LBL-35037
WG-312

Published in the Proceedings of the 1992 IEEE Industry Applications Society Annual Meeting, October 4-9, 1992 in Houston, TX.

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Werner K.E. Osterhaus
Energy and Environment Division
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

and

Ian L. Bailey
School of Optometry
University of California
Berkeley, CA 94720

May 1992

This work was partially supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Building Technologies, Building Systems and Materials Division of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

Large Area Glare Sources and Their Effect on Discomfort and Visual Performance at Computer Workstations

Werner K. E. Osterhaus* and Ian L. Bailey†

*Windows and Daylighting Group
Building Technologies Program
Energy and Environment Division
Lawrence Berkeley Laboratory
Berkeley, CA 94720 U.S.A.

†School of Optometry
University of California, Berkeley
Berkeley, CA 94720 U.S.A.

***Abstract* – This paper studies the effects of a large area light source of variable but uniform luminance surrounding a video display terminal (VDT) on the perceived glare discomfort and visual performance of computer operators. A set of criteria was established for rating the discomfort from glare as either "intolerable", "disturbing", "noticeable", or "imperceptible". Source luminance adjustments by means of a variable transformer to match the subjective glare criteria, as well as ratings of preselected lighting conditions on a visual analog scale with the same criteria, were used to determine comfortable lighting conditions. Results from the experiment indicate that subjects reliably selected a preferred lighting condition at any time when asked to adjust the luminance to produce optimum visual comfort. There was considerable between-subject variation in the range of luminances over which the surround field was neither noticeably too dim nor noticeably too bright. Comfortable luminance ranges also varied with initial presentation luminances immediately preceding the adjustment. Subjects preferred higher luminances following high initial presentation luminances. Performance speed at a difficult letter-counting task suggests that visual performance was slightly impaired by the presence of glare discomfort. Counting errors also occurred slightly more frequently under higher surround source luminances. There was a tendency for subjects to become more susceptible to glare over the course of the experiment.**

I. INTRODUCTION

Computer workstations are frequently installed in office spaces not originally designed for computer use. Limited space availability can lead to unsatisfactory placement of computer screens in relation to window openings and lighting installations, possibly resulting in excessive brightness contrast, screen reflections, and discomfort glare.

Whereas much attention has been given to discomfort glare from ceiling luminaires, there has been little work done to evaluate the discomfort from bright areas surrounding the work task. Existing glare evaluation methods primarily target small to medium size ceiling fixtures [1, 2, 3]. For very large glare sources that occupy a substantial part or all of the visual field, formulae obtained from small source studies have been modified to fit data obtained with large sources, such as luminous ceilings [4, 5, 6]. A Daylight Glare Index was developed to assess visual comfort related to windows [7, 8, 9, 10]. Currently, no data is available on perceived comfort or discomfort and the relations between comfort and task performance under conditions in which the glare source borders or surrounds a work task, since all previous studies evaluated discomfort glare by directly viewing the glare source, rather than focusing on a work task.

Computer operators whose terminals are placed against a window, for example, frequently experience dramatically changing visual comfort conditions throughout the course of a day due to varying daylight availability and outdoor lighting levels. In such a case, the operator's task performance may be adversely affected by glare discomfort.

This investigation examines such a condition in a simulated laboratory environment and evaluates the effect of a large-area light source upon visual comfort and performance.

II. EXPERIMENTAL ARRANGEMENT

The experimental set-up used a large rectangular source, one meter high and 1.5 meters wide, consisting of a bank of sixteen 100-Watt incandescent light bulbs whose light is diffused by an opal plastic screen, to present a large surface of uniform luminance to the observer. The source was placed on a table behind a video display terminal. The center of the computer screen was 33 centimeters above the table top. The screen measured 25 centimeters in width and 18 centimeters in height and the viewing distance was 44 centimeters. The subject's line of sight was tilted downward by 15 degrees. To eliminate reflections on the monitor surface and to limit the visual field to the exterior boundaries of the large surround source, a black screen with viewing slot was placed between subjects and the monitor. A variable transformer permitted smooth control of the source luminance up to approximately 2000 candelas per square meter by either the subject or the experimenter. The testing laboratory was illuminated only by the large source and the VDT screen. The VDT screen luminance was set to measure 12.5 candelas per square meter. Six luminance settings were preselected by the experimenter for evaluation by the subjects. They ranged from 6.3 to 2000 candelas per square meter (0.8 to 3.3 log candelas per square meter) in steps of 0.5 log candelas per square meter.

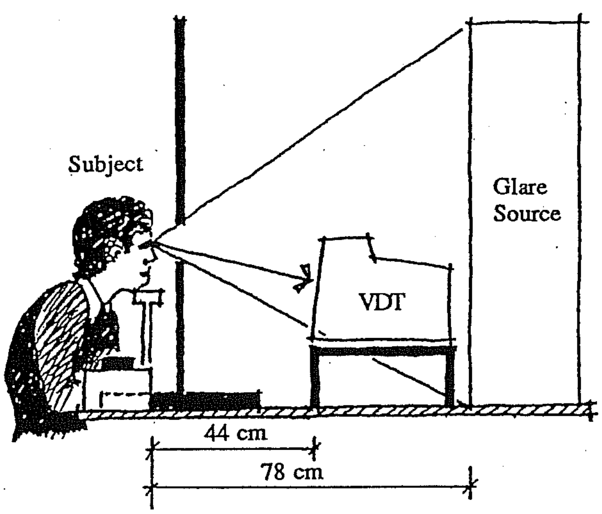

Fig. 1. Experimental set-up.

III. SUBJECTS

The 26 participants in this study were selected from among the scientific staff and students at the Lawrence Berkeley Laboratory and the University of California, Berkeley. All but two of the subjects had frequently used computers and experienced lighting discomfort at computer workstations. There were 20 male and 6 female participants. Fourteen participants had normal vision, 12 used corrective vision aids. The subjects' age ranged from 23 to 45 years. The mean age was 32 years. All subjects were paid.

IV. EXPERIMENTAL PROCEDURE

Each experiment lasted approximately 1-1/2 hour. A 15-minute introductory session familiarized the subjects with the control mechanisms and ranges of the glare source and introduced them to the set of criteria for rating the discomfort from glare as either "intolerable", "disturbing", "noticeable", or "imperceptible".

A. Adjustment Trials

In Part A of the experiment subjects adjusted the luminance of the large surround source to achieve the following borderlines between two defined glare discomfort criteria: the borderline between imperceptible and noticeable glare, the borderline between noticeable and disturbing glare, and the borderline between disturbing and intolerable glare. The different borderlines were set for both, too bright and too dim luminances. Subjects also adjusted the luminance of the surround field to achieve optimum comfort (preferred luminance) for viewing the task presented on the VDT screen. The borderline between imperceptible and noticeable glare was to be the changeover point where glare discomfort would be first noticed by the subject when increasing or decreasing the luminance from the preferred setting. Subjects were told that this criterion would be equivalent to a very slight experience of discomfort that they could tolerate for approximately one day when placed at someone else's workstation, but which they would rather change if they were to work there for longer periods of time. The borderline between noticeable and disturbing glare was defined as a discomfort experience that would be just disturbing and could be tolerated for 15 to 30 minutes, but that would require a change in luminance setting for any longer period. The borderline between disturbing and intolerable glare was defined as the turning point where subjects would no longer be able to tolerate the lighting condition. These adjustments were made at the beginning and at the end of the experiment.

B. Rating Trials

Part B of the experiment consisted of rating six different background luminances on a visual analog scale with the same discomfort glare criteria. One rating trial consisted of six luminance presentations, presented in varying order. Not all six preselected presentation luminances were necessarily presented within one trial. During some rating trials, participants were asked to adjust the glare source luminance to the preferred setting and to the borderlines between imperceptible and noticeable glare immediately following the rating of a presentation luminance. Rating trials were repeated several times during the experiment.

C. Counting Trials

Part C of the experiment included a performance task. A random-letter generator was employed to display paragraphs of randomly selected pseudo-words on the VDT screen (Fig. 2). Subjects were asked to count each occurrence of a specified letter in the central of three paragraphs under a particular lighting condition chosen by the experimenter from the six preselected luminance settings. Letters to be counted were randomly selected from a group of five letters specified by the experimenter as B, R, N, M, and W. These five letters, as well as the six lighting conditions, occurred with approximately equal frequency over the course of six counting sessions with six presentation luminances each. Within the central paragraph, the specified letter occurred between 13 and 26 times. The time needed to complete the counting task was measured by the computer by pressing any key on the keyboard when finished counting. The subject then entered the counted number of occurrences and immediately rated the perceived glare discomfort during task performance on the above described rating scale before the experimenter presented a new lighting condition and counting task. Between counting trials, rating trials were repeated.

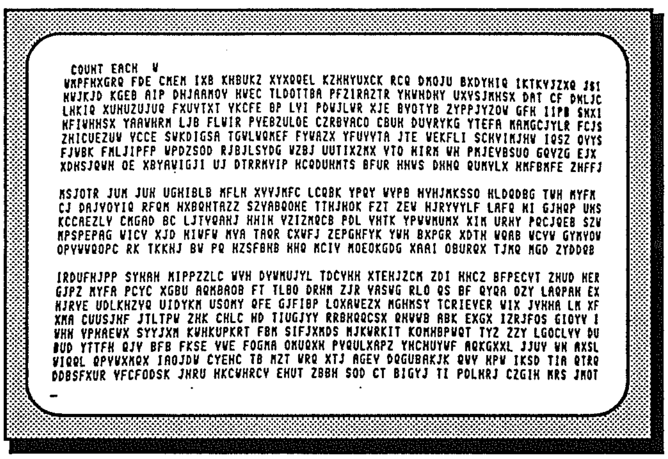

Fig. 2. Sample screen display for the letter-counting task.

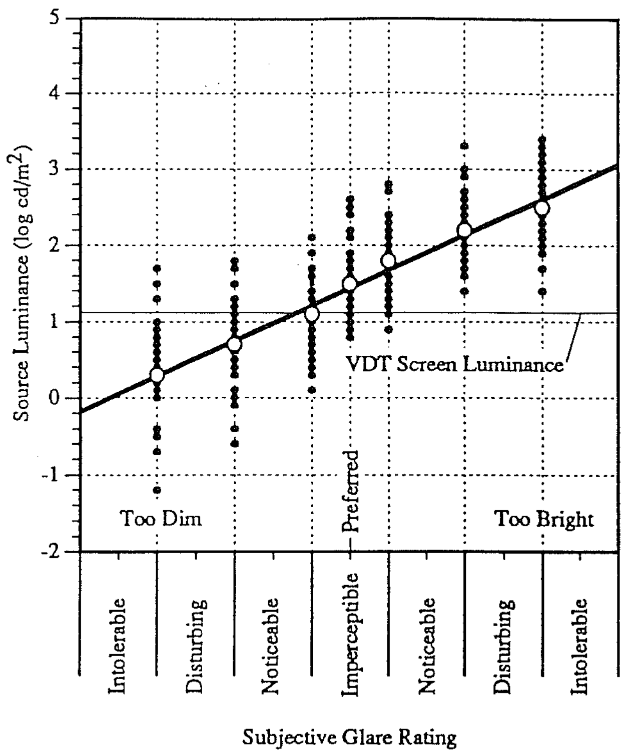

Fig. 3. Luminance adjustments of 26 subjects for various discomfort glare criteria for a large light source surrounding a VDT screen of 12.5 candelas per square meter luminance. Small solid data points represent individual subjects, the large open points indicate mean luminances.

V. RESULTS

On average, subjects preferred a surround luminance from the large source of 25 candelas per square meter (1.4 log units), ranging from 5 to 400 candelas per square meter (0.7 to 2.6 log candelas per square meter units) for a VDT screen luminance of 12.5 candelas per square meter (1.1 log candelas per square meter). The least sensitive subject required an approximately 100-fold (2.0 log candelas per square meter) increase in luminance to arrive at the same subjective glare rating as the most sensitive subject (Fig. 3).

The preferred luminance for the surround source, as judged immediately following the rating of one of the six presentation luminances, varied with initial presentation luminances (Fig. 4). Subjects selected higher luminances when high initial presentation luminances preceded the adjustment. The average settings ranged from 20 to 50 candelas per square meter (1.3 to 1.7 log candelas per square meter) for presentation luminances from 6.3 to 2000 candelas per square meter (0.8 to 3.3 log candelas per square meter).

There was considerable between-subject variation in the range of luminances over which the surround field was neither noticeably too bright nor noticeably too dim, ranging from about 1 candela per square meter (0.1 log candelas per square meter) to 630 candelas per square meter (2.8 log candelas per square meter). The mean change in luminance required to shift from one discomfort glare criterion to the next was about 0.65 log candelas per square meter or a 4.5-fold increase or decrease.

When glare severity was assessed immediately following the difficult letter-counting task the subjects showed less sensitivity to glare so that, on average, a 1.0 log candelas per square meter or a 10-fold change in luminance was required to shift from one glare criterion to the next. The subject-to-subject variation in susceptibility to glare was substantiated. To achieve the same subjective rating of glare severity, the least sensitive subject required a luminance that was about 2.0 log candelas per square meter higher than that of the most sensitive subject (a 100-fold change).

A small decrease, approximately three percent, in visual task efficiency and a marginally elevated error rate were found under high glare levels.

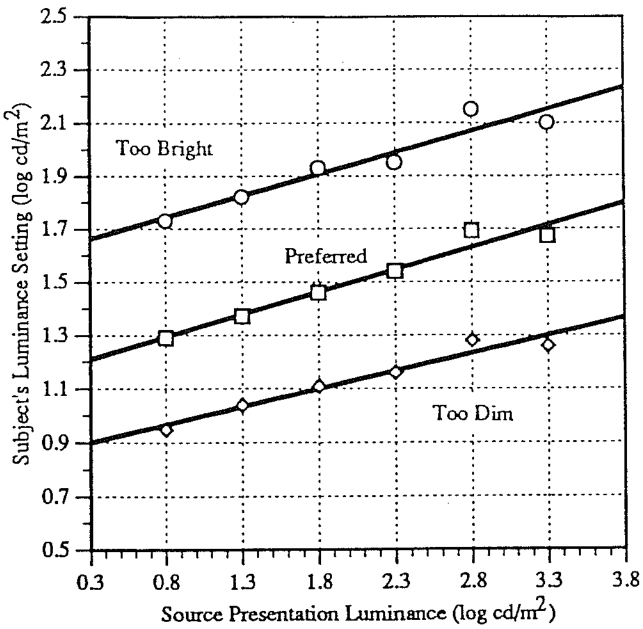

Fig. 4. Mean luminance as adjusted for optimal viewing comfort and the borderlines between imperceptible and noticeable glare discomfort following the six presentation luminances.

Subjects became more sensitive to glare over the course of the 1-1/2 hour experiment, a result that agrees with other studies [6]. Their luminance values for various discomfort criteria were reduced by about 20 percent (0.1 log candelas per square meter).

VI. CONCLUSIONS

The results from this experiment are consistent with the systematic relationship between source luminance and perceived glare discomfort found in previous studies of small and large glare sources. For the glare discomfort criteria employed in this study, a reasonably uniform proportional change was required to shift from one criterion to the next. The mean value for all 26 subjects was found to be 0.65 log candelas per square meter when fixating the center of the VDT screen without actual attention to the task at hand, and 1.0 log candelas per square meter when performing the letter-counting task. This identifies attention to a work task as a relevant variable in the analysis of discomfort glare. We know from experience that we are able to selectively attend to tasks of interest while being relatively unaware of background information not currently required. Discomfort glare has been assessed in previous studies by viewing and rating the glare source directly in conditions that simulate a worker looking up from a work task. For relevance to tasks of today's work environment, it seems important to more carefully consider situations in which the glare source occupies a substantial part of the visual field while subjects actually perform work tasks.

In modern office environments, developments in computer and desktop-publishing technologies have caused the primary work surface to shift from a horizontal desk surface to a vertical display screen surface. For daylit office buildings in particular, the presence of windows introduces potential glare sources in at least one of the four walls of an office space. When a monitor is placed against the window wall, the window opening that is otherwise perceived as an asset can become a substantial source of glare discomfort, depending on outdoor light levels, and may adversely influence task performance. The limited study on the effects of perceived glare discomfort from large sources on visual performance included here indicates that further research is needed. This experiment considered a short-term visual task that was only moderately representative of common real world visual tasks. Similarly, the glare source was not an ideal representation of real world situations. The color temperature, the size, and the structureless appearance of the glare source were all limited and not necessarily representative of common office conditions. This experiment did nothing to consider gradual variations in the luminance of potential glare sources that may change during the day. Although such a study will be difficult to conduct, it appears useful to evaluate task performance in experiments in which subjects are exposed to various levels of glare discomfort for longer periods of time, for example, the eight hours of a regular work day. Decreasing work performance would be expected due to fatigue and distraction induced by glare discomfort. Studies that employ actual windows in the evaluation process would be useful as well, because view content and the experience of a connection to the outside world were found to increase tolerance towards glare from windows in comparison to simple luminous panels of the same dimensions and luminance [7, 8, 9]. Parallel studies by vision scientists of the physiological mechanisms that may be influential in creating glare discomfort might further increase our knowledge of the fundamental processes and open new ways for designing glare-free environments.

ACKNOWLEDGMENTS

This research project was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Building Technologies, Building Systems and Materials Division of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098 and a grant from the Robert M. Thunen Memorial Scholarship Fund of the Golden Gate Section of the Illuminating Engineering Society of North America (IESNA).

REFERENCES

[1] M. Luckiesh and S. K. Guth, "Brightness in visual field at borderline between comfort and discomfort (BCD)," *Illuminating Engineering*, vol. 44, pp. 650-670, November 1949.

[2] S. K. Guth and J. F. McNelis, "A discomfort glare evaluator," *Illuminating Engineering*, vol. 54, pp. 398-406, June 1959.

[3] S. K. Guth, "A method for the evaluation of discomfort glare," *Illuminating Engineering*, vol. 58, pp. 351-364, May 1963.

[4] R. G. Hopkinson and R. C. Bradley, "A study of glare from very large sources," *Illuminating Engineering*, vol. 55, pp. 288--294, May 1960.

[5] R. G. Hopkinson and W. M. Collins, "An experimental study of the glare from a luminous ceiling," *Transactions of the Illuminating Engineering Society (London)*, vol. 28, pp. 142-148, 1963.

[6] R. G. Hopkinson, *Architectural Physics: Lighting*. London: Her Majesty's Stationary Office, 1963.

[7] R. G. Hopkinson, "Glare from windows," *Construction Research and Development Journal (CONRAD)*, vol. 1, pp. 98-105, 1970, vol. 2, pp. 169-175, 1970, and vol. 3, pp. 23-28, 1971.

[8] R. G. Hopkinson, "Glare from daylighting in buildings," *Applied Ergonomics*, vol. 3, pp. 206-215, 1972.

[9] P. Chauvel, J. B. Collins, R. Dogniaux, and J. Longmore, "Glare from windows: current views of the problem," *Lighting Research and Technology*, vol. 14, pp. 482-488, 1982.

[10] T. Iwata, M. Shukuya, N. Somekawa, and K. Kimura, "Experimental study on discomfort glare caused by windows," *Journal of Architectural Planning and Environmental Engineering*, in English and Japanese, pp. 21-33, No. 432, February 1992.