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***Effects of Lumimous
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and Human Preference***

by M.S. Rea, M.J. Ouellette and D.K. Tiller

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The Effects of Luminous Surroundings on Visual Performance, Pupil Size, and Human Preference

Mark S. Rea,¹ M.J. Ouellette,² and Dale K. Tiller²

Research on the influences of luminous areas surrounding visual tasks began in 1842, when "Lister found . . . vision to be improved by holding a sheet of paper behind a test object."¹ Subsequent systematic investigations into the effects of varying task-to-surround luminance ratios (TSLR) on the performance of visual tasks near threshold have reported that surrounds brighter or darker than the immediate task area produce performance decrements.¹⁻⁶

The proximity of the surround to the task is also important. High TSLR values are less important to threshold visibility the further the surround is from the visual task.^{7,8} However, there is little consensus regarding the critical values of the spatial-luminous properties of the task and surround areas for threshold visibility. Cobb and Moss⁹ suggested that surround influence was negligible beyond 8-16 degrees visual angle in the performance of a suprathreshold visual task. In contrast, Luckiesh⁸ speculated that surround effects would not be significant for surrounds beyond 30 degrees visual angle.

McCann and Hall¹⁰ measured contrast sensitivity to sinusoidal gratings surrounded by areas of different sizes and brightnesses. Like many others before them, they showed that the luminance of the surround should be the same as the average luminance of the task (i.e., the sinusoidal grating) for optimal performance. Unlike earlier investigators, however, they showed that the area of the surround important to contrast sensitivity was dependent upon the size, or spatial frequency, of the target. Small gratings needed only small surrounds but large gratings needed large surrounds for optimal performance of this threshold task. Thus, the influence of the surrounding field does not depend, per se, upon its absolute size, but rather upon its size relative to the size (spatial frequency) of the visual target. McCann and Hall's¹⁰ findings clearly indicate how TSLR impacts on threshold visibility, but there is little evidence concerning the importance of TSLR on suprathreshold visual performance.

Other researchers have studied the effects of varying TSLR on preferences, rather than visual performance.¹¹⁻¹⁵ Table 1 summarizes the results of these studies. It suggests that preferred TSLR values vary greatly depending upon the study conducted and the

surface being evaluated. However, one thing is clear: People seem to prefer surround areas slightly darker than the task area, which seems in contradiction to the threshold performance data that indicated surround areas should be approximately equal to that of the task.

Taken together, the research on performance and preference effects has not resulted in a comprehensive set of luminance ratio specifications to guide the lighting designer and illuminating engineer toward better practice. Perhaps this is due to the piecemeal nature of previous work; rarely have preference and performance data been collected in the same experiment. The incoherent nature of these studies may also depend in part on the fact that many of the performance experiments employed abstract, hypersensitive visual tasks near threshold rather than simulated, realistic, suprathreshold visual tasks. The ranges in TSLR values also differ in these experiments making general conclusions more difficult.

This report describes a further step toward an empirically based set of TSLR recommendations for the workplace. An experiment was conducted to assess the effects of different luminous surroundings on suprathreshold visual performance, subjective assessments of task quality, and pupil size. The effects of two widely separated surround reflectances and several surround sizes were studied under several illuminance levels for two target contrasts. These results will hopefully lead to a sounder basis for recommendations on TSLR values for lighting applications.

Methods and procedure

Experimental room and apparatus—The testing room was similar to the experimental "black room" used by Rea.^{16,17} All portions of the ceiling, walls, and floor within the subject's field of view were black (reflectance, ρ , ≤ 0.02).

An irregularly shaped desk was used to ensure that the printed portions of the task were approximately equidistant from the side and top edges of the desk (Figures 1 and 2). The top of the desk, which formed the surrounding field, was either black ($\rho = 0.02$), or gray ($\rho = 0.17$).

The desk was equipped with a fixed chin-rest, which held viewing distance (48 cm), and angle (42 degrees) constant over the course of the experiment. An adjustable chair ensured subjects of different heights were comfortably seated.

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Table 1—Preferred luminance ratios

Experimenter	Area					
	Immediate Surround	Front Wall	Rear Wall	Right Wall	Left Wall	Ceiling
Touw, 1951	0.3					
Bean & Hopkins, 1980	1.0					
Tregenza et al, 1974		0.52	0.64	0.51	0.55	0.85
van Ooyen et al, 1987	0.4		0.3	(all walls)		
Roll & Hentschell, 1987	0.1–0.6					0.1–3

Note: All entries are relative to the task background luminances.

Overlays, the same shape as the desk but of different sizes and reflectances, were placed on the desk top to change the spatial-luminous characteristics of the task background area. Matte-white overlays secured to the desktop were used to extend the white task background past the 48 degrees horizontal visual

Figure 1—Task, background, and surround areas on the desk surface. The left task page is the reference sheet consisting of either gray or black ink on white paper. The right page is the response sheet, always black ink on white paper.

angle subtended by the task pages themselves. Task background areas smaller than the 48 degrees subtended by the task pages themselves were obtained by placing cards the same color and reflectance as the black or gray desktop over the matte-white overlays. In all, the white task background areas subtended angles of about 12, 15, 21, 32, 44, 50, 72, or 100 degrees.

Illumination on the task was provided by 35-W, warm-white fluorescent lamps mounted in a luminaire 126 cm above the desk. It had a light-emitting aperture of 95.5 by 95.5 cm. Two translucent filters and a switching system were used to give the range of task background luminances used in the experiment (i.e., 12.1, 16.4, 21.4, 41.2, 66.8, 106, 169, and 316 cd/m^2 ; measured at the center of the task). One filter was a sheet of 3-mm sanded, translucent, white acrylic. The second filter was a lattice of 25-mm

Note: All units are cm.

Figure 2—Dimensions of the desk and location of the reference and response sheets on the desk surface. The string served as a guide for aligning the pages between trials.

aluminum strips mounted horizontally and vertically at 25-mm intervals in a rigid plywood frame.

The center of the luminaire was located 5 cm ahead of the center of the task. This geometry provided high uniformity of illumination with minimal veiling reflections and body shadow. Veiling reflections were further reduced by masking offending portions of the luminaire. Luminance of the task area varied by no more than +5.1 percent and -6.3 percent from the mean: luminance of the completely white desk surface (with the largest task background size), varied by no more than +18 percent and -23 percent from the mean.

Illuminance was continuously monitored with a remote illuminance cell, mounted on the desk top directly opposite the subject. The cell's response was calibrated prior to the experiment using a Pritchard 1980A photometer, directed at the center of the task.

Tasks

Numerical verification task—On each trial, subjects were presented with two juxtaposed lists of 20 five-digit numbers. The reference list, on the subject's left, acted as a standard against which the numbers on the response list were compared. Each response list, located at the subject's right, contained from zero to six randomly located errors. An error was defined as a single-digit discrepancy between corresponding five-digit numbers on the two lists.

The subject's task was to compare the two lists as quickly and accurately as possible for discrepancies and mark these by placing a tick mark over the discrepant digit on the response list. Reference lists were printed with gray or black matte ink. Under the lighting geometry used in this experiment text contrasts were approximately 0.15 and 0.86. Response sheets were printed in black matte ink and had text contrasts approximately equal to 0.70. Calibration squares printed at the top of each reference and response sheet allowed convenient collection of photometric data under the various lighting conditions (See Rea¹⁶ for complete details on the reference and response lists).

Readability rating—After completing each trial, subjects were asked to write a number ranging from zero (unreadable) to ten (most readable) at the bottom of the response sheet to indicate their subjective level of the readability of the reference sheet presented during that trial. Whole numbers, decimals, and fractions were allowed.

Pupil Size—Changes in the brightnesses in a visual scene will affect pupil size. There are several ways to measure pupil size,¹⁸ but these measurement techniques may, themselves, influence pupil size by affecting the scene brightness or accommodation distance. A

special entoptic pupillometer was constructed for this experiment in an attempt to make in situ measurements of pupil size with minimal bias from the measurement technique itself (after reference 18).

An entoptic pupillometer works on the following principles. A point of light held close to the eye will be seen as a large, circular, defocused luminous disc. As the pupil becomes larger or smaller, the luminous disc appears proportionately larger or smaller. Because the pupil is circular or very nearly so, it is possible to measure the diameter of the pupil with two points of light held close to the eye. The size of both circular discs will be identical, thus, when the blur circles are just tangent to one another, the distance between the two points of light will be equal to twice the radius of the pupil.

Pupil size is affected predominantly by rods because they are the most prevalent receptor in the retina. Rods are less sensitive to long wavelength (red) radiation than cones. Thus small, dim, red lights visible to cones will not strongly influence pupil size.

The pupillometer constructed for this experiment consisted of two parallel fiberoptic light sources. The fiberoptic strands were linked optically at one end to a variable-intensity, long-wavelength (red) light source (λ 645 nm). The other ends of the fiberoptic strands were firmly attached to microscope slides that were themselves secured to a micrometer. The micrometer could accurately measure the separation of the fiber optic strands to within 0.01 mm.

Subjects wore safety glasses during pupil measurements. The subjects held the micrometer in one hand and positioned the fiberoptic strands against the right lens of the glasses. Subjects adjusted the intensity of the light source until the two red luminous discs could be just seen clearly. Throughout the measurement period, subjects were asked to fix their gaze on a photocopied picture of a human face placed in the task area, to maintain fixed accommodation, convergence, and avoid bias in pupil size due to the near-field reflex.¹⁹ Pupil size measurements were not obtained for every combination of experimental conditions but were obtained over their full range.

Subjects and protocol

Eight paid volunteers (five females, three males: 18-24 yrs, mean age 20 yrs) participated in the experiment. All were, or had recently been, students. All but one subject was right handed; none of them experienced difficulty in completing the tasks with their right hand.

Before the experiment, a series of screening tests was administered to ensure that subjects had uncorrected normal vision (Keystone Ophthalmic Telebinocular visual screening test) and were color

normal (Schmidt and Haensch anomaloscope). Color vision was tested to exclude protanopes from the experiment. Since protanopes are less sensitive to long wavelengths than people with normal color vision, a much brighter red light would be required to make pupil size measurements for this group. The relatively brighter red light required for this group might have influenced the rod response and thus biased the results if such data had been included with color normal subjects.

Every subject completed four sessions, one in the morning and one in the afternoon over two consecutive days. An initial series of 24 practice trials, representing the range of conditions to appear during the experiment, were completed prior to the first experimental trial. During the morning and afternoon sessions, data were obtained under the two illumination levels. Eight different illumination levels were presented in the four sessions; the order of presentation was counterbalanced across subjects. In a given session, data were obtained for both desktop reflectances and all eight task background sizes at both illumination levels and for both reference sheet contrasts (64 trials per session); the presentation order for the desktop reflectances, task background sizes, and sheet contrasts were randomly determined.

Prior to the initiation of a trial, the two number lists were hidden from view with a white cover card. Subjects removed the cover card at the experimenter's signal to begin the task. Subjects verbally indicated when they had completed the task; the completion time was then recorded by the experimenter.

A 45-min lunch break was taken on each of the 2 days. Pupil size measurements were collected after completion of each morning and afternoon experimental session. If these measurements had not been completed by the end of the second day, another appointment was arranged for later the same week. At the end of the second day, subjects attended a short debriefing session, which elicited their opinions on the effects of the experimental manipulations.

Results

Numerical verification task—Three "direct" numerical verification task performance measures were obtained in the experiment. These were time, in seconds, to complete a list comparison (S), the frequency of unmarked list discrepancies (misses), and the frequency of correct matching numbers marked as discrepant (false positives). As with Rea,¹⁷ misses and false positives were not considered in subsequent analyses, following the argument developed in that paper that these metrics of task performance produce the same functional relationship with the independent variables as S.

Following Rea,¹⁷ the reciprocal of task time (1/S) was used as a measure of task performance. A preliminary analysis of variance (ANOVA) was conducted to identify the independent variables that affected this measure of task performance (1/S). In agreement with many performance studies,^{17,20} the analysis revealed that both text contrast [$F(1,7) = 84.01$, $p < 0.001$] and task background luminance [$F(7,49) = 6.05$, $p < 0.001$] significantly affected task performance (1/S). There was also a significant interaction [$F(7,49) = 16.04$, $p < 0.001$] between these two variables. In effect, background luminance had a greater influence on the low-contrast task than it did on the high-contrast one. For example, average (1/S) for the gray task was 0.0279/s and 0.0366/s at background luminances of 12 cd/m² and 316 cd/m², giving a difference of 0.0087/s. The black task provided average task performances of 0.0344/s and 0.0386/s at the same levels of background luminance, a difference of only 0.0042/s.

In addition to the above effects, the preliminary ANOVA revealed that surround reflectance also affected task performance significantly [$F(1,7) = 12.64$, $p < 0.009$]. For example, mean (1/S) was 0.0343/s for the gray surround and 0.0338/s for the black surround. Although the effect was statistically significant, it was small in magnitude (i.e., a difference of only 0.0005/s between the two surround conditions, on average). No other significant effects or interactions were revealed in this preliminary analysis. Task background size, in particular, did not significantly affect task performance [$F(7,49) = 1.66$, $p > 0.14$], nor did it interact with other experimental variables.

Visual performance for the reference list is not completely characterized by task time (S) as task time also involves action time (S_a) to write the tick marks, and the time (S_{resp}) to read the response list. As discussed by Rea,¹⁷ a more appropriate metric of visual performance can be obtained by subtracting both S_a and S_{resp} from the measured task time (S). The result is the time (S_{ref}) to read the reference list, the stimulus of interest. As with Rea,¹⁷ the reciprocal of S_{ref} is used to characterize visual performance (VP). Thus

$$\begin{aligned} VP &= \frac{1}{(S_{ref})} \\ &= \frac{1}{(S - S_a - S_{resp})} \end{aligned} \quad (1)$$

S_a is the product of M, the total number of tick marks on a response sheet and α , the estimated time to make each mark. Values of α for each subject are given in Table 2. They were determined by linear

Table 2—Regression parameters for each subject

Subject	Black Surround			Gray Surround	
	α	β	γ'	β	γ
1	0.9933	25.007	-0.3305	26.076	-1.2386
2	1.2051	29.631	-1.4975	29.408	-1.8612
3	1.5024	32.577	-1.9182	29.540	-0.6124
4	1.6556	47.345	-5.8336	44.875	-5.3223
5	1.0140	40.520	-3.6750	38.290	-2.6776
6	0.6633	22.071	-2.0669	21.899	-2.0767
7	1.2268	51.365	-5.8325	59.063	-10.759
8	0.8472	32.380	-0.7091	32.450	-0.9697

regression using the equation $S = \tau + \alpha(M)$, where τ is a regression constant. Figure 3 shows the regression lines for those subjects giving the highest and lowest correlation coefficients. All other subjects showed similar trends. The formulation here differs slightly from that of Rea¹⁷ who used S_a values averaged over all subjects rather than separate values for each individual.*

To determine S_{resp} , it was necessary to assume, as did Rea,¹⁷ that S_{resp} and S_{ref} were equal under comparable task conditions. Thus when the response and reference lists had equal contrast,** background luminance, and surround reflectance,*** then the time to read (but not mark) each list was the same. Since the response list was always printed in black ink, S_{resp} is approximately $= 0.5(S' - S_a)$, where S' is the task time (S) for a given subject to perform the numerical verification task with a black-ink reference sheet at a given background luminance (L_b) and surround reflectance. Thus, Equation 1 can be rewritten as

$$VP = \frac{1}{[S - S_a - 0.5(S' - S_a)]} \quad (2)$$

* Each subject was considered separately, here, because one individual had such rapid completion times that estimates of S_{resp} for this person would have been less than zero if average S_a values had been used.

**The contrast of the response sheet (0.70) was actually less than that of the black-ink reference sheet (0.86). However, visual response is sufficiently compressive at these high contrasts (Rea,¹⁷ Rea and Ouellette²⁰) that VP can be treated as approximately equal for these two stimulus sheets under equal viewing conditions.

***Consideration of surround reflectance was necessary since this variable significantly affected task performance (1/S). It was not necessary to consider background size because the variable was not significant in the preliminary ANOVA.

S' was determined for each subject and surround reflectance using linear regression with the equation: $S' = \beta + \gamma \log_{10}(L_b)$ for all data collected with the black-ink reference sheet. Values of β and γ for each subject and surround reflectance condition are given in Table 2. Figures 4 and 5 show the regression lines

Figure 3—The average time (S) for selected subjects to complete a trial, plotted as a function of the number of tick marks (both hits and false positives) on the response sheet. The solid lines were determined by linear regression. Their slopes (α , Table 2) were used in the calculation of action time, S_a . The subjects selected here are the ones giving the highest and lowest correlation coefficients, r . The error bar represents the largest standard error of the mean.

for those subjects with the highest and lowest correlation coefficients r for the gray and the black surrounds.

The effects of the experimentally manipulated independent variables on VP were assessed using a repeated measures ANOVA. This analysis showed significant main effects for task contrast [$F(1,7) = 68.75, p < 0.01$] and background luminance [$F(7,49) = 2.45, p < 0.03$], indicating that these variables each affected visual performance. The main effects for task background size [$F(7,49) = 1.80, p = 0.11$] and surround reflectance [$F(1,7) = 0.118, p = 0.74$], were not significant, indicating that these variables did not affect visual performance in this experiment. The interaction between task contrast and background luminance also reached statistical significance [$F(7,49) = 6.68, p < 0.01$], indicating that the influence of background luminance was moderated by task contrast.

Figure 4—The average time (S) for selected subjects to perform a trial for a reference sheet printed in black ink and presented with a gray surround. The data are plotted as a function of task background luminance. Each point represents the average of eight measurements, one for each subject. The solid lines were determined by linear regression (β, γ , Table 2). They were used to calculate S' for gray surrounds. The subjects selected here are those giving the highest and lowest correlation coefficients, r . The error bar represents the largest standard error of the mean.

Figure 6 depicts the background luminance by task contrast interaction. The reference lists printed in low-contrast gray ink were less visible than those printed in higher-contrast black ink. Further, the deleterious effects of the lower light levels were more pronounced for numbers printed in low-contrast gray ink, than for numbers printed in high contrast black ink. These effects are similar to those reported by Rea,¹⁷ supporting the reliability and sensitivity of this experiment.

A more quantitative comparison of these results with those reported earlier by Rea¹⁷ was obtained by plotting the reciprocals of raw task completion times for matching conditions in the two experiments. This comparison is depicted in Figure 7. The solid lines show the reciprocals of task completion times obtained by Rea;¹⁷ the plotted points are the reciprocals of the raw task completion times for matched conditions obtained in this experiment. The agreement between the data collected in the two independent experiments is striking, suggesting that the influences of surrounding field reflectance and task background size were relatively unimportant to visual performance.

Figure 5—The same as Figure 4, for black surrounds.

Figure 6—The significant interaction of task background luminance and task contrast on VP. VP is plotted as a function of task background luminance for black ink and gray ink reflectance sheets. The ordinate is scaled identically to those in Figures 8 and 9 for easier comparison. Each data point represents the average of 128 measurements (eight subjects by two surround reflectances by eight background sizes). The error bar represents the highest standard error of a mean.

Figure 7—Comparison of task performance ($1/S$) from this experiment (symbols, left ordinate) and from Rea, 1986 (solid lines, right ordinate), plotted as a function of task background luminance and task contrast, c . Curves were normalized to the highest and lowest common stimulus conditions, denoted by the open square symbols.

Figure 8—The effects of surround reflectance and task background size on VP. The ordinate is scaled identically to those in Figures 6 and 9 for easier comparison. Each data point represents the average of 128 measurements (eight subjects by eight task background luminances by two task contrasts). The error bar represents the largest standard error of a mean.

Figure 9—The effects of task background luminance and surround reflectance on VP. The ordinate is scaled identically to those in Figures 6 and 8 for easier comparison. Each data point represents the average of 128 measurements (eight subjects by eight background background sizes by two task contrasts). The error bar represents the highest standard error of a mean.

Finally, it is interesting to compare the magnitudes of the statistically significant effects of task contrast and background luminance with the nonsignificant effects of task background size and surround reflectance. **Figures 8 and 9** show the influences of task background size and background luminance on VP, respectively. Note that the ordinates on **Figures 6, 8, and 9** are scaled identically. This gives a clear sense that the influences of task contrast and background luminance were of much greater magnitude than either task background size and/or surround reflectance, as was suggested by the results of the ANOVA.

Readability ratings

The repeated measures ANOVA for the readability ratings showed significant main effects for task contrast [$F(1,7) = 42.04, p < 0.01$] and background luminance [$F(7,49) = 8.33, p < 0.01$]. **Figure 10** illustrates the nature of these two effects: Numbers printed in high-contrast black ink were rated as more readable than those printed in low-contrast gray ink; increases in background luminance increased perceived readability. Surround reflectance and background size did not affect subjective ratings of

readability under the range of conditions studied. This suggests that subjects were unaware of any changes in readability from either of these variables. This is consistent with the performance results presented earlier, which indicate weak or unmeasurable effects for surround reflectance and task background size. The rating data are, however, inconsistent with the performance data with regard to the background luminance by task contrast interaction. This interaction was not significant for the rating data, indicating, perhaps, that different visual phenomena mediate the different types of responses.

Pupil size

Time limitations precluded collection of pupil size data for all experimental conditions. Data were collected for the 12, 21, 44, and 100-degree task background sizes. Complete data for these four task background sizes under all eight illumination levels and at both background reflectances were available for only six of the eight subjects; two subjects had difficulty seeing the blur circles in the brighter conditions.

Figure 10—The effects of task background luminance and task contrast on perceived readability. Subjects were instructed to rate the reference sheet as zero if it was unreadable, and 10 if it was the most readable for the conditions presented in the experiment. Each data point represents the average of 128 measurements (eight subjects by eight background sizes by two background reflectances). The error bar represents the highest standard error of a mean.

Figure 11—The effects of task background luminance and background size on pupil diameter (in mm) for tasks presented with a gray surround. Shown are the data for four task background luminances (12.1, 21.4, 66.8, and 316 cd/m^2). Each data point represents the average of 18 measurements (six subjects by three replications). The solid lines were derived from Equation 3.

A repeated measures ANOVA was conducted on the pupil size measurements collected from these six subjects. This analysis showed significant main effects for background luminance [$F(7,35) = 75.08, p < 0.01$], task background size [$F(3,15) = 17.32, p < 0.01$], and a significant interaction between surround reflectance and task background size [$F(3,15) = 11.72, p < 0.01$]. These main effects and the interaction are illustrated in Figures 11-13.

Figures 11 and 12 depict the effects of background luminance and task background size on pupil diameter, for the gray and black surrounds. For both gray and black surrounds, increasing task background luminance produced decreases in pupil size. Surround reflectance and task background size interacted to determine pupil size (Figure 13). Measured pupil sizes were significantly smaller for gray surrounds at 12 and 21-degree task background size conditions (Tukey *post hoc* tests on differences between means, $p < 0.01$, Kirk²¹). However, there were no significant differences in pupil sizes under the gray and black surrounds at 44 and 100-degree task background size conditions (*post hoc* tests on differences between means were not significant).

An attempt was made to develop a preliminary model of pupil size using the independent variables included in the experiment, with multiple linear regression. For the conditions studied, 95 percent of the variance in measured pupil sizes could be accounted for by the following equation:

$$D = 9.137 - 1.948\log_{10}(L_b) - 2.294\log_{10}(B) + 0.572[\log_{10}(B)]^2 - 0.679R + 0.192[\log_{10}(L_b)]^2 \quad (3)$$

where D is pupil diameter (in mm), L_b is the task background luminance (cd/m^2); B is the task background size (in degrees), and R is surround reflectance.

The solid lines on Figures 11 and 12 show the predicted pupil diameter along with the averaged measured values, which are represented by the plotted points. Inspection of these figures shows that the fit between the predicted and measured pupil diameters is remarkably good.

Discussion

The results of this experiment suggest that reflectance of areas that surround a task will have at most a slight influence on suprathreshold visual performance. Of substantive importance to illuminating engineers are the visibility requirements of a particular task and the nature of the specific visual process under consideration.

The performance of typical printed office tasks will not be impaired by differences in reflectance between

Figure 12—Same as Figure 11, for black surround.

Figure 13—The significant interaction of task background size and surround reflectance on pupil diameter (in mm). Each point represents the average of 144 measurements (six subjects by eight task background luminances by three replications). The bar represents the critical difference required to achieve statistical significance on Tukey's *post hoc* tests for differences between means.

the task background and surrounding surfaces. These results showed no statistically significant performance decrements for surrounding fields of different spatial and background reflectance characteristics. However, task contrast and background luminance had statistically significant effects on performance, as has been established by previous research.¹⁷

The similarity between these findings and those reported earlier,¹⁷ support the reliability and validity of this experiment and these conclusions (Figure 7).

This study investigated the effect of varying the size and reflectance of the surrounding field. For suprathreshold visual tasks neither surround size nor reflectance had a statistically significant effect on performance. As a practical example, the color and/or size of a desk makes little if any difference to one's ability to read or write.

The results of Lythgoe¹ and McCann and Hall,¹⁰ however, clearly show that the spatial-luminance characteristics of the area surrounding visual tasks are important near threshold. Further, Rea's²² study of suprathreshold visual performance under task lighting suggested that heterogeneous illuminance patterns in the task area could have detrimental effects. Thus, we do not have a complete understanding of the influence of areas surrounding the task on all forms of visual work. It will be necessary to extend the range of study of visual performance to include much brighter surrounds. It may also be necessary to look to studies of fatigue, glare, and discomfort when confronted with heterogeneous visual fields.

Although surrounding field conditions had little effect on visual performance, previous investigations reported that subjects preferred surrounding field luminances slightly darker than the task background. The reports differed, however, quite considerably in the value of the luminance ratio (Table 1). Touw¹³ assessed preference by asking subjects at which of several tables they would prefer to work under several different lighting conditions. Tregenza, et al¹⁴ asked subjects to nominate a preferred level and spatial distribution of light for performing a variety of visual tasks. Bean and Hopkins¹¹ varied the illuminance on the task and background independently and asked people to indicate their preferred ratio by answering a short questionnaire that elicited their opinions about the level and distribution of light at the task and in the room. Roll and Hentschel¹² had subjects rate whether the luminances of different surfaces in a test office were too bright or too dark.

These more global responses differ from the relatively specific question asked of subjects in this experiment. Rather than asking them which luminance patterns they preferred, they were asked in this experiment to rate a specific stimulus using a specific rating

criterion, i.e., readability of the reference sheets under the different lighting conditions studied. The finding that readability ratings were determined simply by changes in background luminance or task contrast suggests that variations in the preference data collected by others have little to do with visual performance. This does not necessarily imply, however, that luminances in a room have little to do with fatigue, comfort, eyestrain, or headache. More studies need to be undertaken to determine the importance of luminance distributions on other room surfaces for comfort. Nevertheless, the preference data reported by others should not be used as the sole basis for setting visual performance guidelines since, apparently, room luminances have little to do with one's ability to see.

Although task surround conditions in this experiment did not significantly affect visual performance or perceived readability, measured pupil sizes were significantly smaller for gray surrounding fields than for black surrounding fields at 12 and 21 degrees, but were not significantly different at 44 and 100 degrees. Thus, while task surround conditions can mediate pupil size, such changes were inconsequential to visual performance or to subjective judgements of task difficulty.

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Discussion

I question the conditions of the test. Forty-two degrees (from the vertical) for the central viewing is extreme; 25 degrees is the appropriate central angle. Commery studied desk occupants and found the task area of the desk was 12 by 14 inches and 3 inches in from the desk front edge which meant 25 degrees to the center, 40 degrees to the top edge, and 0 degrees at the task front edge. Later these relationships were confirmed by observations made by Allphin, Rae, Chorlton, Dulude, Bradley, Crouch, and Kaufman. Later still, L.J. Buttolph installed a movie camera, one

picture per minute, and took 1600 valid views of IESNA desk workers. He discovered these objective values confirmed the earlier found relationships.

Is 42 degrees as good as 25 degrees for the peak of the frequency curve? No, because of an unnatural position which introduces an awkward holding of the head. I suggest that further work be done at 25 degrees and that a headrest for the forehead be used instead of a chin rest that holds the head up in an unnatural position. You can't tilt your chin down. Check it out. Seated at your desk, look at a task; your chin drops! Now hold your chin up, cupped in your hand and look out over your chin to a task located out at nearly 45 degrees and 19 inches away. This is a forced position.

Further, Mackworth at Cambridge University found that there was appreciable increase in errors (40 percent) when viewing at 45 degrees. Of course, there is a foreshortening of the digits or letters of approximately 30 percent.

The results of this subject study show little effect of enlarging the surroundings. This demonstrates that adding or not adding various areas of different luminance, even black, around the task does little to change the adaptation for greater or less sensitivity. Luckiesh once said that an open 6-by-9 inch book occupies 1 steradian solid angle and therefore controls the adaptation.

Now, if the authors will cut down the size of the test sheet and start with only the two columns of digits put close to each other on white paper and then try the test at 25 degrees central viewing, they will no doubt get different results, as did previous investigators.

However, transient adaptation is involved in the surroundings of a desk task. Carrying out daily desk work, one looks at the work details and then pauses to look away at surrounding area, or looks at another adjacent task (a reference or video screen). Therefore, the adjacent area should be kept in balance for maintaining consistent sensitivity. Guided by Glenn Fry we initiated a study of transient adaptation to serve as a dynamic basis for luminance ratios. This was carried out by Boynton and later by Edward Rinalducci, our current specialist. Therefore, will the authors study transient adaptation as a basis for luminance ratios in offices, schools, etc?

C.L. Crouch

The authors have conducted a carefully designed study with good control over both the dependent and independent variables.

I would like the authors to clarify how they addressed adaptation time for changing luminances and illuminances.

In vision research it is common to use a small sam-

ple, eight subjects in this study. I have reservations on using such a small sample for a preference rating. The method for attaining the subjective assessment of task quality used a specific rating criterion (0 = unreadable to 10 = most readable). This is an effective method. However, in subjective assessment, validity increases with a larger sample.

As typical in vision and visual perception studies, the experimental room was black (reflectance, $\rho \leq 0.02$). The major objective of the study was to take one more step in setting recommended task-to-surround-luminance-ratios for the workplace. Workplaces seldom, if ever, have reflectances that low. I seriously question the authors' conclusion, "The performance of typical printed office tasks will not be impaired by differences in reflectances between the task background and the surrounding surfaces." The authors do state that more studies with brighter surround luminance distributions on other room surfaces are needed. Thus, it seems that the conclusion for a specific application is premature.

In vision research it is typical to use the so-called "normal eye" of a 20-yr-old. This study tested to ensure normal vision and 20 yrs was the mean age. My concern is the same as in the previous point. Prior to making application recommendations, the impact of the aging eye needs to be addressed. Most people in a typical office are over 20, some are even over 45. In other words, it seems important to address task-to-surround-luminance-ratios for the aging eye.

The authors have used a test situation as a basis for an application recommendation. If the subjects experienced many trials, as they did in this study, in a relatively short period of time, the fatigue factor would be very different than in actual office settings. The statement, "For suprathreshold visual tasks neither surround size nor reflectance had a statistically significant effect on performance." is true for the test setting. However, including an example that the color or size of a desk does not affect performance is premature. It may be necessary to further examine fatigue, glare, and discomfort for different visual fields. This reviewer strongly concurs with that statement and perhaps could accept all the conclusions drawn in this paper after more studies have been completed that support the application conclusions. This study does what it sets out to do, but more steps are necessary prior to application conclusions.

Delores A. Ginthner
University of Minnesota

Although I am not completely surprised by the findings of this study, I am delighted to see a quality piece of research on this subject. This experiment was straightforward, without the type of interference that

plagues some similar studies (for example, Roll and Hentschel, 1989). I do have a few questions, however.

Can the authors elaborate further upon and discuss the significance of the difference between **Figure 6** and **Figure 10**? Perhaps performance and subjective judgements are not related in a direct linear function, but are related by a power function; the power is less than one, of course.

For **Figure 13**, what is the maximum deviation obtained from each data point, which comprises 144 measurements? How does this compare with the critical difference between means (gray surround and black surround)?

Why did the authors not also consider a visual environment that allows the subject's visual system to move around in a dynamic fashion, instead of just considering the immediate background?

Great care must be exercised in extrapolating the meaning and application of this finding in a lighting environment. This study narrowly focuses on the visual performance aspect of the lighting, incorporating a very restricted degree of freedom. It does not address the quality of the overall visual environment. Therefore, while from a performance standpoint surrounding luminance is not critical, other considerations, such as occupants' subjective visual comfort and overall luminance distribution preference, may demand an acceptable surrounding luminance.

Peter Ngai
Peerless Lighting Corporation

The authors' results suggest that for suprathreshold visual tasks neither surround size nor reflectance are important. They further suggest that the spatial-luminance characteristics of the area surrounding visual tasks (e.g., size of background field) may be more important for visual tasks near threshold. From the work my associates and I have done on transient adaptation, we have found that background field size upon which a change takes place may have a considerable influence on visibility loss. For example, greater losses are obtained for a 4-degree field superimposed on a 13-by-13-degree background field than for a 4-degree square superimposed on a 56-by-66 degree background field. The greatest losses were obtained for a 54-by-66-degree field superimposed on a 54-by-66-degree background field. In addition, smaller fields changing in luminance placed off-axis from the line of sight in the central visual field produced clear-cut losses in visibility, depending upon how close the changing area was to the line of sight and the absolute intensity of the changing area. These experiments were carried out with reference to both roadway and cockpit operations. However, they

employ a threshold paradigm which is typical of some of real-world situations.

Am I correct in drawing the conclusion that those problems involving threshold-like operations are to be treated different from those involving suprathreshold operations? If so, where does this place the previous work of Blackwell and Blackwell in relation to the work of Rea and his associates?

*Edward J. Rinalducci
University of Central Florida*

Authors' Response

To C.L. Crouch

You raise some interesting issues about these results, which provides us with an opportunity to help clarify our results to the reader. First, the relevance of 25 degrees as an assumed, general viewing angle has been addressed previously by Rea, Ouellette, and Kennedy.¹ It was argued in that paper that the photographic techniques leading to the presumed 25-degree viewing angle had questionable validity. The results by Rea, Ouellette, and Kennedy,¹ obtained from a controlled experiment using two fixed cameras and triangulation, showed that the natural positions taken by observers reading the numerical verification task were usually less than 15 degrees from vertical. Thus, the 25-degree viewing angle assumption is probably not valid for describing typical viewing positions.

This is a moot point, however, for this particular experiment. In this experiment we were attempting to understand more clearly the impact of surround luminances and sizes on visual performance (the speed and accuracy of processing visual information). We were not trying to model task performance (vision, plus non-visual factors such as motivation, fatigue, and intelligence). Our ability to isolate visual performance from the more complex issues of task performance has been demonstrated by our ability to use the relative visual performance model to predict suprathreshold data from previous studies of the numerical verification task (see text), from reaction times (Rea and Ouellette²), and from the reading accuracy data of McNelis).

The success of the model to predict the variety of data described appears to rest on the utility of solid visual angle as the rectifying size variable. Thus, the impact on visual performance by moving further from the task, or changing the viewing angle, can be predicted if the resultant change in solid visual angle is known. Frankly, we doubt that changing from 25 degrees to 42 degrees constitutes a change of 40 percent in visual performance under these experimental conditions. The change in solid angle is small, and the expected change in relative visual performance would

thus also be small, even for the lowest contrast and adaptation luminance used here.

The issue of transient adaptation is irrelevant for this experiment.³ Visual performance was obtained while subjects were viewing the number lists. We did not attempt to have subjects sequentially view dark areas and then the number task. Even if we had used such a protocol, it seems unlikely that the impact on performing the numerical verification task would be very large. Under the adaptation luminances used here, and common to offices, readaptation will take place very quickly. As long as cone bleaching is avoided, readaptation will take place in less than half a second. This time is small with respect to the total time needed to read the 200 digits in the numerical verification task.

We believe that these results are not at odds with other experimental data, and believe that if you more closely inspect the unreferenced data on the subject to which you refer, the present data and discussion will provide an adequate explanation of those findings. We do find your comments helpful for clarifying our results; thank you for the opportunity to respond.

To Dolores A. Ginthner

At least 5 min adaptation time was allowed when luminances were changed. This time was used by the experimenters to prepare the task materials required for the next series of trials.

We did not question subjects about preference. We asked subjects to report on the readability of the text under the various stimulus conditions presented to them.

There is little doubt that running more subjects will produce more significant differences between stimulus conditions. Running more subjects will not, however, affect the relative magnitude of these effects. Task contrast and light level will always be more important than background reflectance and background size on visual performance and subjective judgements of readability. Thus, the validity of these data and the conclusions reached from the analyses would not be improved by running more subjects.

It is inconceivable that the reflectances of the wall outside the visual field will, after adaptation, affect the visual response. Since subjects had sufficient time to adapt to the stimulus conditions, wall reflectance is irrelevant. Again, we did not ask subjects if they preferred to work in a black room.

Our collective knowledge about the aging visual system is increasing to the point where we can make quantitative predictions about typical age-dependent losses in retinal contrast and retinal illuminance. Based upon this knowledge, Wright and Rea⁴ successfully transformed data on the numerical verification task

obtained from older (60–65 yrs of age) to be equivalent to that obtained from younger subjects (20–25 yrs old) in the same experiment. In principle then, it is unnecessary to conduct experiments on people of different ages as long as the visual responses of older subjects are affected by these age dependent losses in retinal contrast and retinal illuminance. If the behavior of older people is affected by non-visual factors, then, obviously, such a transformation would not be able to predict the data.

We did not study fatigue, discomfort, or glare. We studied the impact of task contrast, background luminance, and background size on visual performance, subjective judgements of readability, and pupil size. As these stimulus conditions and behavioral responses apply to practice, they should be useful to lighting application specialists.

To Peter Ngai

Figure 6 shows the effects of task background luminance and task contrast on visual performance, while Figure 10 shows the effects of these same two variables on subjective judgements of readability. This implies that different visual processes are occurring. Recent electrophysiological evidence by Kaplan and Shapley⁵ is at least qualitatively consistent with this interpretation. Thus, visual performance, based upon speed and accuracy, is not synonymous with subjective judgements of readability.

Figure 13 shows the significant interaction between background reflectance and background size on pupil size. The Tukey *post hoc* test enables us to determine which combinations of these variables are significantly different using a fixed criterion ($p \leq 0.05$) and is therefore more meaningful than a comparison based upon maximum deviations. The analysis of variance was used to determine whether the background reflectances were significantly different or not. This comparison is less meaningful than the interaction, however, since it obscures the fact for large background sizes, there is no difference between gray or black surrounds.

We did not choose a dynamic visual task because we believe that, in principle, the functional relationships between the independent variables and the dependent variables would have remained the same, as long as cone bleaching was avoided. Under the adaptation luminances used here, and common to offices, readaptation takes place very quickly. Hence, even if subjects had been asked to sequentially view dark areas and then perform the numerical verification task, the impact on visual performance would have probably been very small.

To Edward J. Rinalducci

Visual performance is most sensitive to changes in

the stimulus conditions near threshold. As stimulus conditions improve, visual performance is less and less influenced by modulations of the stimulus. Indeed, the literature review presented in the introductory section of our paper and the results of our experiment, suggest that results dealing with threshold visibility may not be useful in predicting suprathreshold responses. The implications of modelling suprathreshold visual performance from threshold data has been addressed by the senior author in several places.^{6,7}

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