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THE INFLUENCE OF SPECTRAL COMPOSITION ON DISCOMFORT GLARE FOR LARGE SIZE SOURCES

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ABSTRACT

We have previously demonstrated that brightness perception in full field is influenced by scotopic luminance, even at light levels in the photopic range. We asked here if glare discomfort is distinguishable when comparing a scotopically enhanced source with a scotopically deficient source at the same photopic luminance. Similarly to our previous study on discomfort glare, we used both objective and subjective techniques to assess glare response.

Discomfort glare responses were assessed for 12 subjects who viewed two broad-band glare sources (illuminants) of size 1.22 x 0.91 m (4 x 3 ft) with maximum photopic luminances of 3,700 cd/m^2. The two sources were approximately matched for photopic luminance but due to their spectra they had markedly different scotopic luminances. Both sources were presented separately at three different photopic luminance levels. These six glare conditions were each presented five times, for four second periods, in a randomized sequence. Electromyographic (EMG) responses from the facial orbicularis oculi muscles were subjected to Fourier analysis and integration of the power spectrum provided a measure of EMG activity. Our objective index of the response to glare was the ratio between EMG samples taken before and during the presentation of the source. For the subjective method, discomfort severity was indicated by subjects marking a Visual Analog Scale (VAS) punctuated with four descriptors - perceptible, annoying, disturbing and intolerable.

Both objective and subjective indices systematically increased with increasing luminance. However, the objective measure showed a significantly higher value for the scotopically deficient source at all luminances, while the subjective response was higher only at the greater luminances.

We conclude that discomfort glare is related to both the photopic luminance of the source, and its spectral composition with the absence of long wave length energy in the spectrum associated with lower levels of discomfort.

INTRODUCTION

The negative subjective reaction elicited by the presence of light glare is generally referred to as the discomfort glare effect. The luminances and geometrical conditions that increase or decrease the level of subjective response have been studied extensively over the past 50 years and various formulae have been generated that are used as guidelines for recommended lighting practice in both interior and exterior conditions.[1-5] However, in terms of responses dependent on the spectral composition or color of the glare source, there is a very limited body of information which is mostly concerned with small size sources of order 1° visual field and conditions more relevant to night driving.[6-8] These studies generally indicate that for a given level of adaptation luminance and glare source luminance, the negative subjective reaction to small size glare sources is less when the colors are warmer rather than cooler, i.e., for a given subjective criterion such as "just admissible" a lower luminance level of bluish source (mercury lamp) is obtained when compared to a yellowish source (LPS). Recently, Flannagan et al,[9] have studied glare discomfort reaction to small nearly monochromatic sources of angular subtense of approximately 1° under conditions of very dim surround luminance (adaptation) (.035 cd/m^2) and have concluded somewhat differently that discomfort is less in the middle spectrum range and increases both towards the blue and red spectral limits. We have found no studies that consider spectrum or color when the source size, adaptation levels and illuminances are typical of conditions corresponding to standard fluorescent lamp troffers or windows in buildings.

The question of spectral aspects of discomfort glare response is also of interest because, even though discomfort glare has been studied extensively, to this day we have yet to achieve a satisfactory etiology. A number of investigators including Hopkinson,[10] Fry,[11] Fugate and Fry[12] have claimed a close association between pupillary function and the discomfort glare response. Because the iris is known to contain pain fibers and is also central to pupillary movement, a hypothesis relating discomfort glare and pupillary function might appear as reasonable. Many in the vision and lighting community appear to subscribe to this premise.[13]

By examining spectral responses to discomfort glare it might be possible to provide some test of the discomfort glare–pupillary function hypothesis. It has been well established that over a wide range of "photopic" luminances the spectral response of the pupil for large fields of view is primarily scotopic.[14,15,16] In addition, we have found[17] that brightness perception, for almost full fields of view and luminances typical of building interiors exhibits a large influence of scotopic spectrum. Thus, it can be hypothesized that if there is a close relationship between pupillary function and discomfort glare response, scotopically enhanced large field sources should elicit greater discomfort responses than scotopically deficient sources for equal photopic luminance conditions.

In the study described here we have used both a variant of the traditional subjective scaling methodology[18] and the electromyographical methodology previously employed by the authors as a means to determine an objective correlate to the reported perceptions of discomfort glare.[19] Our results show for a wide range of luminances, contrary to the above hypothesis, that the scotopically enhanced source produces less discomfort for both subjective and objective measures when compared to the scotopically deficient source.

SUBJECTS AND METHODS

Subjects

Twelve subjects aged between 21 and 32 years each participated in one session lasting approximately 90 minutes. Informed consent was obtained from all subjects after explanation of the purpose of the study. The volunteer subjects were students and were paid for their participation. Seven of the subjects were female, seven were Caucasian, and five were Asian. Two subjects wore spectacles and six wore contact lenses. Subjects sat in a comfortable chair inside a cage whose purpose was to reduce EMF interference emanating from the light sources thereby reducing any effects on the electromyographic sensitivity (see Fig. 1).

Glare Sources

The glare sources consisted of two spectrally broad-band sources 1.22 x 0.91 meters, positioned 1.5 meters from the subject each subtending a visual angle of 24° x 33°. Each source consisted of sixteen identical (F40, T12) fluorescent tubes behind opal Plexiglas producing a maximum photopic luminance of around 3,700 cd/m^2. The two sources, either cool-white lamps or Sylvania phosphor #213 lamps (referred to here as F213), were matched for photopic luminance but, due to their spectra, had markedly different scotopic luminances[†]. The ratio of scotopic luminance to photopic luminance (S/P ratio) was 1.49 for the cool-white lamp and 4.31 for the F213 lamp. The spectral distribution of the F213 lamp is principally a narrow peak at 505 nm with a 30 nm width at half maximum providing a greenish-blue color. The luminance of each source was modified by controlling the number of illuminated lamps behind the Plexiglas diffuser. The luminance of the glare source did not vary by more than 10% within the central 80% of the illuminant.

† Spectral distribution weighted by the scotopic luminosity function (V'_λ)

Adaptation Conditions:

Discomfort glare was assessed under three adaptation conditions in a randomized order. These conditions were chosen to cover moderate and low luminance adaptations and to provide some information about the effects of fixation position.

1. Moderate room illumination (wall luminance = 12 cd/m^2) and subjects fixating between the glare sources.
2. Moderate room illumination (wall luminance = 12 cd/m^2) and subjects fixating source as illuminated.
3. Low room illumination (wall luminance = 0.1 cd/m^2) and subjects fixating source as illuminated.

Glare Conditions:

For each of the three experimental conditions, discomfort was assessed using both objective and subjective methods in a single experimental session. The order was randomized with respect to both experimental condition and measurement method. For both methods, each subject was exposed to three different test glare luminance levels for each source, ranging from 878 to 3,740 photopic cd/m^2 in roughly equal increments. This corresponded to the measured vertical illumination levels at the subjects eye ranging from 203 to 810 lux. Each test luminance level was presented five times in a randomized order giving a total of 30 trials per adaptation condition (3 luminances, 2 sources, 5 times). For each trial, the glare source illuminant was energized for a four second exposure, separated by between four and seven seconds. Each experimental run lasted approximately five minutes for each of the three adaptation conditions.

Objective Assessment of Discomfort Glare

This methodology is discussed more fully in reference 19 but briefly reviewed here. At the beginning of the session, three silver/silver chloride surface disc electrodes, 3 mm in diameter, were placed on the subject. Two were positioned just above the eyebrow, the first vertical from the inner canthus and the second was 10 mm to the temporal side of the first. The use of two closely lying electrodes allows for a significant noise reduction due to distal muscular activity by using the common mode rejection technique. In this case, the difference signal between the paired electrodes that are mounted on the facial skin at the orbicularis oculi, is obtained and amplified by the signal processing system. Distal signals are likely to be common to both electrodes and would be eliminated by the differencing procedure. This common mode rejection technique is generally recommended by EMG researchers.[20,21] The third electrode served as a ground and was placed high on the subject's forehead. Prior to application, the skin was cleaned with alcohol and skin resistance lowered by light rubbing with a mildly abrasive skin preparation lotion (Omni-Prep). Annular self-adhesive electrode washers (In Vivo Metric E401) were then placed on the appropriate skin locations. The electrodes were then fixed to the skin with a conductive electrode paste (Ten 20). The electrodes were connected to a Grass amplifier. The amplified signal was then relayed to a IBM 386 computer via an analog to digital converter (Data Translation) and sampled at 3000 Hz.

For each of the 30 trials, EMG activity in microvolts was recorded for six seconds, commencing two seconds before the source was illuminated. Data were analyzed on trial by trial basis by taking two 1.36 second EMG samples. The first sample was from the beginning of the trial and reflected the absence of glare. The second sample was taken from near the end of the 4 second glare trial period and reflected the presence of glare source. Each EMG sample was subjected to Fourier analysis which determined the relative amount of power at each frequency. Frequencies below 10 Hz and at 60 Hz along with its harmonics were removed digitally to eliminate blink and power line artifacts. The FFT power spectrum was then integrated over frequency (by determining the area under the power spectrum) in order to provide an index of EMG activity. An example of the FFT spectrum, with and without the glare source is shown in Fig. 2. The ratio between these two integrals (during and before glare exposure) was used as an index of discomfort. We calculated an *Objective Discomfort Ratio* (ODR) by applying the following formula:[19]

$$\mathbf{ODR} = \frac{\text{Integrated EMG power spectrum with glare source}}{\text{Integrated EMG power spectrum without glare source)}} - \mathbf{1}$$

A value of zero for the ODR reflects no change in EMG activity, while a value of one represents a doubling of activity. ODRs were averaged across trials and determined as a function of glare source luminance for each experimental condition.

Subjective Assessment of Discomfort Glare

For the subjective assessment of discomfort glare, we used a visual analog scale an approach similar to that employed by several workers.[3,22] This technique has been found to be more reliable than the method of adjustment and 2-alternative force choice testing.[18] The visual analog scale comprised a 100 mm horizontal line with a series of demarcations. These marks were positioned to signify the borders between perceptible, annoying, disturbing and intolerable discomfort. Subjects were provided with written descriptors of each of these sensations at the beginning of the experimental session (see Appendix) and the key words were displayed at the top of all recording sheets. Subjects were instructed to place a line or check mark on the scale to indicate their perceived level of discomfort. For example, a source which the subject felt was annoying but did not approach disturbing discomfort might prompt the subject to mark the scale as shown in Fig. 3. The subjects' marks on the VAS scale were identified to the nearest millimeter with values ranging from 0 to 100. Values were averaged across trials and plotted as a function of glare source luminance for each experiment condition.

Data Analysis:

Prior to statistical analysis for each subject, both the objective and subjective responses (ODR and VAS) were averaged over the five repeated presentations for each of the 3 test source luminances, 2 test illuminants (CW and F213) and the 3 adaptation/fixation conditions. The dependent variable, (either objective or subjective response) was then analyzed using a repeated measures Analysis of Covariance (ANCOVA) design with 18 repeated measures (3 source luminances, 2 illuminants and 3 adaptation/fixation conditions) per subject. The ANCOVA design rather than the ANOVA design was necessitated because the study had unbalanced luminance conditions. The three test source luminances for each lamp type were provided by powering 1/4, 1/2, or all of the battery of the 16 fluorescent lamps which composed a test source. Because of their different phosphors, the actual test source luminances (at the diffuser midpoint) differed slightly (935, 1870, 3740 cd/m^2 for the CW source and 878, 1755, 3510 cd/m^2 for the F213 source). We used the BMDP-5V statistical analysis program[23] which is designed to handle unbalanced factors. These lamp luminances are analyzed as covariates which covaried across the repeated measures.

Based on our past work and various other studies we used log luminance as the independent variable. Attempts to include both log linear and log quadratic terms did not improve the analysis because of the small luminance range in logarithmic units. The essentially collinear log quadratic and log linear luminance terms made the quadratic term non-estimable.

The data were also analyzed separately for each adaptation condition using again the ANCOVA procedure.

RESULTS

The ODR and VAS values for each of the 3 adaptation/fixation conditions are shown in Figures 4 and 5. For the objective case the full ANCOVA yielded a highly significant and surprising effect of test light source ($X^2[1dF] = 9.37$; $p = 0.002$) with the ODR values for the lower S/P lamp (CW) on average higher than the ODR values for the F213 lamp. The average difference was 0.1 (s.e. = 0.03). There was a highly significant effect of test source luminance ($X^2[1dF] = 25.2$; $p < 0.0001$) as well as a significant effect of adaptation condition

($X^2[1dF] = 8.9$; $p = 0.012$). There was also a significant interaction effect between light level and adaptation condition ($X^2[1dF] = 12.7$; $p = 0.002$). This indicates that the slopes of the ODR values as a function of log luminance are different for the different adaptation conditions.

For the subjective case, the full ANCOVA yielded a highly significant effect of adaptation condition; ($X^2[2dF] = 63.4$; $p<0.0001$); luminance level ($X^2[1dF] = 207.1$; $p<0.0001$) and test light source ($X^2[1dF] = 8.2$; $p=0.004$). In addition there was a highly significant interaction between test source and luminance level ($X^2[1dF] = 8.8$; $p=0.003$) indicating that the slopes of the VAS function with respect to log luminance were different for the two test sources and that the functions would cross (see Fig. 5 and below) at some luminance value.

The results of the separate ANCOVAs for each adaptation condition for the objective and subjective responses are shown in Tables 1 and 2, respectively. For the objective case, the absence of any interaction effect between test source type and luminance level allows a comparison between the effect sizes. This is especially interesting for condition 3 (dim room) where the S/P effect size is about 22% of the luminance effect size. For the luminance variation of our study this is worth roughly 500 cd/m^2, i.e., to achieve the same objective response the scotopically enhanced source would have to be raised on average 500 cd/m^2 over the scotopically deficient source. In condition 2 (moderate background illumination) the luminance effect size and the test source effect size are comparable indicating an even more severe effect of spectrum in comparison to luminance level. For condition 1 (subjects fixating between sources) the spectrum effect failed to reach significance. Taken together the three conditions provide a strong indication of a significantly greater objective response produced by our subjects to the scotopically deficient light source.

The results for the separate analyses for the subjective case show clearly the interaction effect between luminance level and test source. At the lowest test luminance levels the higher S/P source elicits a higher level of subjective discomfort, but at the two higher levels of test luminance the opposite occurs, i.e., the scotopically deficient source elicits the higher level of subjective discomfort as was the case for the objective measure. The crossing point occurs in the subjective description region defined as "annoying" VAS values between 35 and 40 (see Fig. 3). Note that the slopes for the three adaptation levels for each of the two sources are the same which follows from the lack of a significant interaction effect between light source and adaptation condition. An interpretation of this behavior of the subjective responses is provided below in the discussion section.

DISCUSSION

The results of this study clearly demonstrate that both the objective and subjective responses to glare discomfort caused by the large size sources increase in intensity with increasing source light level in the photopic luminance range from 900 cd/m^2 to 3,700 cd/m^2. The analysis of the data shows a highly significant light level effect for both the objective and subjective measures. The results for the objective measure (the EMG response) show the surprising and unexpected result that the scotopically deficient source, i.e., the source with more energy in the reddish end of the spectrum elicits a significantly larger glare response than the scotopically enhanced source. This result also occurs at the higher test source luminances for the subjective responses, whereas the opposite situation occurs at the lower test source luminance.

It is possible that although both subjective and objective measures increase with source luminance, they are not always measures of the same phenomena. Both discomfort and brightness perception could be a factor in the subjective evaluation. For the lowest test luminance studied about 1000 cd/m^2, subjects VAS ratings were generally in the "perceptible discomfort" range and below the "annoying" level. In this condition the VAS rating was higher for the scotopically enhanced source compared to the scotopically deficient source, while the opposite difference occurred for the ODR values. We believe that this is due to subjects using, in part, a perceived brightness criterion to indicate their rating. We have previously demonstrated[17] that perceived room brightness is higher for scotopically enhanced illumination compared to scotopically deficient illumination at equal photopic luminance and propose that the same effect is occurring in this study at the lower source luminance condition. As the test luminance rises, the discomfort level is more pronounced overtaking the less distinctive brightness feature as is the case for the VAS ratings as they move upwards to the annoying level. On the other hand it is unlikely that the objective response which measures electrical activity in the orbicularis oculi muscle is responding the brightness perception. Thus, the ODR measure does not show the crossing effect present in the VAS measure.

Recently Flannagan et. al.,[9] have reported on the effect of spectrum of a glare source on subjective discomfort rating. They used a slide projector to present a small angle glare source coupled with interference filters to provide spectrum variation. Their glare source produced four different levels of illumination at the subjects' eye ranging from about 3 lux to 0.03 lux while background (adaptation) level was set at about 0.034 cd/m^2. The glare source luminances are not stated but from information in their report the luminance range can be determined as approximately 8,500 cd/m^2 to 85 cd/m^2 based on our estimation of the view angle subtended by the glare source, i.e., about 1°. They found that discomfort is least at 577 nm and increases considerably when the glare source color was blue or red. The pattern of discomfort with respect to wave length was similar for all four levels of glare source illuminance. The observed pattern is similar to what would be observed if the judgements were based on brightness perception for small visual fields rather than discomfort.[24] Even their highest luminance value is lower than the value we[19] measured for the onset of discomfort for similar size glare sources. For their conditions we calculate a luminance of about 12,000 cd/m^2 as the value where the onset of discomfort should occur. This is based on our data[19] and extrapolating to their lower adaptation luminance by use of the measured adaptation power law.[1,7] Thus, it is possible that brightness judgements are confounding the judgements of comfort levels. This effect is probably exacerbated as subjects attempt to fit the extremes of the allowed subjective ratings within the extremes of luminance conditions provided.

For the subjective case, the crossing behavior of the responses for the two spectrally different sources allows the possibility of a more appropriate and less arbitrary procedure for determining a luminance value for the onset of distinct discomfort. This demonstration is usually described by the border between comfort and discomfort (BCD), a measure often used in lighting design. Our hypothesis of the mechanism underlying this crossing effect is the opposing spectral character of brightness and discomfort. The crossing occurs when the discomfort elicited outweighs the brightness perception. This crossing luminance point can be defined as the empirically determined value for distinct discomfort or perhaps for BCD. For the conditions of this study the crossing occurs at the source luminance of approximately 1700 cd/m^2 for all three adaptation conditions. The crossing occurs at the same luminance point because the significance level of the interaction effect between adaptation and luminance level was insufficient, i.e., the slopes for all three adaptation conditions are not significantly different. Examination of the mean values for condition 3 (dim room) shows (see Fig. 5) a possible trend towards a crossing point at a lower luminance value, but verification of this feature would require repeating the study with a larger number of subjects. Since we would expect any methodology for determining a practical BCD to find a lower value for condition 3 as compared to conditions 1 and 2 we view the crossing concept as promising, but needing further study.

A suggestive hypothesis to account for the generally larger discomfort levels obtained for the scotopically deficient test source (CW lamps) is based on the proposition that the discomfort should be related to retinal illuminance rather than source luminance. If the scotopically deficient source produced, on average, larger pupil sizes than the scotopically enhanced source, then the concomitant retinal illuminance would be larger with a subsequent possible higher level of discomfort.

Subject pupil sizes were not measured during the test sessions. However, some exploratory estimations of pupil size variation were made at a later date by the use of a video camera and subsequent direct measurement of the video frames with a micrometer. Eight subjects (4M and 4F) were evaluated by this procedure under adaptation conditions 1 and 3. Five of the eight had been participants in the glare study.

Pupil size did have a small, but statistically significant variation with source luminance for both the dim and moderate adaptation condition. Typically average pupil areas diminished by about 20% between the lowest and highest test source luminances. The smallest mean pupil diameter for the F213 source at its highest luminance was approximately 3.5 mm indicating that pupils were most likely not saturated.

There was a tendency for pupils to be larger for the scotopically deficient source. However, this exploratory data was inadequate to test the hypothesis that a sufficient increase in retinal illumination would occur to account for the large effect of source luminance determined by our results. Detailed measurements of pupil size by infrared pupilometry for the study participants under the three adaptation conditions is being undertaken. Subsequently, we will apply our ANCOVA procedure to perform the full statistical analysis based on the individually variable retinal illuminances for the two source types caused by subjects' intrinsically different pupil sizes. This analysis will permit a test of the retinal illuminance hypothesis.

Taken together, i.e., the lesser influence of the scotopically enhanced source on the discomfort evaluations and the presence of pupillary activity in the range of luminances studied, we find little evidence for the hypothesis of a connection between discomfort glare response and the pupillary channel. Our previous study[25] examining changes in pupillary hippus due to the presence of discomfort glare also showed no effect. Although our studies do not investigate the origins of discomfort glare, we believe it is unlikely that the pupillary channel is primary in its etiology.

Should the retinal illuminance hypothesis fail to explain the lower discomfort responses for the source with less energy in the long wave length portion of the spectrum, then considerably more speculative hypothesis might be considered such as the possibility of a larger net discomfort signal related to the more populous long wave length cones. However, in the absence of prior knowledge supporting such a conjecture, we strongly recommend further confirmation of the results reported here.

CONCLUSION

We conclude the use of scotopically enhanced light sources operated at the same or lower photopic luminances is likely to elicit a lower level of discomfort glare response.

Acknowledgments

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Table 1. The main results of the separate ANCOVAs for the ODR values (objective measure) for the 3 adaptation conditions.

	Condition 1			Condition 2			Condition 3		
	X^2	p	Effect Size	X^2	p	Effect Size	X^2	p	Effect Size
test source	1.6	0.21	n.s.	10.9	0.001	.12 (0.04 s.e.)	5.0	0.026	0.15 (0.06 s.e.)
luminance level	13.0	<0.0001	0.2 (0.06 s.e.)	4.0	0.047	.15 (0.07 s.e.)	24.0	<0.0001	0.68 (0.14 s.e.)

Table 2. The main results of the separate ANCOVAs for the VAS values (subjective measure) for the 3 adaptation conditions.

	Condition 1		Condition 2		Condition 3	
	X^2	p	X^2	p	X^2	p
test source	3.6	0.059	8.7	0.003	6.9	0.009
luminance level	117	<0.0001	129	<0.0001	263	<0.0001
interaction effect	3.5	0.060	8.6	0.003	9.0	0.003

APPENDIX

Instructions to Subjects

We will require you to rate the glare source using the scale provided. The scale consists of these four levels:

Perceptible

The point at which you would prefer the light not to be present. Imagine that it is a pilot light on a computer and you are obliged to set the pilot light on/pilot light off. This is the level at which you would begin to care about such a decision.

Annoying

You could live with this glare source present if you were borrowing someone else's computer for a day. If this glare source were present, you would prefer to remove the glare source if it were possible, but could live with this annoyance for the next hour or so.

Disturbing

This makes you feel uncomfortable. If you had to work like this for any reasonable length of time, (5 minutes or so), you would do something to cover the source, shield your eyes, etc., in order to avoid the discomfort.

Intolerable

You could not imagine yourself working with the light source like this. You would certainly close your eyes or take another avoidance action.

Figure 1: Experimental set-up.

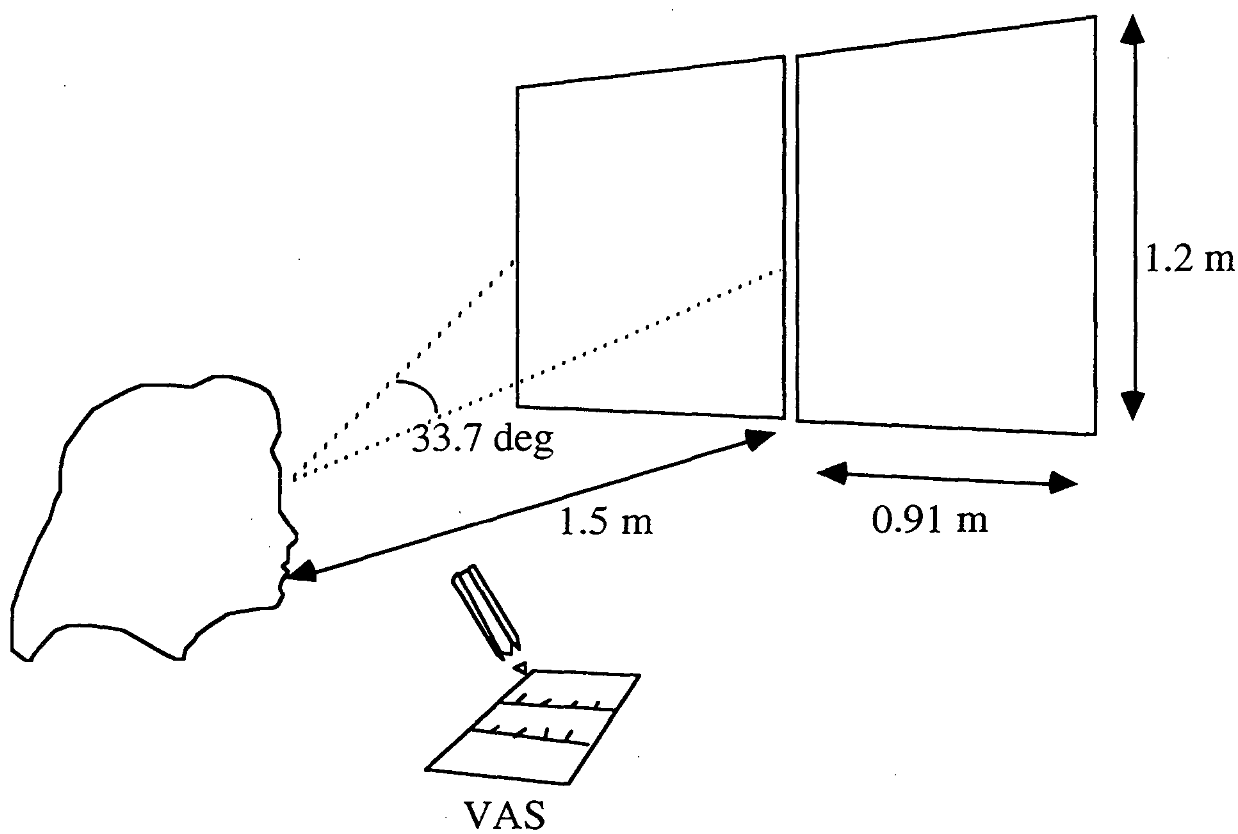


Figure 2. The influence of a glare source on the FFT power spectrum. The introduction of the glare source produces a marked increase in power at all temporal frequencies above 10 Hz. Note that power line artifacts have been removed by digitally filtering frequencies and 60 Hz and its harmonics.

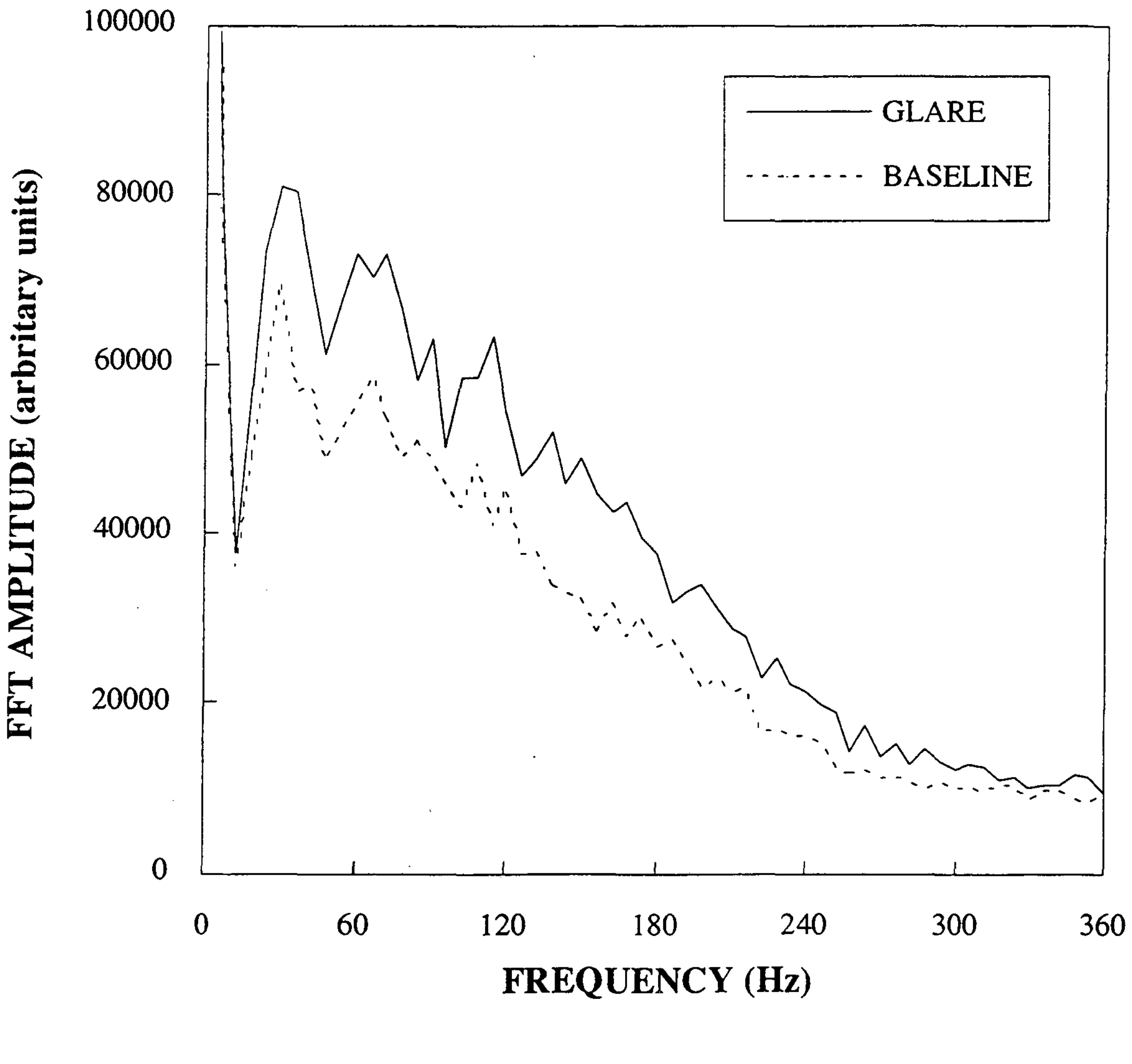


Figure 3: Visual Analog Scale (VAS) used in the subjective assessment of discomfort glare. The check mark represents a VAS score of 35 and corresponds to a glare source which is annoying but does not approach disturbing. The numbers represent distances in mm (from the left end) and are not displayed to the subject. See appendix for full description of the scale.

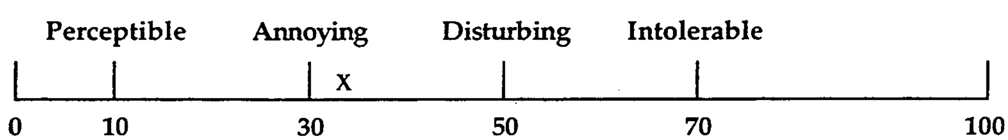


Figure 4: Objective Discomfort Ratio (ODR) as a function of glare source luminance. Error bars represent one standard error from the mean.

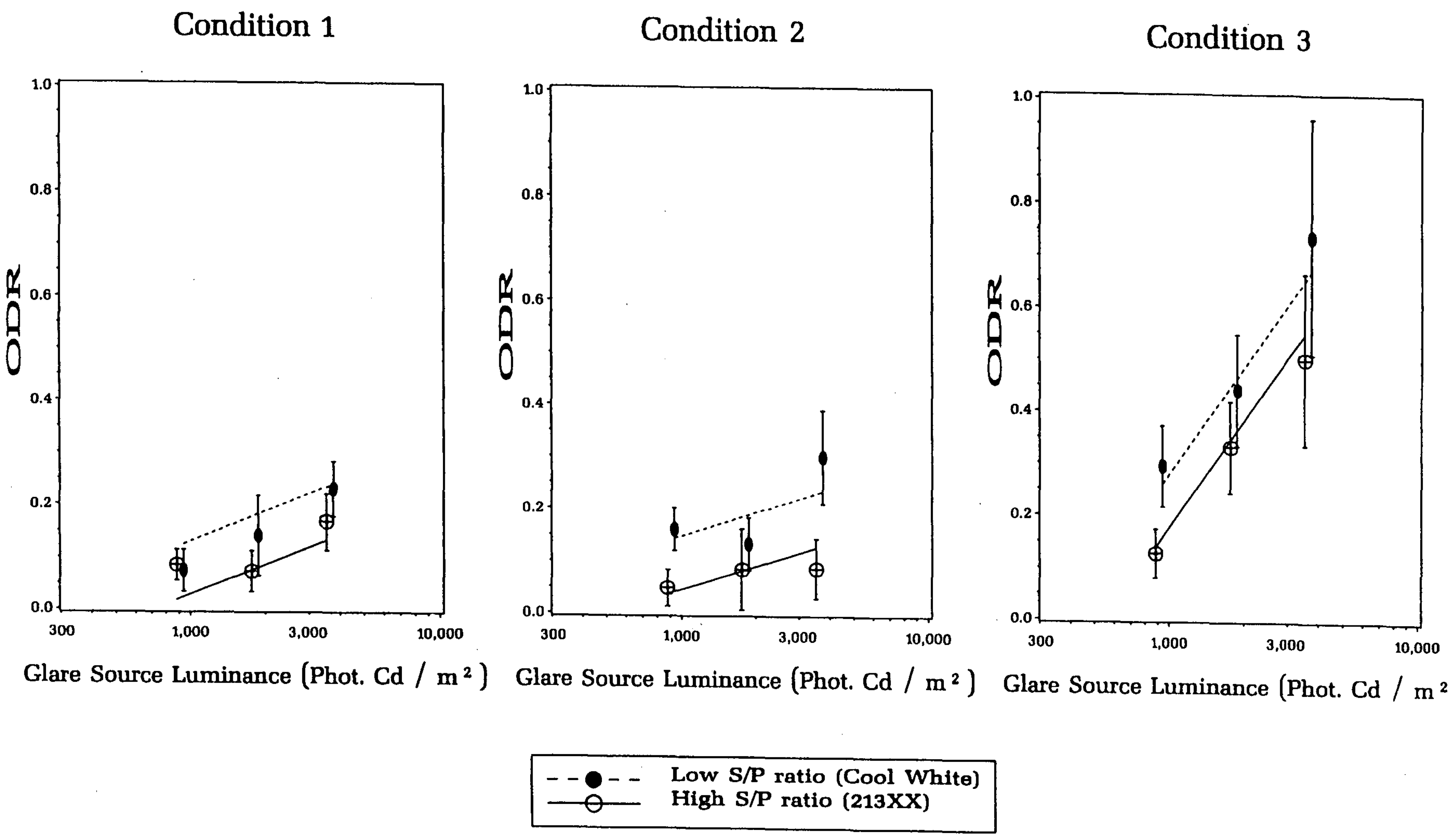
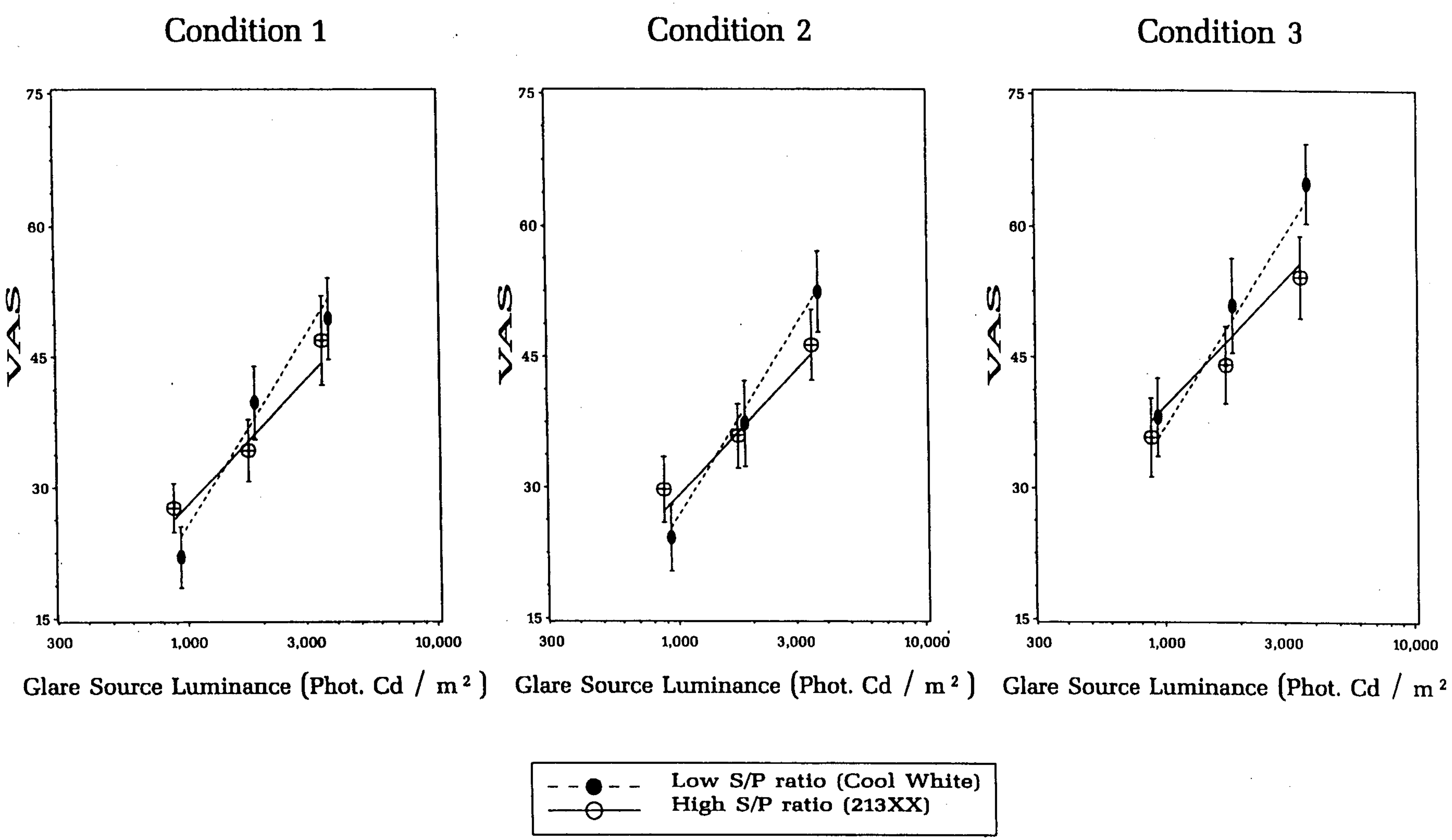


Figure 5: Subjective Discomfort Ratio (VAS) as a function of glare source luminance. Error bars represent one standard error from the mean.



Discussion:

Dr. Berman and his colleagues have provided a fascinating examination of the relationships between spectral composition of the light source and objective and subjective glare. Contrary to their hypothesis that glare would be greatest for scotopically enhanced lights, with more blue-rich light which would tend to shrink pupil size, they found that glare was greatest for scotopically deficient lights - on both objective and subjective glare measures. Thus, the red-rich light source produced 'glare' which increased with increasing source luminance and adaptation luminance. These results suggest that the glare response may not be mediated by the pupillary response as others have suggested. Berman proposes a subsequent analysis to examine the hypothesis that greater retinal illuminance due to greater pupil size may have accounted for their results (not enough pupil diameter data were obtained in the present experiment for statistical significance - although they do show a trend in the hypothesized direction).

Would the authors please comment on whether they randomized the order of presentation of stimuli as order effects could have affected the subjective measures? Could they comment on the probable effects of source size? Would smaller, more peripheral sources produce similar results? Their conclusions that the subjective data may in fact be rating of brightness, rather than glare, at lower luminances are interesting - would they comment on the relationship of the subjective data to the objective data - which do not show a similar shift in criterion? It would appear that the objective data reflect the same physiological response, while the subjective data do not reflect the same psychological response.

The perception of glare has been studied, rather unsuccessfully, for many years. The field has lacked a clear understanding of the underlying variables, both physical and psychological. Berman and his colleagues have added spectral composition to the mix of parameters that affect the perception of glare. It is to be hoped that continued careful analysis of all the physical variables that are present in a glare source will provide some real understanding of the underlying physiological and psychological responses.

Belinda L. Collins, Ph.D
NIST

Response to Belinda L. Collins

Subsequent to the collection of data presented here we recalled 8 of the 12 subjects and measured their pupil sizes using infrared pupilometry for the conditions of the study. Both subjective and objective analyses were performed using as the "independent" variable the subject mean trolands (corrected for Stiles Crawford effect). The analyses using BMPD-5V statistical package shows the same results as reported in the paper but with somewhat less statistical significance. The figures added below are similar to the figures 4 and 5 of the paper.

Presentation randomization was performed and is discussed in the section on glare conditions. We definitely argue that at the lowest glare luminance, the subjective rating is based on brightness perception while the objective measurements are recording a response to discomfort. As stated in the paper we propose that the change in criteria for the subjective response is the basis for the crossings shown in Figure 4. We have not examined source size as an independent variable but the size chosen for the study (3x4 feet) should be representative of fluorescent troffers and windows.

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