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Lighting and Task Parameters Affecting Posture, Performance and Subjective Ratings

by M.S. Rea, M.J. Ouellette and M.E. Kennedy

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ABSTRACT

The study identifies various task and lighting parameters that affect 1) posture and viewing angle, 2) performance of a numerical verification task, and 3) subjective ratings of task difficulty. It is concluded that a single (25-deg) viewing angle incorporated into most lighting design algorithms may not be adequate, since observers modify their posture in response to environmental conditions, apparently trying to achieve a constant level of task performance.

RÉSUMÉ

Cette étude identifie divers paramètres d'accomplissement de tâches et d'éclairage qui influent sur 1) la posture et l'angle de vision, 2) l'exécution d'une tâche de vérification numérique, et 3) l'évaluation subjective de la difficulté des tâches. On conclut qu'un angle de vision unique (25 degrés) dans les algorithmes de conception de l'éclairage ne sont pas adéquats, car les observateurs modifient leur posture en réponse aux conditions environnementales, en essayant d'atteindre un niveau constant de rendement au travail.

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LIGHTING AND TASK PARAMETERS AFFECTING POSTURE, PERFORMANCE AND SUBJECTIVE RATINGS

by

M.S. Rea, M.J. Ouellette and M.E. Kennedy

Introduction

The location of a person's eyes with respect to a visual task and the sources of illumination can greatly influence the visibility of the task. Printed text, for example, can be completely obscured by light reflected from the surface of a task. The importance of these so-called veiling reflections can be enhanced or minimized by changing the optics of the light source, the specularity of the task, or the optical (source-task-eye) geometry [1]. In fact, this last technique is the most effective in improving visibility of such materials. Geometry is, therefore, very important for a proper evaluation of the visual effectiveness of any lighting system.

This has been recognized for some time, and several photographic field studies [2-4] have been conducted to assess the variations in viewing angle adopted by office workers looking at tasks on a horizontal surface. Cameras were positioned more-or-less perpendicular to a sagittal plane through the worker's line of sight. Approximately 85% of the photographed profiles gave estimated viewing angles (between vertical and the line of sight) from 0 to 40 deg. Twenty-five degrees was taken as the angle of central tendency for adults (i.e., the average). Ever since these studies were published 25 deg has been used almost exclusively in evaluating the visual effectiveness of lighting systems [5].

Now regarded as orthodox, viewing angle is based solely on these early studies and their two-dimensional photographs. Some error must have occurred in estimating the viewing angles from the photographs, however, because precise profile perspectives could not be achieved in all field photographs. As well, the true viewing angles in three-dimensional space could not have been obtained from two-dimensional views when workers' lines of sight were not perpendicular to the camera. In other words, the angular magnitude for people leaning towards or away from the camera cannot be determined from such photographs.

More importantly, the lighting and task conditions associated with the viewing angles were not documented. The specularity of the task, light levels, heights of chair and desk, and even the visual capabilities of the worker would in all likelihood influence viewing angle, yet none of these factors was documented. Consequently, their influence on viewing angle cannot be assessed.

The limitations of the previous field studies have prompted a new investigation, a controlled parametric study, of the influence of various lighting and task parameters on several dependent variables related to viewing angle, subjective ratings of difficulty, and performance at the numerical verification task [1]. The independent variables (parameters) employed in the study were lighting geometry, task background luminance, task contrast, and task specularity. Two levels of each parameter, representing extremes that

might be found in typical office environments, were chosen for investigation. In this way an efficient sensitivity analysis could be performed to determine whether the parameters assumed to be important in practice actually influence the dependent measures. Subsequent experimentation is required to permit quantitative interpolations among these extremes.

Experimentation

Environment

The experiment was performed in a black room (Figure 1) in which reflectances, r , of ceiling, walls and floor were 0.05, 0.02 and 0.53, respectively. Illumination on the horizontal task was provided by cool white fluorescent lamps enclosed in a single luminaire mounted on a black ($r = 0.02$) metal superstructure. A white translucent diffuser covered the light-emitting aperture (95.5×95.5 cm) of the luminaire. Background luminances of the task response sheets, calibrated against the output of a photocell secured to the top of the observer's work table, were monitored and held constant at either 12 or 169 cd m^{-2} for a 25-deg viewing angle to the center of the task.*

Observers sat in an armless chair with castors at a horizontal, white-topped desk ($r = 0.84$). The height of the chair was adjusted so that when each observer was seated erect his or her eyes were at a 25-deg viewing angle to the center of the task. The desk was located at one of two orientations with respect to the luminaire. At the so-called 0-deg desk orientation, veiling reflections interfered with the task area if the observer maintained the initial, erect posture. At the 90-deg orientation, desk and observer were rotated clockwise about the center of the task, eliminating any possibility of veiling reflections.

Task and stimuli

For the numerical verification task used in this experiment, subjects were required to compare two juxtaposed lists of numbers for discrepancies. These were nearly identical, except for random single-digit errors. Subjects were required to compare the lists from top to bottom, find the errors (from zero to six on a given trial), and mark them with a pen stroke.

Both lists consisted of twenty five-digit numbers printed on white matte paper (22×28 cm). The list of numbers on the right, the response sheet, was printed with matte black ink; that on the left, the reference list, was printed with either matte black ink or matte grey ink. A small ink square was printed on every sheet for photometric evaluation of task contrast with a (6-min) spot photometer.

During a given trial a black ink response sheet and either a grey ink or a black ink reference sheet were presented to the observer for comparison. On

*With the specular plastic sheet overlying the task reference sheet and 0-deg desk orientation, the reflected image of the luminaire gave task luminances considerably higher than these values if the subjects maintained the 25-deg viewing angle. Similarly, the plastic overlay slightly reduced the luminance of the task reference sheet at other geometries, including the 90-deg desk angle, since its transmission was not unity.

half the trials a glossy, clear plastic sheet (transmission, $t = 0.89$) was placed on top of the reference sheet. The parameters, 1) reference sheet ink density (grey or black), and 2) clear plastic sheet (with or without), were completely balanced; each combination of the two experimental parameters represented 25% of the trials. Reference and response sheet contrasts obtained at the initial, erect 25-deg viewing angle are reported in Table 1.

Subjects

Eight volunteers, five male and three female from the staff of the National Research Council of Canada, Division of Building Research, participated in the experiment. Ages ranged from 21 to 27 (median = 23.5) years. All subjects were right handed and had excellent uncorrected vision, as determined by the battery of visual screening tests with the Keystone Ophthalmic Telebinocular. Subjects were not informed of the purpose of the study prior to testing. All wore a dark (laboratory) coat during testing to minimize and hold constant any light reflected from the body.

Time-lapse photography

On each trial two photographs were taken of the subject performing the numerical verification task. One 8-mm movie camera was positioned to give a profile view; an orthogonally positioned movie camera provided a frontal view. Both cameras, operating in a single-frame mode, were computer controlled to produce exposures 10 s after the start of a trial. Synchronized digital clocks in the cameras' fields of view identified each exposure.

The two photographic images, profile and frontal view, for a given trial were sequentially projected on sheets of paper. Key reference points in the projected images (bridge of nose, edges of desk, and center of task) were marked on the papers. The viewing angle for a reference point near the top of a list of numbers will, of course, be different from that for a reference point near the bottom of the list. Because the lists were scanned at different rates for each trial, the photographic images obtained 10 s after the start of the trial are not related to a common reference point. On more difficult trials (e.g. trials of low luminance and low contrast) subjects will be more likely to look at numbers near the top of the list than they will on easier trials (e.g. trials of high luminance and high contrast). Thus, the viewing angles obtained from the photographic images will be systematically larger for difficult conditions than for easy conditions. Preliminary testing showed that subjects scanned each pair of lists at a fixed rate and that the head positions were held relatively constant during a trial. Assuming that this also held true during the experiment, it was possible to determine viewing height, viewing distance, frontal viewing angle, and profile viewing angle for a common reference point (the center of the task) from the photographed images. It was also possible to calculate the three-dimensional viewing angle at the center of the task. Each of these measures was used as a dependent variable for statistical analysis.

Experimental design

A repeated-measures mixed design [6] was used in this experiment. All subjects experienced both levels of the following within-subject, independent variables:

- 1) desk orientation (O), 0 or 90 deg
- 2) task luminance (L), 12 or 169 cd m⁻²
- 3) reference sheet ink density (C), grey or black
- 4) reference sheet specularity (P), with or without glossy plastic overlay.

Four subjects were instructed to perform the numerical verification task as quickly as possible. The other four were instructed to complete the task as accurately as possible. Instruction (I), then, was the between-subjects variable.

Each of the sixteen unique combinations of within-subject variables was presented to every subject once during a practice session performed prior to the experiment. Each combination was repeated four times for every subject and counterbalanced across subjects in both instruction groups for the experiment (N = 64 trials/subject).

The following ten dependent variables were used in separate analyses of variance (ANOVA's) to determine the influence of the independent variables on posture, performance, and subjective rating of task difficulty:

Posture:

viewing height, mm
 viewing distance (to center of task), mm
 frontal viewing angle (to center of task), deg
 profile viewing angle (to center of task), deg
 three-dimensional viewing angle (to center of task), deg

Performance:

time to complete the list comparisons (S), s
 errors of commission, false positives
 errors of omission, misses
 score (R), where $R = (20 - E) / (S + 5)$, and E is the number of errors, both of omission and of commission, during the list comparisons [1]

Subjective rating:

magnitude estimations, from 0 (lowest) to 10 (highest), of task difficulty.

Protocol

At the start of the first practice trial a subject grasped, with the left hand, a white, opaque card covering the numbers on the reference and response sheets. On a verbal signal from the experimenter the subject removed the cover card and began to compare the lists for discrepancies. Simultaneously, the experimenter started the computer timing device; the computer triggered the cameras 10 s later. Immediately after the last pair of numbers on the lists were compared, 1) the subject said "Stop," 2) the experimenter stopped the computer timing device, and 3) the elapsed time was stored in the computer. The subject immediately gave an estimate of task difficulty and

wrote the number on the response sheet. The reference and response sheets were then removed.

Illumination level, desk orientation, and camera aperture were adjusted, if necessary, in preparation for the next trial. (An adaptation period of 5 min followed all transitions from bright to dim illumination levels.) New reference and response sheets and, if required, the plastic overlay were placed on the desk and then covered by the card. This process was repeated until the observer completed the 16 practice trials. After a 10-min rest this process was continued until 32 experimental trials were completed. After another 10-min rest, the second half of the experiment was completed. The duration of an entire session was approximately 3 h for every subject, including practice and rest periods.

Results and Discussion

The results of the ANOVA's are shown in Table 2, which presents a matrix of significance levels; the dependent variables head the columns and the significant ($p < 0.05$) main effects and interactions denote the rows. A problem with such a presentation of results is that the significance levels are not independent. Performing many ANOVA's increases the likelihood that some of the terms (main effects or interactions) will be significant by chance alone. Several values in Table 2 are probably unimportant, therefore, and could not be replicated in another experiment. Rather than select a more stringent significance level (e.g. $p < 0.005$) to correct for the positive bias created by performing multiple ANOVA's, it was deemed appropriate (for a pioneering study of this type) to present in Table 2 all of the statistically significant (as well as potentially important) terms from the ANOVA's.

An appropriate strategy for limiting positive bias when performing multiple ANOVA's is to combine the various dependent measures into one dependent measure for each of the three kinds of response (performance, posture and subjective rating) [7]. In the subsequent discussion emphasis will be placed on score as the dependent measure characterizing performance. Performance score has been used before [1,8,9], and although this particular combination of primary measures (errors and time) is somewhat arbitrary, it is not very different from the reciprocal of each measure [1]. Similarly, the three-dimensional viewing angle will be emphasized as the dependent measure characterizing posture. Magnitude estimations of difficulty will be used to characterize subjective assessments.

Discussion will not be limited to the three dependent measures. To illustrate other potentially important behavioral phenomena (like changes in height and distance), those values in Table 2 that were deemed consistent and reasonable will also be discussed. It should be recognized that the statistically significant values omitted from the discussion may be found important in subsequent replications or extensions of this study.

Conditions important to subjects' behavior

Ink pigment density (C) is clearly an important variable. It affected score, rating, and three-dimensional viewing angle to a significant degree (Figure 2). Similarly, most of the other dependent measures in Table 2 indicated that ink pigment density is important to behavior. Measures of both

performance and rating show that grey ink is significantly more difficult to see than black ink. People tended to position themselves in what they considered to be a more uncomfortable position [10,11] when confronted with gray ink. Subjects' three-dimensional viewing angles were significantly smaller for grey ink than for black ink; they 'hunched over' the task.

The interaction between the variables, reference sheet ink pigment density (C) and desk orientation (O), is also quite important (Figure 2). These results are similar to those for the main effect, i.e., reference sheet ink pigment density, described in the previous paragraph. Most of the dependent variables in Table 2 show that the $O \times C$ interaction is significant. Performance and ratings were particularly affected by the combination of grey ink and the 0-deg desk orientation. Similarly, subjects assumed much smaller three-dimensional viewing angles under these conditions. Photometric analysis of this position revealed that subjects deliberately tried to avoid veiling reflections at the 0-deg orientation, especially when the reference sheet ink was grey. This point is reinforced by the significant changes in the three-dimensional viewing angle when the plastic overlay (P) was used. Subjects adjusted their posture to reduce or eliminate veiling reflections, and in doing so maintained a high level of performance.

Other parameters and combinations of parameters were less consistent in producing significant results in the various ANOVA's. The main effect of task luminance (L) and the three-way interaction among variables, desk orientation (O), reference sheet ink pigment density (C), and plastic overlay (P), are worth special note.

Task luminance (L) produced significant changes in viewing height and viewing distance but not in three-dimensional viewing angle. Subjects apparently moved closer to the task without significantly affecting the angle at which they viewed the task (Table 2). This movement, characterized in Figure 3, effectively removed the (expected) performance changes normally incurred with changes in task luminance [12]. Further, subjects did not rate low luminance tasks as more difficult than high luminance ones. Apparently by moving closer to the task young adults can (over the range of luminances used in this experiment) effectively eliminate any deleterious effects on performance of short-duration tasks caused by lower luminance. Older individuals with less accommodative power in their lenses [13] and less flexible spines [14] may not, however, have this option.

Similarly, the $O \times C \times P$ interaction had a significant effect on posture (height, distance, and two viewing angles) but not on performance (Table 2). By systematically moving their bodies to smaller viewing angles when the lighting-task conditions were poor (Figure 4) subjects avoided the deleterious effects of veiling reflections on performance. Unlike the task luminance main effect (L), however, subjective ratings of task difficulty also reflected the changes in the lighting-task conditions.

Task instruction (i.e. emphasis on speed or on accuracy) was not important as a main effect, although subjects stressing accuracy tended to sit more erect. Task instruction did interact with several of the environmental factors to affect posture and perceived task difficulty. It should be emphasized that owing to the small sample size (four subjects in both task instruction groups) instructions may have remained statistically insignificant as a main effect and, further, that the significant interactions may only be

artifacts of the large individual differences rather than a result of the experimental parameters.

Subjective ratings

Subjective ratings showed more sensitivity to changes in the lighting-task conditions than to posture or performance, as evidenced by the number of significant terms in the last column of Table 2. These results indicate, then, that subjective ratings of task difficulty are not necessarily representative of changes in performance or posture. The effect of desk orientation and several interactions was only significant for subjective ratings of task difficulty. A subtle but important point can be made here. When asking a subject for an evaluation of task difficulty, it is impossible, without some validation [15], to determine whether he is responding to what is, in fact, difficult or to what might be difficult.

Conclusion

Lighting and task conditions affect peoples' posture. As a rule, people position themselves to improve task visibility. They move closer to the task when illuminance levels are low [16,17] and assume viewing angles that reduce veiling reflections. The latter is consistent with earlier findings [18], which showed that people will move an adjustable desk lamp to a position that reduces veiling reflections. Consequently, it is inappropriate to evaluate the visual effectiveness of lighting systems at an assumed 25 deg [5]; the implicit assumption that people adopt this fixed viewing angle and allow performance to deteriorate is incorrect.

Viewing angle may be an important design criterion, not because of reduced visual performance but because of reduced task performance created by strained or uncomfortable posture. It seems that people will do what they have to do to perform a task [19-21] even if it makes them uncomfortable. Although postural changes helped to maintain performance in this experiment, a number of studies [22,23] have shown that uncomfortable posture will (ultimately) impair task performance. Perhaps lighting systems should be designed to include the best orthopaedics as well as highest visibility. Further investigation of ergonomic effects as well as visual effects of lighting are clearly justified.

Summary

Lighting and task parameters affect subjects' posture when they perform reading-writing tasks on a horizontal plane. Subjects move closer to the task when light level or task contrast is reduced and position themselves to reduce veiling reflections. These postural adjustments to improve visibility decrease the deleterious effects on performance of poor lighting. The assumption that people adopt a fixed (25-deg) viewing angle and allow performance to deteriorate, as implied in current lighting calculation procedures, is therefore incorrect.

Subjective reports of task difficulty are more sensitive to changes in lighting and task parameters than are measures of performance and posture.

The assumption that subjective ratings necessarily reflect changes in objective measures of performance or in orthopaedic comfort is questionable.

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Table 1. Photometric Measurements*

Stimulus Sheet	Ink Type	Specularity	Lighting Geometry	Contrast ($\frac{L_b - L_t}{L_b}$)
Reference	Black	matte	0°	0.753
		gloss		0.369
	Grey	matte		0.119
		gloss		0.080
	Black	matte	90°	0.898
		gloss		0.903
	Grey	matte		0.169
		gloss		0.144
Response	Black	matte	0°	0.711
		matte	90°	0.781

*Measurements of task background luminance (L_b) and task target luminance (L_t) were made with a Pritchard model 1980A telephotometer from a reference angle of 25 deg from vertical to center of the task. Typical reference sheets with grey and black matte inks were used in the measurements.

Table 2. Significance levels, p , from analysis of variance. Empty cells have significance levels greater than 0.050

Independ- ent Var. and Inter- actions	Dependent Variables									
	Misses	False Pos.	Time	Score	Height	Dist.	Frontal angle	Prof. angle	3-D Angle	Rating
O										0.005
L					0.005	0.020				
C			0.001	0.001	0.005			0.010	0.005	0.020
P								0.050	0.050	0.020
OC			0.005	0.020	0.010	0.010		0.010	0.050	0.001
OP	0.050									0.001
LC									0.050	0.001
CP				0.050						
IOC			0.050							0.050
ILP							0.005			
ICP							0.050			
OCP					0.050	0.050		0.010	0.020	0.050
LCP										0.001
IOLC					0.020	0.020				
ILCP					0.020					0.001

Independent Variables: C Contrast O Lighting Geometry
 I Instructions P Specularity
 L Luminance

Figure 1 Side view of experiment room

Figure 2 Interaction between the independent variables - desk orientation and reference sheet ink pigment density (ink type) - affecting the dependent variables - three-dimensional viewing angle (view angle), performance (score), and magnitude estimation of task difficulty (difficulty). The magnitude of the significant ink pigment density main effects for the three dependent variables are shown in parentheses

Figure 3 Effect of task background luminance on eye height and eye-to-task distance

Figure 4 Significant interaction among desk orientation, ink pigment density (ink type) and specularity affecting viewing angle (view angle) is shown by the inconsistent relation of column heights in the quadrants

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