experiment is underway in the modified space that will use the same methods and luminance ratios as the experiments reported here.

References

- AS/NZ 1994. AS HB59 Ergonomics –The Human Factor: *A Practical Approach to work systems design*. Australia: Standards Australia.
- AS/NZ 2006. AS/NZ 1680.1. Interior and Workplace Lighting Part 1: *General Principles and Recommendations*. Australia: Standards Australia.
- CUTTLE, C. 2015. *Lighting Design: A Perception Based Approach, 2nd Ed.* Abingdon: Oxford.
- DAY, R. H. 1972. Visual Spatial Illusions: A General Explanation. *Science*, 175(4028).
- MANAV, C. 1999. Effects of different Lighting Arrangements on Space Perception. *Architectural Science Review*, 42(5).
- MEEK, C 2014. *Daylighting and Integrated Lighting Design, 1st Ed.* London: Routledge.
- PILBROW, R. 2002. Stage Lighting Design: *The Art, the Craft, the Life, 2nd Ed.* Hollywood: By Design Press.
- RODDY, D 1999 *Barringer Crater on Earth [Photo]*. Lunar and planetary Institute, Texas. Retrieved from <https://apod.nasa.gov/apod/ap990711.html>
- VOS, J.J. 2008. Depth in Colour: A History of a Chapter in Physiologie Optique Amusante. *Clinical and Experimental Optometry*, 91(2).
- WANDELL, B.A. 1995 *Foundations of vision*. Sunderland, Massachusetts: Sinauer Associates.
- WARDLE, S.G. 2015. Zen Mountains: An Illusion of Perceptual Transparency. *i-Perception*, 6(2).