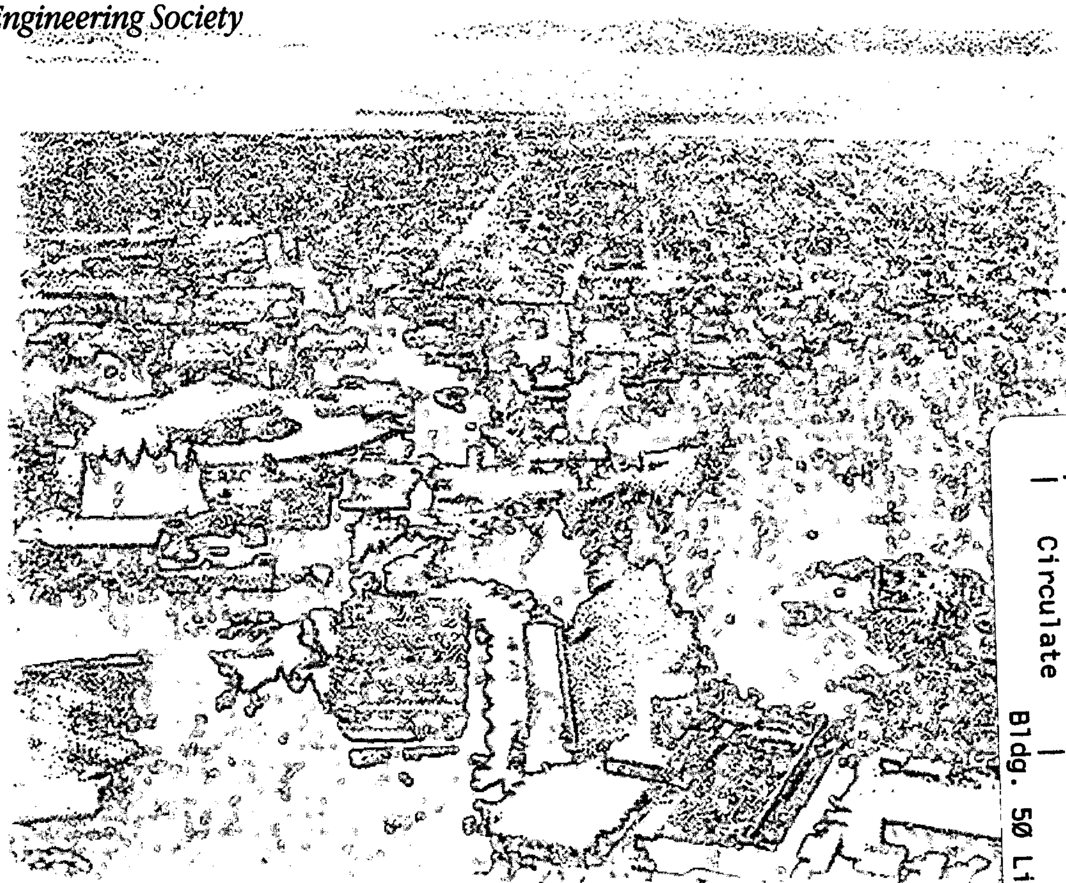
LBL-37009
UC-1600
Preprint

# Ernest Orlando Lawrence Berkeley National Laboratory

# Lighting Spectral Effect on Landolt C Performance is Enhanced by Blur and by Mydriasis

S.M. Berman, G. Fein, D.L. Jewett, B. Benson,
T. Law, A. Myers, and M.A. Bullimore
**Energy and Environment Division**

June 1995
Submitted to
*Journal of the Illuminating Engineering Society*



LBL-37009
L-196

JIES Vol. 25, No. 1, Winter 1996

# Lighting Spectral Effect on Landolt C Performance is Enhanced by Blur and by Mydriasis

S.M. Berman
Building Technologies Program
Energy and Environment Division
Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

G. Fein
Neurobehavioral Laboratory Software
41 Rhinestone Terrace
San Rafael, CA 94121

D.L. Jewett, B. Benson, T. Law, and A. Myers
School of Optometry
University of California
Berkeley, CA 94720

M.A. Bullimore
Abratech Corporation
475 Gate Five Road, Suite 255
Sausalito, CA 94965

June 1995

This research was supported by the Assistant Secretary for Energy Efficiency and Renewable Energy, Office of Building Technologies, Building Equipment Division of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

# Lighting Spectral Effect on Landolt C Performance is Abolished by Mydriasis

S.M. Berman, G. Fein[1], D.L. Jewett[2], M.A. Bullimore[3], B. Benson[2], T. Law[2] and A. Myers[2]

Lawrence Berkeley Laboratory
University of California
Berkeley CA 94720

[1]Neurobehavioral Laboratory Software
41 Rhinestone Terrace
San Rafael CA 94121

[2]School of Optometry
University of California
Berkeley CA 94720

[3]Abratech Corporation
475 Gate Five Road, Suite 255
Sausalito CA 94965

**Abstract**: When pupil size is changed by varying the surround spectrum, there is a perceived color shift of the task towards the complimentary hue of the surround. This ocurs even though none of the surround light falls on the task. This perceived effect is a neural process and is caused by the chromatic adaptation effect of the surround light scattered in the eye. To investigate whether such a mechanism is an alternative explanation of our results on visual performance for spectrally controlled pupil sizes, we have performed a study with and without mydriasis (pharmacologically induced dilated and fixed pupil). If the induced color hypothesis is valid, then it should occur for both fixed and light sensitive pupils. In addition, we have examined whether the pupil size effect on visual performance is present in correctly refracted subjects as well as an addition of a small amount of blur (0.5 DS).

We have studied 12 subjects, 21 to 35 years of age, correctly refracted for both normal pupils and under mydriasis. We compared Landolt C recognition at a fixed task luminance for two different surround spectra, both producing 50 photopic cd/m$^2$. For normal pupils performance was better with smaller pupils, while under conditions of mydriasis changing the surround spectrum had no effect on performance. Adding a small amount of blur reduced the performance for the mydriasis condition showing our measures are sensitive. We thus rule out the induced color hypothesis and demonstrate the benefits of smaller pupils on contrast sensitivity even though subjects are correctly refracted.

**Introduction:** In our previous studies[1,2] relating visual performance and pupil size changes, we have independently varied surround luminance and task luminance. Pupil size of test subjects has been controlled by changing the surround spectrum. Typically, a scotopically enhanced surround spectrum elicits significantly smaller pupils than a scotopically deficient spectrum, both at the same photopic luminance. Performance on

Landolt C recognition and word reading accuracy at fixed task luminance have been shown to be significantly higher when subjects are provided the scotopically enhanced surround lighting and hence smaller pupils. Because the spectrum (chromaticities) or color of the comparison surround illuminations are quite different, the observed color of the foveal task is perceived to undergo a change when the surround illuminants are interchanged. This perceived effect is not due to any surround light leakage into the task, but is the result of the neural process of chromatic induction[3] which induces a change in the task hue in the direction of the color complimentary to the color of the surround.

Since we did not control for this effect in our previous studies, it could provide an alternative hypothesis for the observed performance effects. This hypothesis would propose that visual performance is better when the task appeared to be pinkish in hue and poorer when appearing greenish in hue. If that were the case then our proposition that pupil size variation was the principal underlying mechanism responsible for the visual performance effects would be incorrect.

In the study presented here we examine whether this chromatic adaptation caused by the different surround spectra could be the mechanism responsible for the observed performance differences. To test this proposition we compare subject performance with natural pupils and under the condition of mydriasis. If chromatic adaptation is the correct mechanism, then performance should be similar under both natural and mydriasis conditions. On the other hand, if the pupil size variation is the correct hypothesis then the performance differences observed with natural pupils should be absent for the same subjects under mydriasis where the pupil is stationary. For such a comparison, subjects are refracted under both conditions to assure that their dioptrics are equally optimized.

Because we are refracting our subjects in this study we can also examine the question of whether spectrally induced pupil size changes cause visual performance differences when subjects perform the task with their correct refractions. In our previous studies we did not control for subject refractive state other than the requirement that subjects possess a minimum of 20/30 vision. Since it has been demonstrated that pupil size effects on vision are more pronounced under conditions of imposed blurring[4], the question arises as to whether our previously observed performance differences were a result of imperfect refraction conditions of the subjects.

The study presented here shows that induced color is not the mechanism underlying the performance changes and further demonstrates that correctly refracted subjects perform better with smaller pupils.

## Methods

**Subjects:** Three females and eleven males between the ages of 21 and 35 were recruited from the University of California at Berkeley, School of Optometry. All subjects were examined during a screening visit by an optometrist (Author MAB). Each subject's distance optical correction or refractive error was determined for both natural and dilated pupils, and for both eyes using standard optometric techniques[5]. Measurements were made first for natural pupils at a test distance of 6 meters. Following this, one drop of tropicamide hydrochloride (Mydriacyl, Alcon Labs) was instilled into each eye. Tropicamide is an anti-muscarinic which relaxes the sphincter dilator muscle, thus producing a dilated pupil[6]. Unlike sympathomimetic drugs, tropicamide also abolishes the pupillary light reflex, and paralyzes accommodation, our ability to focus our eyes for near work.

Fifteen minutes after the drug instillation, the subject's refractive error was determined again. In a few subjects there was a small difference in refractive error between the natural and dilated pupils. This could be due to the relaxation of the subjects' accommodation or the increase in spherical aberration associated with a larger pupil[5].

**Surround Lighting:** The study took place in a light tight rectangular room of dimensions 2m x 2m with ceiling height of 2.5m. The walls and ceiling are painted with a high reflectance spectrally flat white paint (Kodak). Surround lighting is provided indirectly by flourescent lamps of two different spectra, a scotopically enhanced lamp (F213) with a greenish-blue hue wich has its spectrum peaked at about 510 mm, and a scotopically deficient lamp, pinkish in hue. The ratio of scotopic to photopic output for the two lamps are s/p = 4.31 for the F213 and s/p = 0.54 for the pink lamp. The lamp fixture was located directly above, but shielded from the subject's head, 1.4m from the front viewing wall and extended down 0.5m from the ceiling. The comparison wall luminance was measured with a Pritchard Spectrophotometer (Model 1980A), at a point on the front viewing wall approximately 1m from the floor and 0.5m from the left wall. The luminance distributions were approximately constant and similar for the two lamps. For the study, the front wall photopic luminance was set at 50 cd/m$^2$ for both lamps.

**Task:** The task used for this study, a Landolt C presented on a VDT, is the same as used in our previous studies[1,2]. The 'C' subtends a visual angle of approximately 15 min. with a gap of 3 min of visual angle. The task is viewed at a distance of 3m achieved by a front surface mirror situated at a distance 1.5m directly in front of the subject chair. The mirror viewed the 'C' on the VDT. The immediate task background was set at a luminance of 13.2 cd/m$^2$ and the C contrast was varied by changing the luminance of the C. Contrast was determined using the Pritchard Spectrophotometer to obtain a mean luminance of the C ($L_T$)by averaging the values measured at 12 different points on the C surface and a mean luminance of the task background ($L_B$)by averaging the luminance at 5 points around the C. The contrasts to be used for the study were in logarithmic steps taking the values 4, 6, 10, 16, 25, 40, 63 and 80%, with contrast defined as the ratio $(L_B - L_T)/L_B$. A matte black shield covers most of the VDT surface except for a diamond shaped opening approximately 5 times larger than the C. This shield extended an additional 0.9m from the edge of the VDT thereby eliminating direct reflections of the surround lighting. The viewed front surface mirror is surrounded by a matte black cloth which provides a black surface subtending a visual angle of 20 deg. with a central opening slightly larger than 1 deg. The C luminance on the VDT was produced with a Matrox graphics card. Figure 1 shows a diagram of the experimental layout.

**Task Protocol:** The C's are presented in groups of 80 trials, broken into 20 C's at each of four contrasts. The four contrasts were determined separately for each subject prior to the data run as covering that particular subject's range from near chance to near perfect score. The C's were set to face the four diagonal directions (NE, NW, SE, SW) with north defined as the ceiling. Each C was presented for 200 msec and the subject took as much time as needed to make his or her forced choice by pressing one of four buttons corresponding to the C orientation. Subject could choose as much time as desired to relax between groups. Within a group of 80 presentations, contrast and orientation were randomized. Four principal conditions were studied, natural pupils, dilated pupils (mydirasis condition), and the two different surround spectra. Measurements were taken in 3 sets of 80 C presentations for each condition. The 3 repetitions of each of the four conditions were randomly distributed as well as whether natural or dilated pupils came first. Subjects were given a minimum of 2 minutes between groups to allow for adaptation to the surround lighting.

Subjects were seated in a comfortable chair in the experimental chamber and familiarized with the various equipment. The eyetracker focus and positioning was then adjusted and calibrated for reliable point-of-gaze measurements. At the outset of the session, each subject was given a few practice sets of the C presentations to familiarize them with the procedure. Subsequently, a variety of different contrasts was used in order to determine which of four contrasts (for that subject) lie in the robust portion of their probability of seeing function.

**Blur Condition**: Because we were concerned with the posibility that correctly refracted subjects might not show a detectable performance difference under the two surround lighting conditions, we added to the above measurements a separate condition where the subjects are provided a small positive blur, typically 0.5 DS. (The studies of Atchison et.al.[4] have established increasing effects of pupil size differences on acuity as blur increases). The amount of blur was generally chosen as 0.5 DS but for a few subjects it was slightly lower (0.25 DS) or slightly higher (0.75 DS) in order to achieve significant performance changes within the contrast variations available.

**Pupil Size Recording:** An ASL 4250R Eyetracker/Pupilometer was used to measure subjects' pupil size continuously as they performed the task. The instrument measures point of gaze and pupil diameter (horizontally across the pupil), at a sampling rate of 60 Hz. The ASL PC-EYEANAL (V. 2.1) software package was used for blink reduction.

**Data Analysis:** The data were analyzed in two ways: using structured covariance matrices to perform polynomial modeling of the data, and modeling the data as probability of seeing functions using Probit function Logistic Regression. We chose to use the polynomial modeling as our primary analysis for two reasons. First, polynomial regression is likely to be a more sensitive measure of the effects of surround lighting and blur because it focuses on modeling the ascending portion of the performance curve where those effects are most apparent. Second, probability of seeing modeling assumes a symmetric probability of seeing curve, which may not be valid because of a possible shift in criterion at lower contrasts where the task becomes more difficult. Visual inspection of the performance curves suggests that such may be the case. Moreover, with only four contrasts studied per subject per condition, enough data were not available to accurately model performance with an asymmetric probability of seeing model. Thus, the primary analyses used polynomial modeling, with the probability of seeing analysis performed to also express effect sizes in probability of seeing terms.

The primary analysis used the P5V procedure of the BMD statistical package[7] to analyze the data within a 2 x 2 x 4 repeated measures Analysis of Variance framework separately for the normal pupil and the mydriasis condition. The factors were: Blur (normal vs. +0.50 DS blur), Surround lighting (50 pcd/m$^2$ F213 vs. 50 pcd/m$^2$ pink), and (4 levels). Since the range of task contrasts was different for different subjects and sometimes needed to be adjusted within a subject between conditions (to accommodate for poorer performance with blur and/or dilation), the data were unbalanced and could not be analyzed using standard ANOVA procedures. The P5V procedure uses Maximum Likelihood estimation with structured covariance matrices to solve the unbalanced design problem. Prior to statistical analysis, for each subject, the average pupil size and the Landolt C task accuracy (i.e., percent correct) were computed for each contrast level for each of the eight experimental conditions. Task-contrast was then converted to effective task contrast by adjusting for the effective veil luminance produced by surround light scattered in the eye (approximately 4% of surround luminance for the geometry of our study) and by the small amount of light traversing the tube (1%). In BMDP5V, the unbalanced factor $\log_{10}$ (effective task contrast) was analyzed as a covariate which varied across the repeated measures. Both linear and quadratic effective task contrast effects on Landolt C accuracy were estimated.

The probability of seeing analysis was performed using the SAS Logistic Procedure with the Probit function[8]. Data for each subject under each condition (mydriasis by blur by surround light) were analyzed separately as performance vs. $\log_{10}$ (effective task contrast) yielding estimates of the best fit slope and inflection point for the probit curve. The SAS GLM procedure was then used to analyze the slopes and inflection points as dependent variables within 2.2 (blur by surround light) balanced repeated measures ANOVAs separately for the normal pupil and mydriasis condition.

## Results:

The pupil area data are presented in Figure 2, while the Landolt C performance data are presented in Figure 3. We note that, even though each subject was only studied under four contrasts, the Landolt C performance data are plotted for six or seven values of effective task contrast. This reflects the fact that different contrasts were used for different subjects and (occasionally) across different conditions. The area of the circles in Figure 3 reflect the number of subjects who contributed to the measurement at each point.

**Dilated Pupils:** The mydriasis was effective. Under mydriasis, all subjects had dilated pupils ranging from 36.0mm$^2$ to 59.3mm$^2$ with a mean of 46.6mm$^2$ (2.3 mm$^2$ s.e.). There was a very small change in pupil size as a function of surround spectrum with a mean reduction of 3.8% under the F213 surround condition ($F_{1,11} = 25.1$ ; $p = 0.0004$) indicating that the mydriasis, although effective, was not total. With dilated pupils, there was a highly significant linear effect of $\log_{10}$ (effective task contrast) on Landolt C accuracy ($\chi^2$ [1 df] = 30.61, $p< 0.0001$), and a highly significant reduction of 26.0% (s.e. 1.7%) in Landolt C accuracy with the blurring lens ($\chi^2$ [1 df] = 245.3, $p < 0.00001$). With dilated pupils, there was no effect of spectrum of the surround lighting on Landolt C accuracy ($\chi^2$ [1 df] = 2.19, $p = 0.14$). The p=0.14 value should not even be interpreted as a trend for a surround effect, since the means were in the direction of slightly better performance (+2.3 %, s.e. 1.5 %) for the scotopically deficient surround lighting.

**Normal (i.e., light responsive) pupils:** With normal pupils, there was a strong effect of surround spectrum on pupil size. Pupils were reduced by about 41.8% (s.e. 2.7%) from a mean value of 21.5mm$^2$ (s.e. 2.2mm$^2$) for the pink lamp to 12.2mm$^2$ (s.e. 1.1mm$^2$) under the F213 lamp. With natural pupils, there were highly significant linear and quadratic effects of $\log_{10}$(effective task contrast) on Landolt C accuracy ($\chi^2$ [1 df] = 902.9 and 8.9, p << 0.00001 and p=0.003, respectively), and a highly significant reduction of 27.1% (s.e. 1.4%) in Landolt C accuracy with the blurring lens ($\chi^2$ [1 df] = 372.6, p << 0.00001). With light responsive pupils, there was a main effect for the surround illuminant ($\chi^2$ [1 df] = 80.6, p <<0.00001), wherein performance was 12.0% (s.e. 1.3%) better on average for the scotopically rich illuminant compared to the scotopically deficient illuminant. There was also a significant interaction effect wherein the improvement with scotopically rich lighting was larger under the +0.5 DS blur condition (14.8% s.e. 1.8%) than under the non-blur condition (9.0% s.e. 1.7%).

**Probability of seeing results:** The pattern of statistical results from the probability of seeing analysis was very similar to that reported above, although the significance levels were somewhat lower. The shift in the probability of seeing curve with blur was 0.25 (s.e. .07) and 0.24 (s.e. .10) $\log_{10}$ (effective task contrast) units for natural and dilated pupils, respectively. For the natural pupil condition, the shift in the probability of seeing curve with scotopically rich surround lighting was 0.16 (s.e. .11) and 0.10 (s.e. .09) $\log_{10}$(effective task contrast) units for the -blur and non-blur conditions, respectively (see Table 1 below for a summary of these effects). For this analysis, the surround light by blur interaction effect was only a weak statistical trend (p=.19). For the dilated pupil, the shifts for scotopically rich lighting were non-significant for both the blur and non-blur conditions (-0.05 (s.e. 0.07) and -0.02 (s.e. 0.11) $\log_{10}$(effective task contrast) units, respectively).

A summary of the various effects and their significance levels for the probablility of seeing analysis is provided in Table I.

Probability of Seeing Analysis
Mean Threshold Contrast *, %
(Interval Containing One Standard Error +, %)

A: Natural Pupil

| | Scotopically Rich (F213) | Scotopically Deficient (Pink) | Difference |
|---|---|---|---|
| Corrected | 10.0 (9.9, 11) | 12.5 (11.3, 13.7) | -2.5 (-1.9, -3.3) $p < 0.0025$ |
| +0.50 DS Blur | 16.5 (15, 17.2) | 23.7 (20.6, 27.2) | -7.2 (-5.4, -9.0) $p < 0.0006$ |
| Difference | -6.2 (-5.2, -7.2) $p < 0.0001$ | -10.9 (-9.2, -12.4) $p < 0.0001$ | |

Surround by Blur Interaction $p<0.19$

B: Dilated Pupil

| | Scotopically Rich (F213) | Scotopically Deficient (Pink) | Difference |
|---|---|---|---|
| Corrected | 17.5 (15.7, 19.4) | 16.8 (15.1, 19.8) | 0.7 (-0.6, 1.9) $p < 0.6183$ |
| +0.50 DS Blur | 30.7 (27, 34.7) | 28.2 (25.1, 31.8) | 2.5 (1.0, 3.8) $p < 0.1207$ |
| Difference | -12.8 (-10.4, -15.3) $p < 0.0001$ | -11.4 (-9.3, -13.7) $p < 0.0001$ | |

Surround by Blur Interaction $p<0.55$

* Value at 50% Probability of Seeing
\+ Intervals are not symmetrical due to the transformation from log to linear units.

Table I

**Discussion**: The results of our study demonstrate two principal conclusions. In the mydriasis condition performance showed no differences when the surround lighting was changed from the scotopically enhanced case (213 lamp) to the scotopically deficient case (pink lamp) while maintaining the same photopic luminance. On the other hand, the task color shifted towards the complimentary hue, greenish for the pink lamp and pinkish for the 213 lamp. Under the condition of natural pupils, the same subjects' pupil sizes were smaller for the scotopically enhanced surround case compared to the scotopically deficient surround case and performance on the Landolt C task was also better under the conditions of smaller pupils. Thus we can conclude that the induced color difference of the task, caused by the different surround spectra, is not the mechanism responsible for the performance effects.

A second conclusion of our study follows because subjects were refracted under conditions of both natural pupils and mydriases (dilated pupil fixed in size). As mentioned above, subjects performed better under the scotopically enhanced surround light for the condition of natural pupils so that we can conclude that the pupil size effect on performance occurs even when subjects have been correctly refracted.

When subjects performed the task with 0.5 DS of blur then accuracy decreased both under conditions of natural and dilated pupils. As expected, the surround condition with scotopically enhanced lighting that produced smaller pupils for the natural pupil condition also showed less of a decrement of performance with the added blur than the larger pupils showed (obtained with the scotopically deficient surround lighting) confirming the results of Atchison et.al.[4] Since the task was situated about 3m distance from the subject position, the chance of blur power (0.5 DS) should assure that accommodation did not play a role in subjects performance.

On the other hand, because we did not undertake to experimentally verify exactly where our subjects fixated between trials, e.g., they could have inadvertantly shifted their fixation from the task to the mirror edge, the black curtain, the tube edge, etc. we cannot unequivically argue that only acuity is improved under the smaller pupil conditions. Since the task presentation duration was 200 msec, it is possible that the subjects were accommodating for a different distance at the time of task presentation and the performance differences obtained were related to the larger depth of field allowed by the smaller pupil condition. In our study of word reading accuracy[9], the task arrangement was much simpler and there was an absence of other visual material located at different distances assuring steady accommodation. In that study, subjects performed better with smaller pupils which supports directly our hypothesis of the pupil size effect on acuity.

This study, along with our five other studies (each carried out with a different set of subjects ranging in age from 20 to 70 years old), represent a collection of demonstrations of the effect of spectrally controlled pupil size on visual task recognition or discrimination. In all of these studies, task performance was compared at two different pupil sizes obtained by changing the surround lighting conditions while task luminance was held fixed. The results of each comparison showed that performance was significantly better when pupils were smaller. In these studies, pupil diameters ranged on average from 3.5 mm to 4.8 mm, while task luminance varied between 12 cd/m$^2$ and 70 cd/m$^2$. Because task luminance is held fixed while pupil size is manipulated through the surround variations, the results all demonstrate that recognition or discrimination is improved under the condition of *lower* task retinal illuminance (smaller pupil condition). This result leads us to hypothesize that when task luminance is in the "photopic" region, improvements in visual recognition or discrimination ostensibly arising from increasing illumination levels are likely to be solely a result of decreasing pupil size. This hypothesis is also supported by various other studies in the vision literature[10,11] which show grating acuity and contrast sensitivity to asymtote at low photopic values of task luminance for conditions of fixed pupils.

If pupil size is the limiting factor controlling visual recognition and discrimination at photopic light levels, then the lighting community has a significant opportunity to improve the national lighting energy efficiency while maintaining present standards of visual performance. Shifting lamp spectra towards scotopic enhancement while operating lighting at lower energy levels offers the means to provide this desired result.

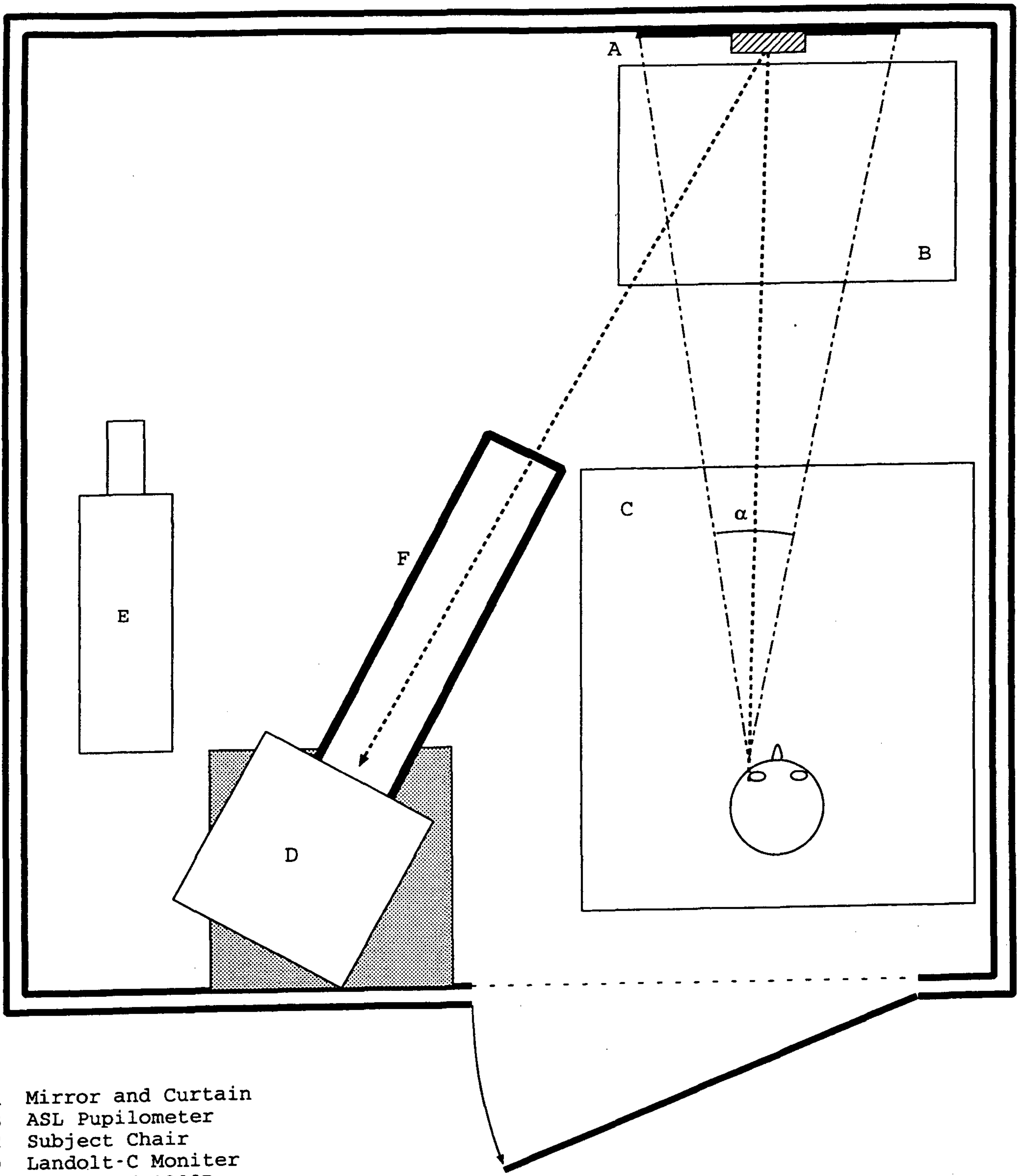
**Acknowledgement**

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

**References**

1. Berman S.M., Fein G., Jewett D.L., Ashford F. "Luminance controlled pupil size affects Landolt C test performance". *J. IES,* 22(2), Summer 1993.
2. Berman S.M., Fein G., Jewett D.L., Ashford F. "Landolt C recognition in elderly subjects is affected by scotopic intensity of surround illuminants". *J. IES,* 23(2), Summer 1994.
3. Walraven J. "Spatial characteristics of chromatic induction; The separation of lateral effects from stray light artefacts". *Vision Res.*, 13:1739-1753, 1973.
4. Atchison D.A., Smith G., Efron N. "The effect of pupil size on visual acuity in uncorrected and corrected myopia". *Amer. J. of Optom. & Physiol. Optics,* 56(5):315-323, 1979.
5. Borish I.M. Clinical Refraction (Third Edition). The Professional Press. Chicago, IL., 1970.
6. Egashera S.M., et.al. "Comparison of cyclopentalate versus tropicamide cycloplegia in children". *Opt. and Vis. Sci.*, 70:1019-1026, 1993.
7. BMPD - Statistical Software Manual. W.J. Dickson, Chief Editor, University of California Press, Berkeley CA, 1992.
8. SAS/STAT - Users Guide (Volume 2), GLM-VARCOMP, Version 6, Fourth Edition. SNS Institute Inc., Cary NC, 1990.
9. Berman S., et.al. "Luminance controlled pupil size affects word reading accuracy". Submitted to this National IESNA.
10. Shlaer S. "The relation between visual accuity and illumination. *J. of Gen. Physiol.* 21:165-188, 1937.
11. Van Nes F.L. and Bouman M.A. "Variation of contrast sensitivity with luminance". *JOSA*, 57:401-406, 1967.

Landolt-C Chamber Layout




A Mirror and Curtain
B ASL Pupilometer
C Subject Chair
D Landolt-C Moniter
E Pritchard 1980B
F Matte Black Baffle Tube
α 20 degrees

*Figure 1:* Layout of the aparatus used in our Landolt C experiments. The black curtain which surrounds the mirror subtends approximately 20 degrees and enables us to independly control the "surround" and the "task" lighting.

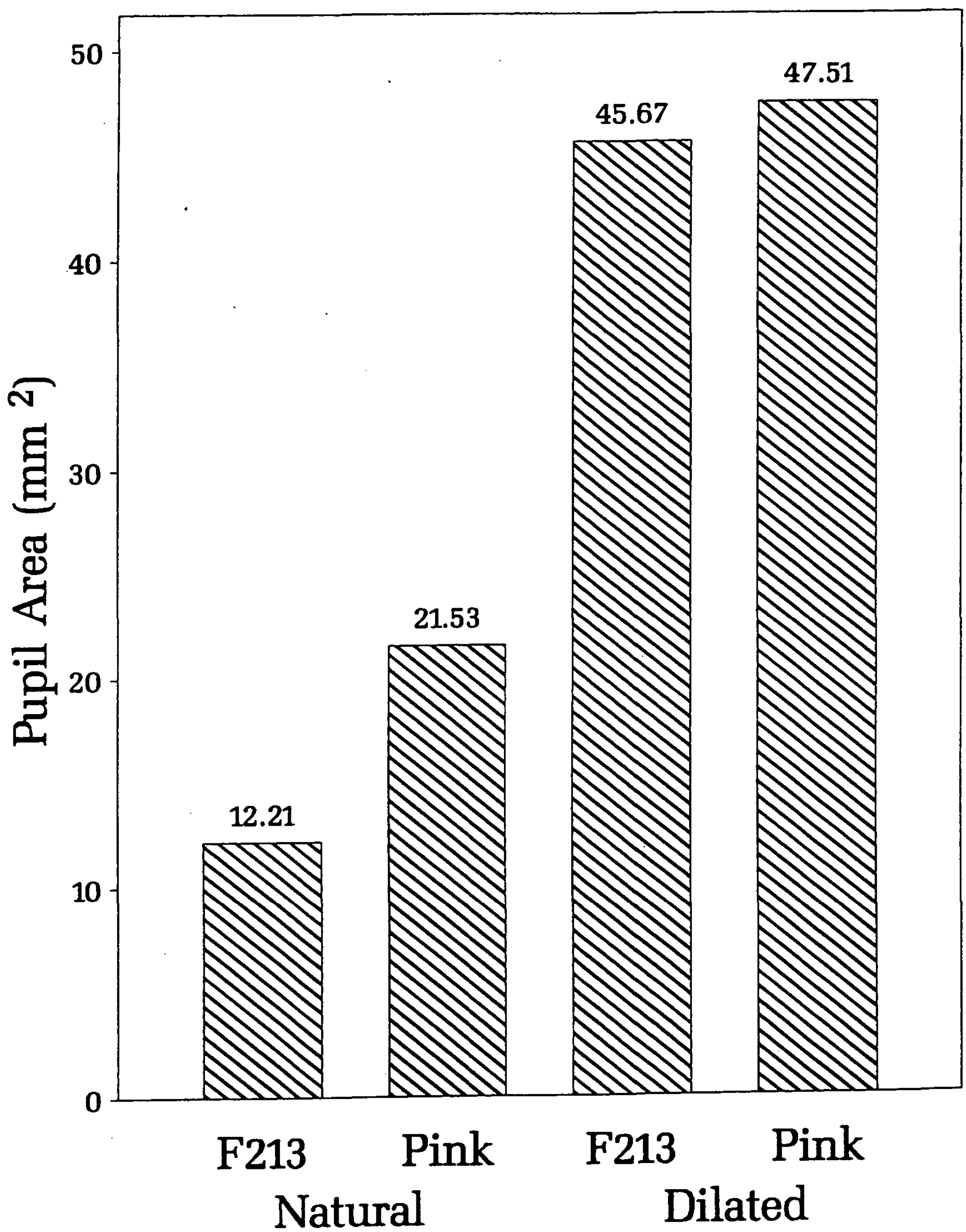



*Figure 2:* Mean pupil size for each lighting condition averaged across the correct refraction and the +0.50 DS blur.

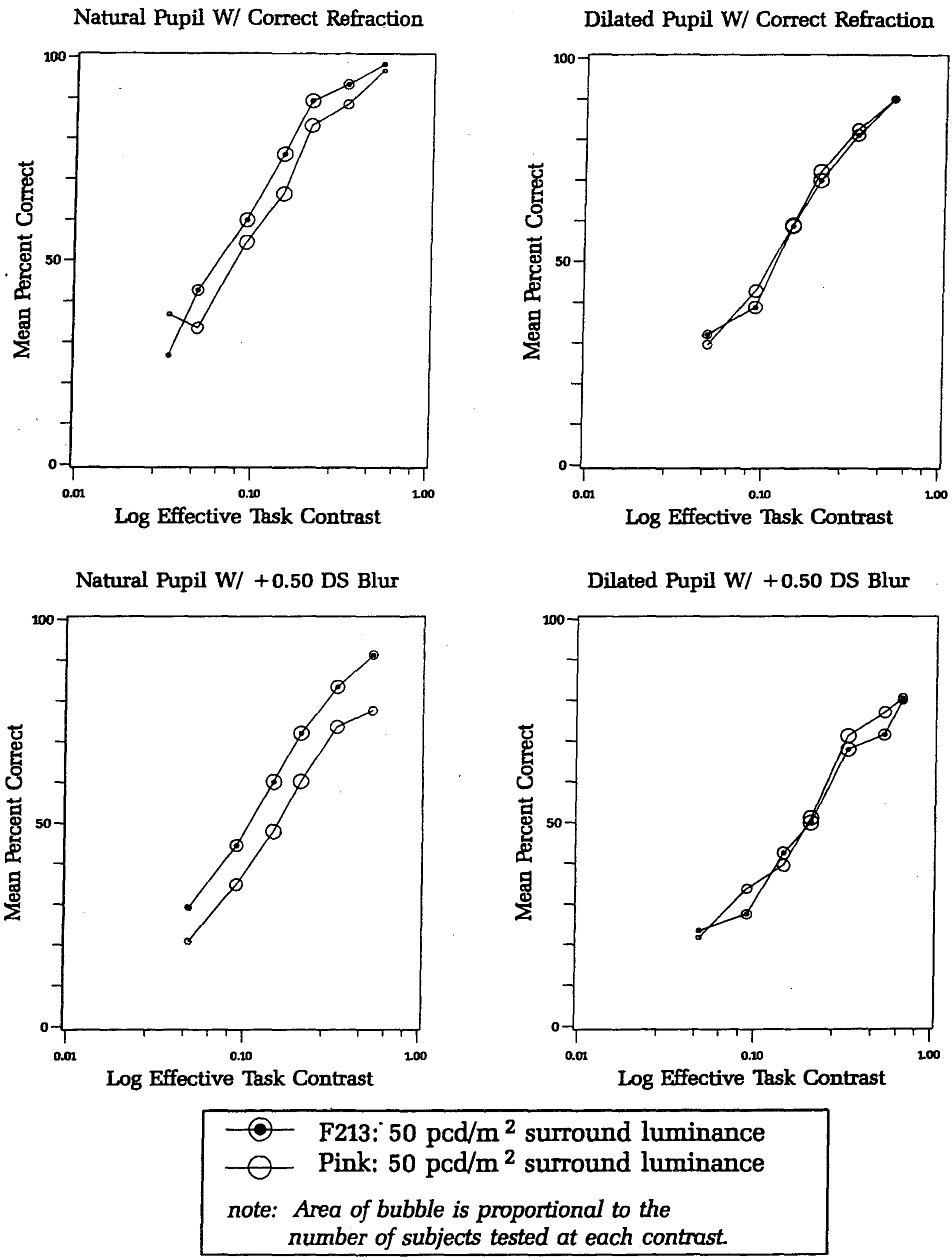



*Figure 3:* Mean percent correct for recognition of orientation of a Landolt C as a function of its contrast (light background ( 13.3 cd/m$^2$ ) and dark C) for natural and dilated pupils with and without a +0.50 DS blur. F213 and Pink are the scotopically enhanced surround and the scotopically deficient surround respectively.

Prepared for the U.S. Department of Energy under Contract No. DE-AC03-76SF00098