The Effect of Overhead Glare on Visual Discomfort

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Introduction

Formulae systems for predicting discomfort glare nearly all use the Position Index (Luckiesh and Guth, 1949), or simplifications thereof (Fry, 1976), to take account of the deviation of the glare source from the line of sight. While this Position Index can be calculated for a wide range of angles, the standardized conditions used to calculate the Visual Comfort Probability (VCP) data commonly given in photometric data sheets in North America limit the angle above the horizontal line of sight to 53 degrees and less (IESNA, 1993). The implication of this limit is that at greater angles from the line of sight, conventional luminaires are unlikely to cause discomfort glare.

Unfortunately, since the introduction of the parabolic luminaire there have been persistent anecdotal complaints about discomfort occurring when there is a luminaire overhead, i.e. at angles much greater than 53 degrees from a horizontal line of sight, and sometimes even when the luminaire is not in the field of view. At first, it might be thought odd that a luminaire that is at the edge of or even outside the field of view could cause discomfort. However, there are several routes whereby such a luminaire could make its presence felt. First, there is light reflected into the eye from parts of the face adjacent to the eye, such as the nose. Second, there is the possibility of light being scattered at the cornea of the eye, and at the eyebrows. Third, if spectacles are worn, there is the possibility of an image of the luminaire being reflected from the lenses. Obviously, the probability of any of these mechanisms occurring will depend on the facial characteristics of the individual and if they wear spectacles. Nonetheless, if light is reflected from spectacles and facial features and is scattered at the cornea, it can be expected to reduce the visibility of the scene and could be a source of distraction. Thus there are plausible mechanisms for discomfort from luminaires overhead. This paper describes four experiments undertaken to determine the magnitude of discomfort occurring due to a luminaire overhead, for a range of conditions representative of current office lighting practice.

Method

Setting

The experiments were conducted in a 8.8 m (29 ft) by 7.9 m (26 ft) rectangular space with a 2.9 m (9.5 ft) ceiling, fitted with a direct/indirect and a direct lighting installation and a series of fluorescent wall-washers. For

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the experiments, the ambient lighting in the room was provided by two continuous 6.1 m (20 ft) long rows of three-lamp, direct/indirect luminaires. The windows in the classroom were covered with blinds. The blinds and the room surfaces were all finished in shades of white or gray. The ceiling consisted of lay-in fiber tiles (reflectance = 0.83); the walls were white painted plaster (reflectance = 0.81); and the floor was gray carpet (reflectance = 0.11). There were two measurement positions set up in the classroom, symmetrical about the long axis of the room. The chairs on which the subjects sat were located approximately 1.2 m (4 ft) from the long wall on each side and about equidistant from the wall and one line of direct/indirect lighting luminaires. The subject sitting on the chair looked horizontally along the long axis of the room to the end wall approximately 4.3 m (14 ft) away. Two tracks were attached to the ceiling above the subject. Suspended from these tracks was a single luminaire, 1.19 m (47 in) long and 14.9 cd (5.8 in) wide, with the long dimension lying across the subject's line of sight. The luminaire contained six 55 W compact fluorescent lamps, mounted end-to-end, in three pairs. These lamps have a correlated color temperature of 3500K and a CIE General Color Rendering Index of 82. These lamps operated from three rapid-start dimming electronic ballasts. The top, sides and ends of the luminaire were opaque white painted metal. The bottom aperture of the luminaire, which was 1.19 m (47 in) long and 10.2 cm (4 in) wide, was covered with a layer of opal plastic and a panel of prismatic material. The bottom of the moveable luminaire was 2.44 m (8 ft) above the floor. By dimming the lamps, the luminance of the luminaire could be varied over a wide range. By moving the luminaire along the tracks, it could be placed at a defined angle from the horizontal line of sight for an observer sitting in the chair.

The direct lighting element of the direct/indirect luminaire adjacent to the tracks of the moveable luminaire was shielded from the subject's view by a valence attached to the side of the direct/indirect luminaire. For each subject the height of the seat was adjusted to place the subject's eyes at a constant height of 1.2 m (4 ft) above the floor. Because the moveable luminaire contributed such a small amount to the total luminous flux in the room and the interreflection of light in the room was high, moving the luminaire made no noticeable difference to the overall distribution of light in the room. **Figure 1** shows a plan of the classroom, the location of the subject's seating, the location of the cards defining the viewing position and the location of the moveable luminaire.

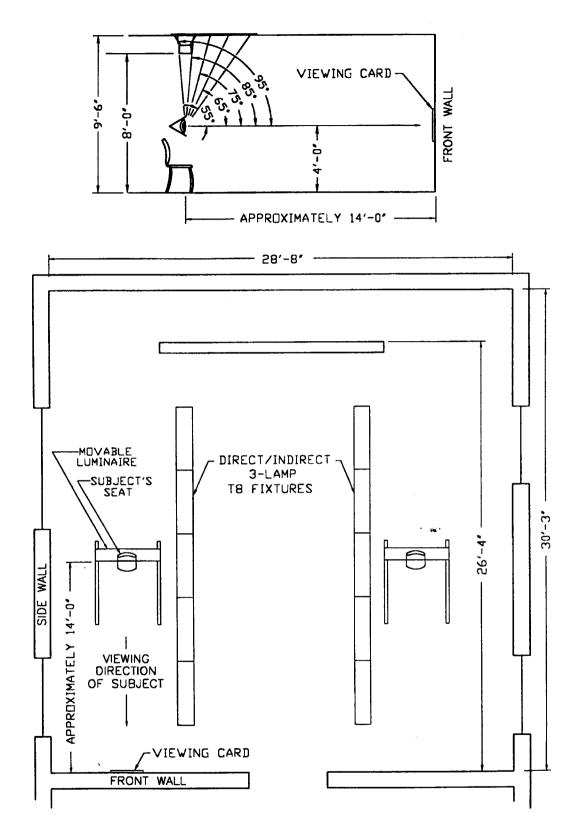


Figure 1—A plan of the classroom showing the location of the subject's seating, the location of the card defining the viewing position and the location of the moveable luminaire.

Subjects

Sixteen subjects took part in the experiment. They were all experienced in lighting. Their characteristics are summarized in **Table 1**.

Table 1-Characteristics of the subjects used

Two different ambient illuminances were used. With only one of the lamps in each direct/indirect luminaire being lit, the average illuminance 0.76 m (30 in) above the floor was 280 lx (26 fc). With two lamps in each of the

direct/indirect luminaires lit, the average illuminance 0.76 m (30 in) above the floor was 506 lx (47 fc). Ambient illuminance was chosen as a variable because it was expected the ambient illuminance would influence the visibility of the indirect effects of having a luminaire overhead, such as light reflected from spectacles. These two ambient illuminances will be called the low and high illuminance.

Three different levels of luminaire luminances were used, the different levels being achieved by dimming the lamps in the moveable luminaire. The three levels were chosen to approximate to the luminances of T12, T8 and T5 fluorescent lamps. The mean luminance of the bottom aperture of the luminaire, measured at three positions on the prismatic panel, from the subjects seated position, for the five different angles, for each level, are given in Table 2. There is clearly some variation in luminaire luminance with angle but not sufficient for the three levels of luminaire luminances to overlap. These three levels will be called high, medium and low luminaire luminance.

The impact of these different luminaire luminances on the lighting of the room can be seen by the changes in luminance of the end wall viewed by the subjects when looking horizontally ahead. These luminances are given in **Table 3**.

Five different angles from the line of sight were used, the five angles being shown in **Table 2**.

This range of angles was chosen to stretch from the conventional end of the Position Index (55°) to an angle where the luminaire would have been behind the subject's head (95°). The angle was measured from the center line of the luminaire.

Sex: 6 male, 10 female

Age range: 22 - 65 years, Median = 45 years, Interquartile range 31-57 years

Wearing spectacles: 5, Wearing contact lenses: 4, Wearing neither: 7

Hair color: Fair = 6, Dark = 8, Brown = 2

Hair projecting forward: 7, Hair not projecting forward = 9

Eyebrows: bushy and extensive = 3; close and small =11, close and extensive = 2

Table 2—Mean luminance of the prismatic panel of the moveable luminaire for each angle from the line of sight, for the three levels of luminaire luminance.

Angle (degrees)	High	MediumLuminance	Low	
	Luminance		Luminance	
55	14,500	7,250	4,785	
65	16,000	8,000	5,280	
75	17,166	8,583	5,664	
85	17,300	8,650	5,709	
95	17,300	8,650	5,709	

Table 3—Mean luminance (cd/m^2) of end wall seen by subject when looking horizontally ahead, for each luminaire luminance level and ambient illuminance (moveable luminaire at 75 degrees above horizontal line of sight).

Ambient Illuminance	High	Medium	Low	
·	Luminaire luminance	Luminaire luminance	Luminaire luminance	
Low ambient illuminance	32.3	28.8	27.4	
High ambient illuminance	60.6	56.1	53.6	

Independent variables

The three independent variables used were ambient illuminance, luminaire luminance and angle from the line of sight.

Table 4-Rating scale used in experiments 1 and 4

Category	Name	Description of Reaction		
1	Imperceptible	I am not aware of anything overhead		
2	Just perceptible	I am aware there is something overhead but cannot tell what it is		
3	Noticeable	I am aware of the presence of the luminaire overhead but it does not bother me		
4	Just uncomfortable	I am aware of a luminaire overhead and I wish it was not there		
5	Uncomfortable	I am aware of a luminaire overhead and I would complain to my supervisor about it		
6	Just intolerable	I am aware of a luminaire overhead and if somebody doesn't do something about it I will take direct action myself		
7	Intolerable	I am aware of a luminaire overhead and I will not stay here a moment longer if somebody doesn't do something about it, now		

Experimental procedure for order

For all four experiments the subjects were split into four groups of four. In each experiment, the order in which the subjects experienced the two ambient illuminances was balanced across the four groups. For each ambient illuminance, the order in which the subjects experienced the different combinations of luminaire luminance and angle was randomized for each subject individually.

Experiment 1: Glare rating scale

Procedure

In this experiment, the subjects experienced all combinations of ambient illuminance, luminaire luminance and angle. For each combination of conditions, the subject was asked to rate their reaction to the luminaire overhead on a seven-point rating scale (see **Table 4**). The scale was printed on a large piece of card that was mounted on the end wall with its center at eye level. The subject could view a condition for as long as he/she wanted before giving a rating.

Results

Figure 2 shows the mean ratings on the seven point scale for every combination of ambient illuminance, luminaire luminance and angle. The error bars around each point represent the 95 percent confidence interval

about the mean rating. Examination of Figure 2 shows a familiar pattern of results. The level of discomfort implied by the reaction to the luminaire decreases with increasing angle, decreasing luminaire luminance and higher ambient illuminance. A three-factor, repeated-measures analysis of variance revealed statistically significant effects of ambient illuminance (p<0.0013), luminaire luminance (p<0.0001) and angle (p<0.0001). There is also a statistically significant interaction between luminaire luminance and angle (p<0.0001) and an almost statistically significant interaction between ambient illuminance and angle (p<0.051). Figure 3 shows the interaction of ambient illuminance and angle. Figure 4 shows the

interaction between luminaire luminance and angle. Post-hoc Scheffe tests showed all three luminaire luminance levels were statistically significantly different from each other and all the angles were statistically different from each other, apart from 55 and 65 degrees.

It seems reasonable to assume the mean scale value corresponding to the condition where discomfort starts to occur is 3.5 (see Table 4). The mean rating for the low luminaire luminance is below this value for all the angles studied and for both ambient illuminances (see Figure 2). For the medium luminaire luminance, the mean rating approaches 3.5 for 55 degrees at the high ambient illuminance but is greater than 3.5 for 55 and 65 degrees for the low ambient illuminance. For the high luminaire luminance, the mean rating exceeds 3.5 for 55, 65, 75 and 85 degrees for the low ambient illuminance and exceeds it for 55, 65 and 75 degrees for the high ambient illuminance. None of the luminaire luminances have mean ratings at 95 degrees which are greater than 3.5. These results suggest that a luminaire overhead can produce reactions associated with discomfort given a high enough luminaire luminance.

Experiment 2: Comfortable? yes or no

Procedure

In experiment 2 the subjects saw the same combinations of conditions as in experiment 1. However, in

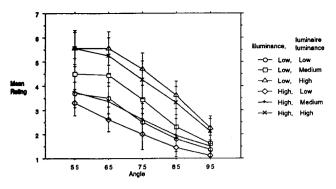


Figure 2—Experiment 1: The mean rating on the seven-point scale for every combination of ambient illuminance, luminaire luminance and angle. The error bars around each point represent the 95 percent confidence interval about the mean rating.

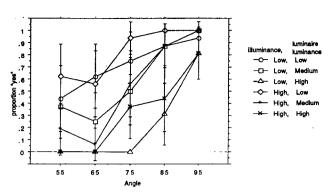


Figure 5—Experiment 2: The proportion of subjects saying they were comfortable for every combination of ambient illuminance, luminaire luminance and angle.

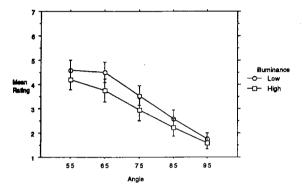


Figure 3—Experiment 1: The mean rating on the seven-point scale for every combination of ambient illuminance and angle, averaged over all luminaire luminances. The error bars around each point represent the 95 percent confidence interval about the mean rating.

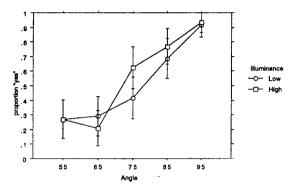


Figure 6—Experiment 2: The proportion of subjects saying they were comfortable for every combination of ambient illuminance and angle, averaged over all luminaire luminances.

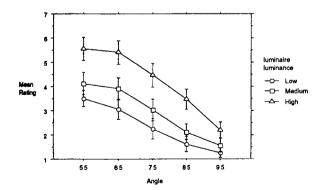


Figure 4—Experiment 1: The mean rating on the seven-point scale for every combination of luminaire luminance and angle, averaged over both ambient illuminances. The error bars around each point represent the 95 percent confidence interval about the mean rating.

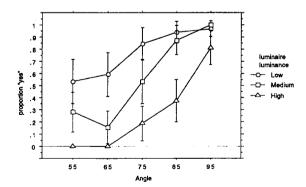


Figure 7—Experiment 2: The proportion of subjects saying they were comfortable for every combination of luminaire luminance and angle, averaged over both ambient illuminances.

experiment 2, they were asked simply to say whether they considered the lighting conditions comfortable or uncomfortable. Again, the subject could view a condition as long as he/she wanted before answering the question.

Results

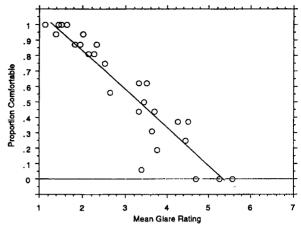
Figure 5 shows the proportion of subjects answering they were comfortable for every combination of ambient illuminance, luminaire luminance and angle. Figure 6 shows the interaction of ambient illuminance and angle. Figure 7 shows the interaction between luminaire luminance and angle. The same pattern of results that occurred in experiment 1 is evident. The proportion of subjects considering the lighting comfortable increases as ambient illuminance increases, as luminaire luminance decreases and as angle increases. Of particular note is the fact that for the high luminaire luminance, at 85 degrees only about 30 to 40 percent of the subjects consider the lighting comfortable. Again, it is evident a high luminance luminaire overhead can be a source of discomfort, even when it is at the edge of the field of view.

One direct comparison between the results for experiments 1 and 2 is possible. Figure 8 shows the proportion of people saying the lighting is comfortable plotted against the mean rating from experiment 1, for all combinations of the conditions examined. The best fitting line through these points allows an estimate of the percentage of people who would consider the lighting comfortable for any given mean rating to be made. It is encouraging to note the percentage of people considering the lighting comfortable for a mean rating of 3.5 is 46 percent. If a mean rating of 3.5 is where the average subject would start to experience discomfort and the distribution of ratings is normal, the percentage of people considering such lighting comfortable should be 50 percent. It should also be noted the data used to calculate the mean ratings and the percentage comfortable were obtained from the same people but on two different occasions, separated in time by about two hours, time which was spent outside the classroom.

Experiment 3: Boundary between comfort and discomfort (BCD)

Procedure

In this experiment the subjects were presented with all the possible combinations of ambient illuminance and angle, and they were asked to adjust the luminance of the luminaire overhead to the boundary between comfort and discomfort (BCD) while looking straight ahead. The adjustment of luminaire luminance always started from the maximum possible.



Proportion Comfortable = 1.327 - .248 * Mean Glare Rating; R^2 = .884

Figure 8—The proportion of people saying the lighting is comfortable in Experiment 2 plotted against the mean rating on the seven-point scale from Experiment 1, for all combinations of the conditions examined.

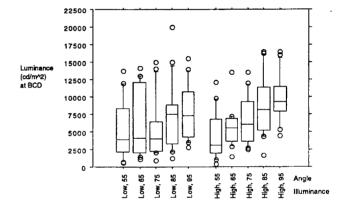


Figure 9—Experiment 3: Box plots of the distribution of luminances set for the boundary between comfort and discomfort (BCD), for all combinations of ambient illuminance and angle.

Results

There were wide individual differences in the luminaire luminance settings made for the same condition, a characteristic of discomfort glare responses in general (Stone and Harker, 1973) and BCD measurements in particular (Luckiesh and Guth, 1949; Bennett, 1977). The variability can be seen in Figure 9, which shows the distribution of the settings made for each ambient illuminance and angle. In each vertical box, the horizontal line in the middle is the median luminaire luminance set. The ends of the box are the 25th and 75th percentiles, the extended lines represent the 10th and 90th percentiles and the individual points are outliers, defined as individual settings beyond the 10th and 90th percentiles. These data distributions are skewed. A log transformation was used to make the data suitable for analysis of variance. A two-factor, repeated-measures analysis of variance applied to the transformed data revealed only one statistically significant effect, that of angle (p<0.015). As angle increases, the luminaire luminance for the BCD increases. This is consistent with the idea that the discomfort is reduced with greater angles from the line of sight. It is also interesting to note the median BCD luminance does not exceed 9,000 cd/m² for any angle, a value which supports the idea that a luminaire with a luminance greater than 9,000 cd/m² will cause discomfort to 50 percent of people, even when it is 85 degrees above a horizontal line of sight. Again, it should be noted these BCD data were obtained from the same people as the data in the other experiments, but at a different time.

Experiment 4: Maximum or average luminance

Procedure

In this experiment the subjects experienced the two ambient illuminances and all five angles but not the low, medium and high levels of luminaire luminance. Rather, the bottom aperture of the moveable luminaire was divided into two equal parts, along the long axis. One half of the aperture was unchanged but the other half had one of three different transmittance filters placed immediately above it. The resulting mean luminances for the two halves of the luminaire at each angle are given in **Table 5**. Examination of **Table 5** shows the maximum luminance is similar for all three filters, but the average luminance for the whole luminaire differs. The reactions to these lighting conditions were given using

the same procedure as was used in experiment 1. This experiment provides a test of the hypothesis that the level of discomfort is determined by the maximum luminance rather than the average.

Results

Figure 10 shows the mean ratings on the seven-point scale for each combination of ambient illuminance, percentage reduc-

tion in luminance for half the luminaire and angle from the horizontal line of sight. The error bars around each point represent the 95 percent confidence interval about the mean rating.

Examination of **Figure 10** shows a similar pattern of results to that occurring in Experiment 1 (c.f. **Figure 2**). The mean rating decreases with increasing angle and with higher ambient illuminance, increasing as the lower

luminance of half of the luminaire increases. A three-factor, repeated-measures analysis of variance revealed statistically significant effects of ambient illuminance (p<0.0011), half luminaire luminance (p<0.0024) and angle (p<0.0001). There were no statistically significant interactions. Figure 11 shows the effect of ambient illuminance at different angles. Figure 12 shows the effect of different half luminaire luminances at different angles. Also shown for comparison is the mean rating for the high luminaire luminance obtained in experiment 1. Post-hoc Scheffe tests showed there were no statistically significant differences between the mean ratings for the zero percent and 10 percent filters but there was a statistically significant increase in mean rating for the 50 percent filter. Observation suggests there is little difference in mean ratings for the 50 percent and 100 percent transmittance conditions. As for angle, all the angles were statistically different from each other apart from 55 and 65 degrees. These results imply the maximum luminance of the luminaire is not the only factor determining the degree of discomfort experienced. The area over which that luminance occurs is also important, the perception of discomfort increasing as the area of high luminance increases.

Discussion

The results presented above show a consistent pattern for three different response measures; mean rating, percentage comfortable and BCD, collected from the same people, viewing the same conditions, but at three different times. The pattern is an increase in discomfort with

Table 5— Mean luminance of the two halves of the prismatic panel of the moveable luminaire, for each angle from the line of sight, for the three filters (cd/m^2) .

Angle (degrees) 55	Zero percent Filter Open Filtered		10 percent Filter Open Filtered		50 percent filter Open Filtered	
	14,333	516	14,333	2,000	15,333	6,633
65	15,333	733	14,666	1,800	15,666	7,000
75	15,333	450	15,333	1,933	16,533	7,766
85	16,500	516	15,833	2,266	17,000	7,466
95	16,500	516	15,833	2,666	17,000	7,466

increasing luminaire luminance and luminaire area and a decrease in discomfort for an increase in ambient illuminance and an increase in deviation from the line of sight. This pattern is exactly what would be expected from the fundamental formulae on which the conventional discomfort glare prediction systems, such as Visual Comfort Probability (IESNA, 1993), Glare Index (CIBSE, 1994) and the Unified Glare Rating system

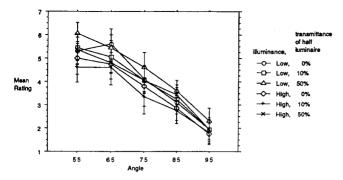


Figure 10—Experiment 4: The mean ratings on the seven-point scale for every combination of ambient illuminance, percentage reduction in luminance for half the luminaire, and angle from the horizontal line of sight. The error bars around each point represent the 95% confidence interval about the mean rating.

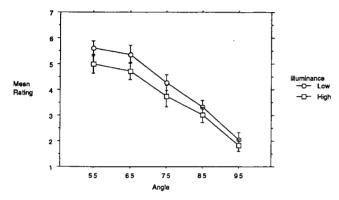


Figure 11—Experiment 4: The mean ratings on the seven-point scale for every combination of ambient illuminance and angle, averaged over all levels of the percentage reduction in luminance for half the luminaire. The error bars around each point represent the 95 percent confidence interval about the mean rating.

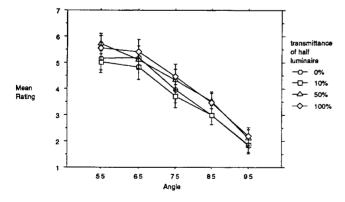


Figure 12—Experiment 4: The mean ratings on the seven-point scale for every combination of the percentage reduction in luminance for half the luminaire and angle, averaged over both ambient illuminances. The error bars around each point represent the 95 percent confidence interval about the mean rating. For comparison, the mean ratings for the unfiltered luminaire (100 percent) at all angles and averaged over both ambient illuminances, measured in experiment 1, are shown.

(CIE, 1995) are based. The effect of increased deviation from the line of sight is also consistent with the results of Kanaya, Akashi and Hashimoto, (1987) who showed reduced glare discomfort for a fixed luminaire luminance as the deviation from the line of sight increased from 61 to 76 degrees.

This finding implies the phenomenon of overhead glare is simply an extension of discomfort glare and not an entirely separate phenomenon. It also implies discomfort glare does not cease at 55 degrees from the line of sight, but continues until the glare source passes outside the field of view. Of course, the data demonstrates the luminaire luminance required to produce discomfort at very high angles, i.e., when the luminaire is overhead, is much higher than is required at lower angles, i.e., when it is closer to the line of sight. Nonetheless, there can be no doubt such luminances are well within the range that can occur with small diameter, high output, fluorescent light sources, seen directly or by reflection in highly specular reflectors.

While the pattern of results is consistent and their implications are important for the design of luminaires, it is necessary to note two limitations in the data. The first is the bias represented by the systematic variation in luminaire luminance with angle. There is a tendency for the mean luminaire luminance at each level to increase as the angle increases, probably because of the distribution characteristics of the luminaire's prismatic panel (see **Table 2**). This systematic increase in luminance with increasing angle would be expected to lead to an overestimate of the mean glare rating and an underestimate of the percentage of people comfortable at the higher angles. However, given the magnitude of the change in luminaire luminance with angle and the fact that the perception of brightness is related to the logarithm of luminance rather than luminance itself, this bias is slight and seems unlikely to be sufficient to explain the trends with angle.

The second limitation is the fact that the subjects consisted entirely of people knowledgeable in lighting who might be expected to be more sensitive to lighting conditions than the average office worker. Again, if the subjects used here are more sensitive to lighting conditions than the average office worker, it would be expected to lead to an overestimate of the mean rating and an underestimate of the percentage comfortable, relative to what would be found for a representative sample of office workers. Of course, it could be argued if the objective of glare prediction systems is to ensure all office workers are comfortable under office lighting, then using a subject group which is more sensitive to lighting conditions than all office workers is the right thing to do. Unfortunately, exactly how the sensitivity to lighting conditions of these subjects compares to that of office workers with no knowledge of lighting is unknown.

These two limitations, together with the importance of the implications of these results for luminaire design and lighting practice, suggest an urgent need for a replication of these studies, using precise control of luminaire luminance and subjects representative of office workers. If such a replication were to produce results similar to those presented here, there would be a need to carefully consider how to use the higher luminance fluorescent light sources now available and to reconsider the suitability of luminaires with strongly downward light distributions for use in offices.

10. Acknowledgments

These experiments were conducted at a workshop organized by Quality of the Visual Environment/Metric of Quality Committee (QVE/MOQ), a joint committee of the IESNA and the IALD. The workshop was held at the Litecenter of Litecontrol Corporation in Hanson, Mass. It is a pleasure to acknowledge the contributions of Litecontrol, who supported this study by making their staff and facility available and by feeding the participants; the skill of the technicians at Peerless Lighting who constructed the moveable luminaire; and the participation of all the subjects.

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Discussion

This paper is a nicely conceived and executed pilot study which lays out a testable hypothesis, selects and applies appropriate and varied test protocols and provides intriguing data for the lighting community to consider. Using four different experimental protocols, the authors demonstrate that luminaire position, luminance and ambient illuminance interact to influence the perception of visual discomfort, and luminaires located overhead do produce discomfort, particularly if their luminance is sufficiently high. The authors relate these findings to those of glare and suggest similar mechanisms may be involved in the perception of both visual discomfort and glare. The major question raised by the study is the fact that the subjects were all experienced lighting professionals who would be more likely to be aware of the changes in luminaire position and its possible relationship to visual discomfort. Do the authors plan to repeat the study with a naive group of subjects, now that they have determined the experimental protocols are appropriate? Would the use of the discomfort metrics within a visual task be a useful way to determine if the effects observed in this paper are sustained during normal office work? Certainly, the authors should be encouraged to continue their approach and continue to demystify the models of visual discomfort and glare to provide guidance for luminaire and office design.

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This paper investigates the degree to which the discomfort glare index used by the IESNA (Visual Comfort Probability-VCP) adequately addresses light emanating from angles to the line of sight greater than 53 degrees to the horizontal (the limit of VCP calculation). The authors suggest facial features (e.g. prominent eyebrows), reflections from the back surface of spectacle lenses, or scatter from the cornea and contact lenses could make luminaires from high angles a significant source of discomfort and disability glare. Only discomfort glare is addressed in this paper.

Although subjects were employed who differed in facial characteristics, spectacle wear and contact lens wear, data from all subjects were grouped in the results. Consequently, no conclusions are available with regard to the hypotheses suggested in the introduction.

A modified BCD (borderline between comfort and discomfort) scale was used to evaluate the degree of discomfort experienced by the 16 subjects.

Perhaps not surprisingly, discomfort ratings increased with both luminance and luminaire area. This is consis-

tent with virtually all glare-rating systems recommended by the IESNA and CIE. The study does point out, however, high luminance luminaires may be significant sources of glare well beyond the 55 degree limit suggested by the VCP glare-rating system. Furthermore, the authors point out, just because a luminaire may have a relatively sharp vertical cutoff, it may still be capable of producing discomfort glare symptoms.

It would be interesting to know the degree to which these results are quantitatively predicted by the various discomfort glare-rating systems — especially the Unified Glare Rating, endorsed by the CIE.

> Alan L. Lewis Michigan College of Optometry

Authors' response

We thank both Belinda Collins and Alan Lewis for their thoughtful comments. The fact that the subjects were all knowledgeable in lighting is certainly likely to have had an effect on the results obtained. Other work has shown that people knowledgeable in lighting tend to be more sensitive to lighting conditions than those naive in lighting, although the direction of the effect is the same. The question that needs to be asked is whether the responses of the lighting experts are so different from the lighting-naive that they cease to be representative of the mass of the population, or do the lighting experts simply represent the most sensitive extreme of the normal distribution. If this latter is the case, then the use of lighting experts can be justified on the basis that meeting their responses will ensure none of the rest of the population will experience discomfort. The answer to this question can only be given by repeating these measurements using lighting-naive subjects, something we would like to do. If such an experiment showed lighting-naive people also experienced visual discomfort from luminaires overhead, in some conditions, then it would be desirable to validate such laboratory findings in the field. This could be done by examining office workers' perceptions of discomfort from luminaires overhead, for a large number of lighting installations, using different luminaire types, covering a wide range of luminaire luminance. We believe this process would answer the question as to whether the experience of visual discomfort from luminaires overhead is sustained during normal office work.

Alan Lewis points out no conclusions can be reached with regard to hypothesized causes of discomfort glare from luminaires overhead. This is correct. We do not have enough subjects to enable us to separate the subjects into various types and to treat each group separately. It would be interesting to know which combination of the possible causes listed was most closely related to the experience of discomfort glare from luminaires overhead, but that will have to wait until an experiment is completed with that objective in mind.

Finally, it would indeed be interesting to know the degree to which these results are quantitatively predicted by the VCP and UGR discomfort glare prediction systems. Unfortunately, we do not have all the photometric data required to make the necessary calculations. If we do replicate the experiment using lighting-naive subjects, we will be sure to collect the necessary data to examine this question.