DISCOMFORT GLARE EFFECTS OF VEILING REFLECTIONS IN PAPERS

by

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THIS BOOK CONTAINS NUMEROUS PAGES WITH THE ORIGINAL PRINTING BEING SKEWED DIFFERENTLY FROM THE TOP OF THE PAGE TO THE BOTTOM.

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INTRODUCTION

People have at least two distinct requirements for light. The first is a physical need to make the task of seeing accurate, fast and effortless. The second is a need for light of a distinct character to create and influence emotional response. In work areas the emphasis has been on the physical needs of workers.

Proper lighting of the work area is important from the viewpoint of visual performance, that is, speed and reliability of perception and the stress imposed on the person concerned and his willingness to perform visual tasks. Hence it is imperative to be concerned, both with the quality and quantity of lighting, thus taking note of the fact that an adequate illuminance is fundamental but not the only requirement.

The ability of the eyes, in general, to do the job is primarily dependent upon the visibility of the work, but is modified by the visual capabilities of the human being himself. The visibility of a task or object is determined by its size, contrast, time of viewing and luminance. Each of these factors is largely dependent upon the others, in the sense that a deficiency in one may be compensated by augmenting one or more of the others.

The direction of light is another factor which can affect the appearance of reading and writing tasks. In case of an unfavorable direction, contrast loss and in cases, even glare can occur, affecting performance.

Contrast

To be readily visible, each detail of the task must differ in luminance from the surrounding background. The contrast between the luminance of an object and its immediate background is $(L_b - L_d)/L_b$, where L_b and L_d are the luminances of the background and object, respectively. For example, the luminance contrast of the black printed letters against the white background of this page is high. Conversely, the luminance contrast of black print on a dark colored paper is low. Luminances in the visual field which surrounds an object or task can have different effects on visual ability depending upon the areas involved. This luminance may produce a decrement in visual ability, visual comfort or both.

Contrast Rendering Factor

In experiments involving the evaluation of contrast loss, it is useful to relate the luminance contrast, C, under each different lighting system to a standard value of contrast with ''spherical illumination'', which is the illumination on a task from a source providing equal luminance in all directions about that task.

Veiling Reflection

For years lighting designers and those engaged in vision research have recognized that substantial losses in contrast can result in the deterioration of light quality. This results when normal reflections are superimposed on diffuse reflections from a task causing the details of the task to be partially or totally obscured. This has been known as the general subject of reflected glare. At one extreme of the scale is the reflection of a bright light source on a polished metal surface causing annoyance, distraction and even disability from the visual standpoint, to the other extreme, when light rays are reflected from the specular surface of the task rather than absorbed and re-radiated in the direction of the observer's eye. For example, the reflection of a large luminous area on the surface of a magazine printed on dull paper causes a milder form of reflected glare known as veiling reflection.

Factors causing Contrast Loss

In the study of contrast losses due to veiling reflections, it is not just enough that the lighting system alone be analyzed; other factors to be considered include the worker's orientation and viewing angle and the visual task, like printing or handwriting or the paper itself.

Most papers consist of rough fibers that have been matted together. Though the fibers making up the paper have a certain amount of shine, their random orientation causes nearly equal reflection in all directions. The luminance of the paper depends both, on the amount of light being diffusely reflected from it and the reflection of light from any specular surfaces in it. The latter may be discernible as in the case of coated papers, but frequently is indistinct and goes undetected, though serious losses in visibility occur. The specularity of the graphic medium -- pencil, pen, ink, carbon, etc., again covers a very wide range. The degree of specularity depends on how the medium is deposited. For example, a soft pencil brushed lightly across a rough paper would leave a very diffuse mark. On the other hand, a hard pencil applied with pressure on a smooth surface can be very shiny, causing reflection from the bright spots. Hence, when considering task contrast both diffuse and specular reflections of the paper and the graphic medium need to be considered. The pressure applied by the pen, pencil, typewriter key or printing type actually embosses the paper. The groove thus created causes the reflection of the light source to occur from the groove, other than the usual angle of reflection from the plane of the paper.

The orientation of the observer with respect to the task greatly influences the magnitude of the effect of veiling reflections. For one eye position and one point of regard, a simplified relationship between the eye, the task, the perpendicular to the task, and an offending zone can be established (Figure 1). If the task was perfectly flat and specular, the offending zone would merely be a point. However, since the types of task involved are diffusing, the theoretical offending point is enlarged to an offending zone. If the eye is in a position such that the rays of light from the offending zone are reflected toward it, veiling reflections occur.

Evaluation of Lighting Systems

Those tasks which are affected by veiling reflections are subject to the visibility criterion, known as Equivalent Sphere Illumination (ESI). ESI is used as a tool in determining the effectiveness of the control of veiling reflections and as part of the evaluation of lighting systems. The basic principles underlying the concept of Equivalent Sphere Illumination include the establishment of a reference lighting condition. Sphere lighting (perfectly diffuse lighting) is used as the reference, since spheres have repeatable illumination characteristics. It is an arbitrary standard chosen to measure relative visibility potential, wherein it is assumed that for this reference lighting condition, the same amount of sphere illumination will always produce the same amount of visibility. Equivalent spherical illumination is the same concept taken one step further -- to the real lighting environment, the ESI of a visual task in a real environment being the equivalent illumination produced by a sphere. That is, the visibility of the task in the real situation is equivalent to that produced by a certain amount of sphere illumination.

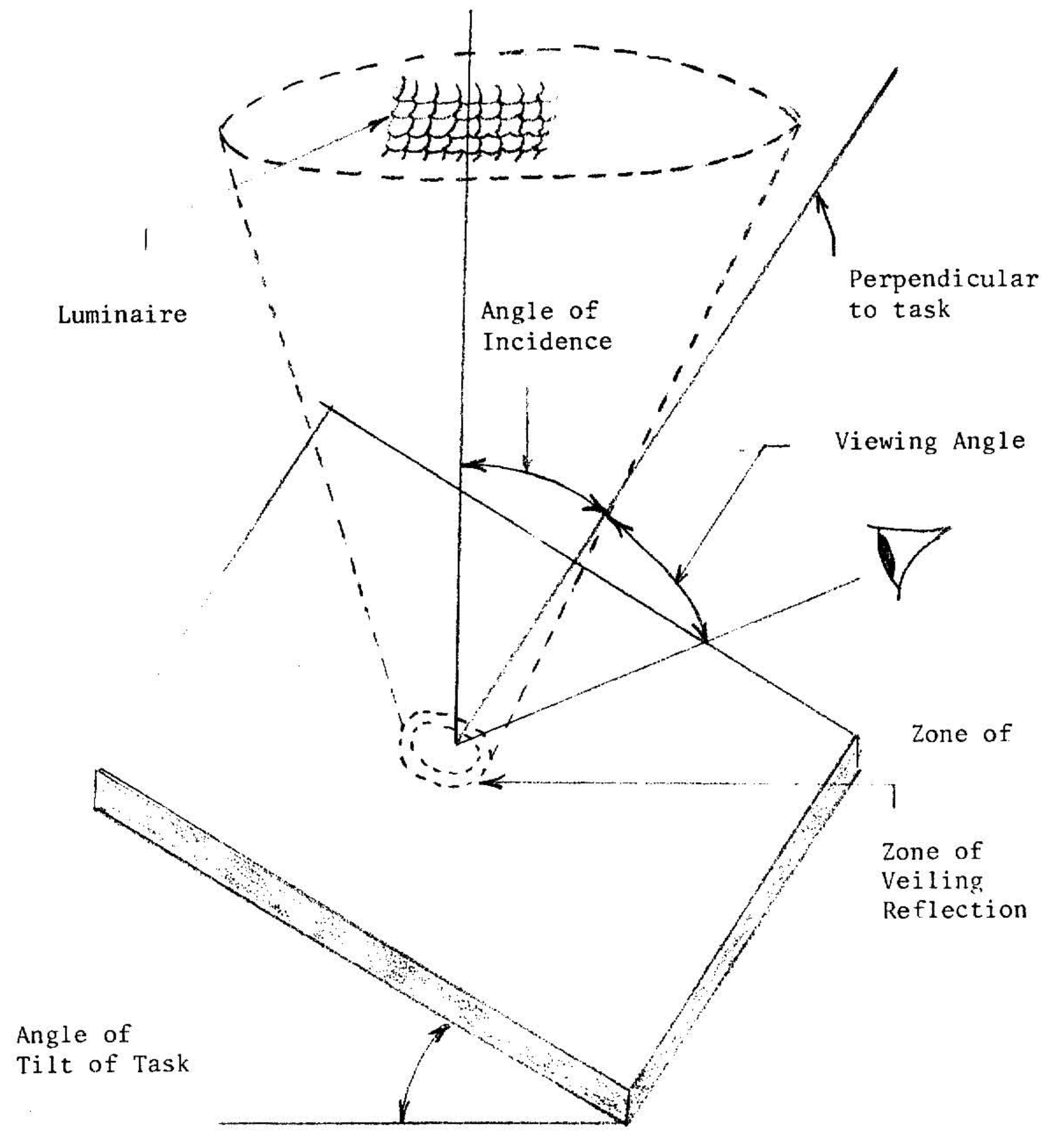


Figure 1. Description of Angular Relationships in Analyzing Veiling Relections.

Blackwell and DiLaura (1973) have investigated application procedures for evaluation of veiling reflections in terms of Equivalent Sphere Illumination using a Visual Task Photometer for different viewing angles and four different lighting materials - diffusers, prismatics, batwings and polarizers. The authors have tabulated the predetermined and measured values of Contrast Rendering Factor for a penciled script task.

Recent research has led to the development of a Contrast/ESI meter designed to provide for the easy measurement of contrast instead of using a cumbersome photometric process. This has been accomplished by modifying the angular response to light of an illuminance meter. The meter designed by Smith, Hinchman and Grylls Associates, Inc., consists of a base and adaptor plate for positioning an illuminance meter probe and two transmittance modifying cylinders. The cylinders have transmittance patterns that mimic bidirectional reflectances of a particular standard visual task. Thus, an illuminance meter, when used with the cylinders, responds to the light in the same way that a standard visual task does. However, a different pair of cylinders is required for each visual display. Standard visual displays include:

1. Number 2 pencil on white paper,
2. IBM Selectric typing on bond paper,
3. Xerographic copy,
4. Drafting on Mylar
5. Felt tip pen on white paper
6. Ball point pen on white paper
7. Black offset printing on semi-matte paper.

Using the two cylinders, the background and task luminance is obtained from which the contrast of the standard visual display is calculated. The contrast rendering factor is determined as a ratio of the contrast in the lighting situation to the contrast the visual display exhibits in a photometric sphere.

Landolt Visual Task

The effect of illumination on the actual performance of a task has been studied using a visual task. Weston (1945) developed a series of visual tasks which consisted of a large number of Landolt (broken) rings printed in a pattern arranged so that the position of the gaps in the rings fall in a random distribution in the pattern (Figure 2). The 16 by 16 matrix of Landolt rings had eight possible orientations of the gaps in the rings -- East, West, North, South, Northeast, Northwest, Southeast, and Southwest. The task of the observer was to cancel every ring with the gap in one of eight orientations in a given fixed amount of time. Visual performance was quantified by the number of rings correctly marked minus the number of incorrectly marked rings, thus giving a measure of both speed and reliability of perception.

Reitmaier (1979) has studied the effect of veiling reflection and its subjective evaluation. He was able to correlate the physically measured quality of lighting in terms of the contrast rendering factor with the subjective evaluation of paper gloss. The author studied five different samples of paper at a constant illumination of 93 foot candles, but varying the ratio of illumination (light field composition) from the diffuse and directional light sources. In his study the subjects evaluated the paper samples for gloss on a six point scale as follows:

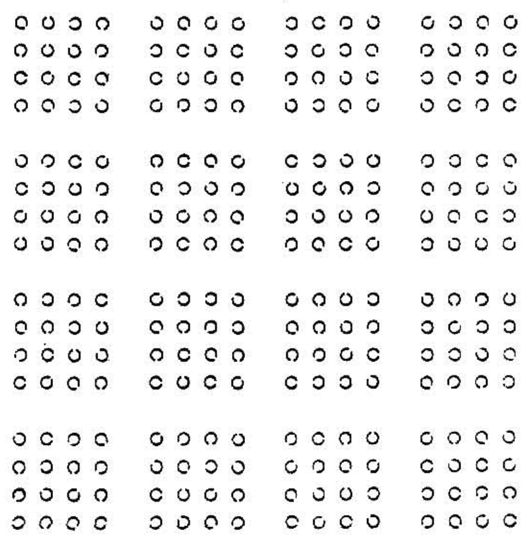


Figure 2. Ring Orientation in Landolt Visual Task.

A. No gloss
B. Hardly noticeable
C. Low
D. Medium
E. Strong
F. Extremely strong

By using regression analysis, the author obtained a correlation between the median gloss index score for each paper sample and a maximum factor

$$\xi = \beta_{max} / \beta_o = \beta(V_1 = 25^o) / \beta \ (V_1 = 0^o)$$

where

β = $L(V_1) / L_w$.

$L(V_1)$ = Luminance of the paper sample for the angle of incidence of light.

L_w = Luminance of a diffuse reference standard.

Reitmaier also reported that with increasing gloss index values, the contrast rendering factor decreased. The contrast rendering factor was maximized at a gloss index value of one. Similarly, the relative performance of a Landolt Visual Task increased with increasing contrast and reached a maximum at a contrast value of one. His studies concluded that for good visual performance, adequate values of contrast and luminance were required.

From the viewpoint of visual comfort, the author reported that, ''a value P_{max} can be defined, which is the maximum percentage contribution of the offending zone to the overall illuminance at the visual task, if discomfort is to be avoided''. In other words, the P_{max} value had to be low for paper samples with higher gloss indices.

A pilot study was done by Narain (1982) on the effect of paper gloss and light field composition on performance of a visual task. The study was done with four different paper samples and five light field compositions, with a fixed directional source of light. It was found that performance was not affected by any of the above factors, thus not supporting the earlier study by Reitmaier (1979).

There seems to have been minimal work done in the area of correlating the physically measured quality of lighting based on contrast and Equivalent Sphere Illumination and the judged quality which is based on performance of visual tasks like the Landolt visual task, and subjective evaluations of paper gloss and overall visual conditions. It is also felt that there were certain shortcomings in the investigations of Reitmaier and Narain, like the oversimplified visual task and the use of non-directional lighting for the paper gloss evaluation process. One of the objectives of this research, is to overcome the above defects and search for correlations between physically measured and judged quality of lighting.

PROBLEM

The objective of this study is to measure the quality of lighting physically, based on

1) Equivalent Sphere Illumination,
2) Maximum Factor
3) Light Field Composition
4) Directional Light Source Position

and the judged quality of lighting on the basis of

a) judged paper gloss,
b) subjective evaluation of the quality of visual conditions and
c) performance on the Landolt Visual task,

and, hence, correlate the physically measured and judged quality of lighting. Specifically the following hypotheses are set:

1. The overall quality of lighting decreases as the maximum contribution of illumination from the offending zone increases.
2. Performance on the visual task increases with decreasing contribution from the directional light source.
3. Equivalent Sphere Illumination is a function of light field composition and directional light source position.
4. Judged paper gloss is related to the maximum factor which is a function of the paper luminance.
5. The directional light source to the side of the observer, will cause least visual discomfort.
6. The quality of visual conditions is affected by paper type, in effect, the paper gloss -- increased gloss index causing lower visual quality.

METHOD

The study consisted of four parts. In the first, 21 subjects made subjective evaluations of paper gloss for six paper samples under a constant illumination of one hundred horizontal foot candles. In the second part of the experiment, the subjects performed the Landolt Visual Task under varied lighting conditions [light field composition,] each group of seven performing at one of the three lighting positions of the directional source. Next, the subjects evaluated the overall quality of visual conditions for each of the five lighting conditions and finally the subjects participated in the "validation part" of the study. The first three parts were conducted in a light booth. Physical measurements of contrast and luminance were made.

The Chit Lighting Booth

The visual task was performed by the subject at the light booth [Figure 3], which was constructed from wood panels with an opening at the front for the subject to view the task placed in the booth. The light booth had facilities for varying the illumination by either switching off or on, the fifteen incandescent lamps on the ceiling of the booth. The booth walls were painted white on the inside for better light reflection properties. The incandescent lamps provided a non-directional lighting, while the source of directional lighting, was a table lamp placed inside the booth a little above the observer's eyes and at an angle of twenty five degrees to the vertical. The position of the directional light source was changed among three positions [Figure 4], zero degrees, forty five degrees and ninety degrees (to the left of the subject), with each subject performing the task and evaluation at a particular position. The total illumination at the

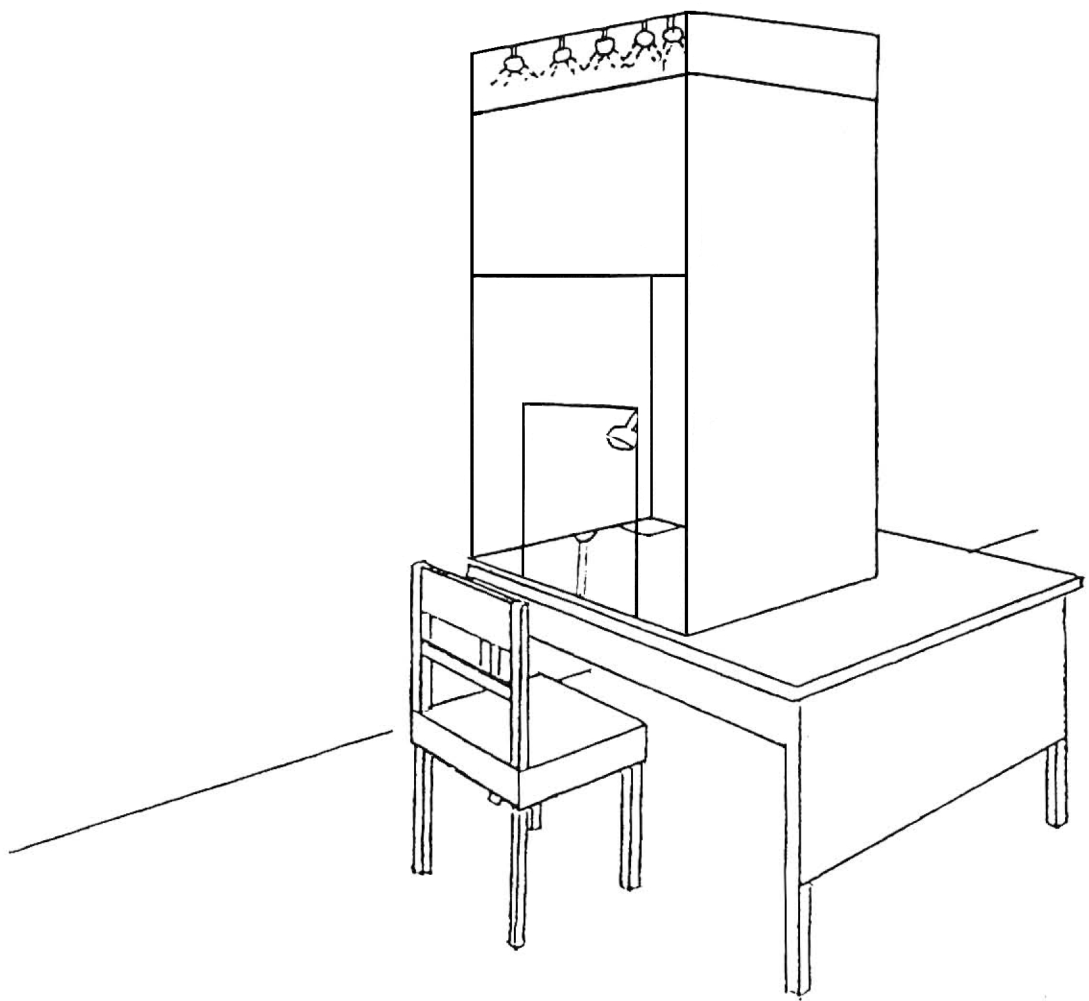


Figure 3. View of the Chit Lighting Booth.

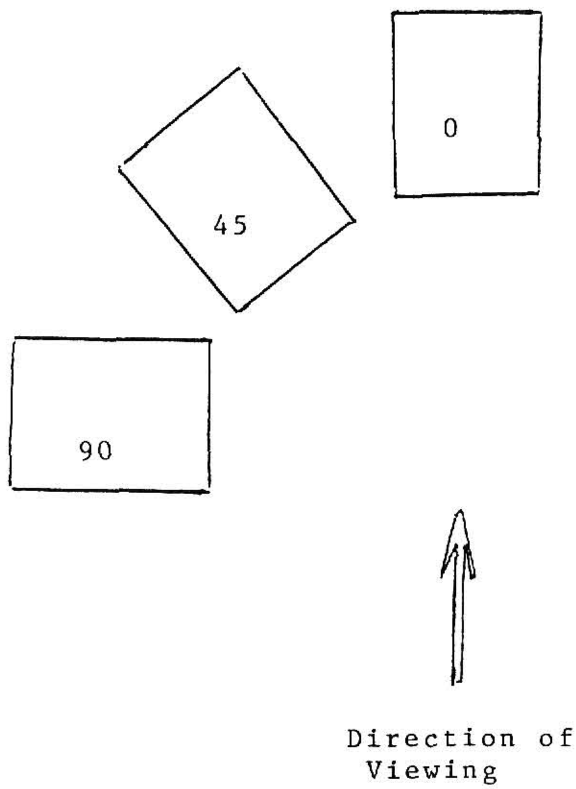


Figure 4. Light Source Position.

surface of the booth was maintained at a constant level of one hundred horizontal foot candles, varying the quantity of illumination from each of the two light sources -- this being referred to as the light field *composition* (Table 1). During the experiment the subject viewed the task at an angle of twenty five degrees by placing his chin on a chin-rest. The background and task luminances for the five light field compositions and three light positions were computed from the values of R_B and R_D obtained by measurements with the ESI/Contrast meter. They were as follows:

$$L_b = K_b \times R_b \times 10.76$$

$$\Delta_L = K_d \times R_d \times 10.76.$$

where R_b and R_d are in footcandles. K_b and K_d are the calibrating constants.

$K_b = 1.0284$ For ''B'' cylinder #B-0615101

$K_d = 0.1959$ For ''D'' cylinder #D-0615101

L_b = background luminance

Δ_L = luminance difference between background and task.

The contrast was then computed as

$$C = \frac{\Delta_L}{L_b},$$

from which the contrast rendering factor was found.

$$CRF = \frac{C}{C_o}$$

where $C_o = 0.1675$ for a Number 2 pencil task.

The equivalent sphere illumination,

Table 1. Light Field Composition

	Light Field Composition	
	Overhead Luminaire (footcandles)	Directional Light Source (footcandles)
1.	0	100
2.	25	75
3.	50	50
4.	75	25
5.	100	0

$$EST\ (\text{Footcandles}) = \frac{\pi}{\beta_b}\left[\frac{0.568558}{\frac{2.19572}{x + \log\ (CRF)} - 1}\right]^5 \times 10.76$$

where

$$x = \left[1 + \frac{2.19572}{\frac{1}{1.75885\ [L_b)^{-2}]}}\right] .$$

β_b, the reflectance has a value of 0.858, for the number 2 pencil task.

Appendix A, gives further details of the ESI/Contrast meter. The computed values of contrast, contrast rendering factor and equivalent sphere illumination are shown in Table 2. This procedure was repeated in computing the ESI values for the ''validation study'' [Table 3].

Photometric measurements of the luminance of paper samples were made in the light booth from which the maximum factor ξ was computed, this is shown in Table 4.

Subjective Reaction

In this part, subjects evaluated the gloss of six paper samples on a six point scale. The paper samples were selected in consultation with the professionals at the K-State Printing Press [Figure 5, 6, 7, 8, 9, and 10]. They were as follows:

1. Kromekote Cast Coated One Side paper.
2. Dull Coated Offset Enamel paper.
3. Coated Offset Enamel paper.
4. Erasable Bond paper
5. Handmade Embossed Finish Offset paper and,
6. Sulphite Bond paper.

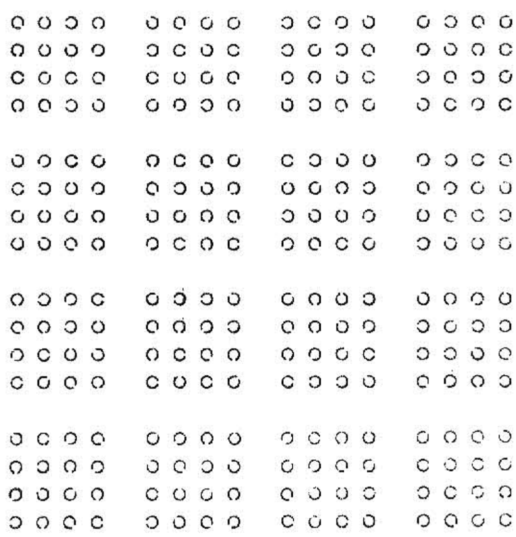


Figure 5. Kromekote Cast Coated One Side Paper.

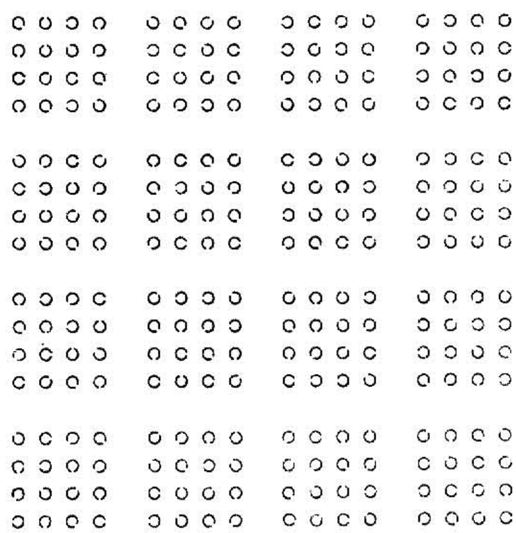


Figure 6. Dull Cast Offset Enamel Paper.

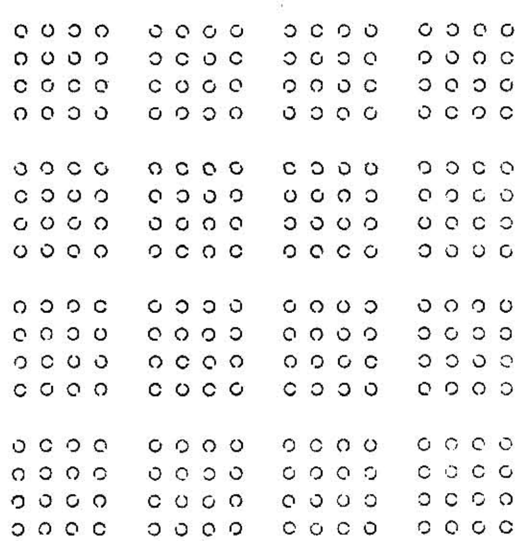


Figure 7. Coated Offset Enamel Paper.

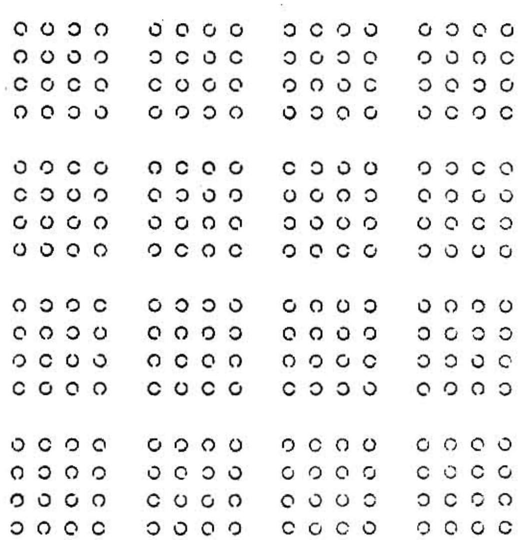


Figure 8. Erasable Bond Paper.

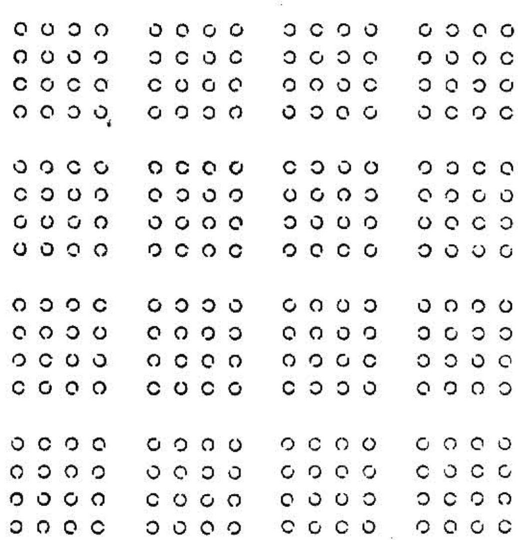


Figure 9. Handmade Embossed Finish Offset Paper.

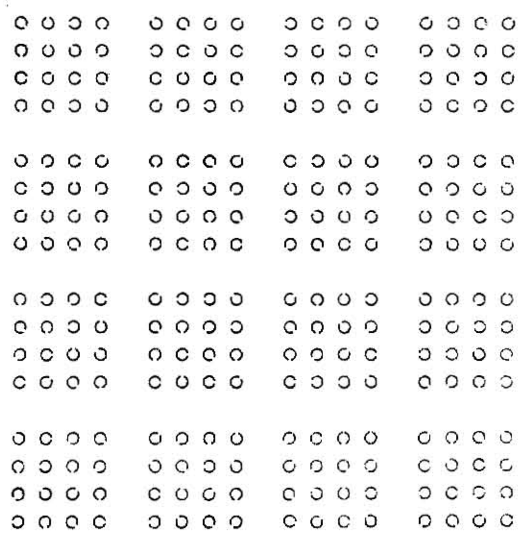


Figure 10. Sulphite Bond Paper.

Table 2. ESI Values for Different Light Positions and Light Field Compositions in the Light Booth

Light Source Position	Light Field Composition Overhead (footcandles)	Light Field Composition Directional (footcandles)	Contrast C	CRF	ESI (footcandles)
	0	100	0.0699	0.4170	0.7971
	25	75	0.1062	0.6343	3.7122
0°	50	50	0.1172	0.6998	6.2268
	75	25	0.1229	0.7337	8.8276
	100	0	0.1370	0.8180	26.5143
	0	100	0.1524	0.9099	56.4934
	25	75	0.1438	0.8583	34.0206
45°	50	50	0.1395	0.8326	29.2484
	75	25	0.1492	0.8909	48.7881
	100	0	0.1455	0.8685	37.9826
	0	100	0.1587	0.9477	75.5846
	25	75	0.1425	0.9098	56.4499
90°	50	50	0.1478	0.8823	44.2699
	75	25	0.1437	0.8579	36.1225
	100	0	0.1455	0.8685	37.9826

Table 3. ESI Values from ''Validation Study''

Subject #	Illumination Footcandles	Contrast C	CRF	ESI Footcandles	Performance %
1	53	0.1587	0.9477	31.60	55.0
2	74	0.1587	0.9477	31.60	73.0
3	65	0.1397	0.8339	17.34	46.7
4	50	0.1714	1.0235	21.73	50.0
5	65	0.1651	0.9856	51.06	43.6
6	35	0.1524	0.9009	10.77	50.0
7	67	0.1397	0.8340	17.35	60.0
8	65	0.1524	0.9098	19.13	70.0
9	65	0.1397	0.8340	17.35	59.4
10	46	0.1333	0.7961	9.35	75.0
11	40	0.1482	0.8845	15.71	60.0
12	125	0.1168	0.6970	6.65	56.3
13	77	0.1667	0.9951	58.2	68.8
14	90	0.1524	0.9098	38.95	53.3
15	100	0.1681	1.0035	77.26	56.3
16	65	0.1361	0.8123	13.97	37.5
17	105	0.1612	0.9623	73.65	41.2
18	77	0.1172	0.6998	9.68	50.0
19	40	0.1429	0.8529	13.92	75.0
20	40	0.1587	0.9478	16.27	43.3
21	40	0.1524	0.9099	10.77	32.4

Table 4. Mean Gloss Index and Maximum Factor for Six Paper Samples at Three Light Positions

Directional Light Source Position	Paper Type*	Maximum Factor (ξ)	Gloss Index (G)
	A	2.143	4.429
	B	1.414	3.857
	C	1.290	2.571
0^{o}	D	1.219	2.143
	E	1.111	0.571
	F	1.464	0.571
	A	0.999	4.571
	B	1.039	3.286
45^{o}	C	1.074	2.429
	D	1.144	1.857
	E	1.161	0.286
	F	1.079	0.714
	A	1.099	3.429
	B	1.094	2.714
90^{o}	C	1.099	2.571
	D	1.134	2.857
	E	1.151	1.857
	F	1.096	0.857

*
A. Kromekote Cast Coated One Side Paper
B. Dull Coated Offset Enamel Paper
C. Coated Offset Enamel Paper
D. Erasable Bond Paper
E. Handmade Embossed Finish Offset Paper
F. Sulphite Bond Paper

During this part of the experiment, the paper sample was illuminated completely by the directional light source. Written instructions were given to the subjects as shown in Figure 11.

Performance Task

In this part, the subject performed the task designed to test the speed and accuracy of visual perception. The Landolt Visual task which has been described in the previous chapter was used. The subject performed the task for a particular position of the directional light source, five different light field compositions and six samples of paper at a constant illumination of one hundred foot candles. The 30 combinations were completely randomized and the subject marked the broken rings in one of the eight orientations. The subject was given 60 seconds to perform each of these tasks. Written instructions were given to the subjects as shown in Figure 12.

The subject then evaluated the overall quality of visual conditions for each lighting condition and paper sample on a seven point scale. The subject evaluted a total of 30 samples. The light field composition was varied using two variable transformers for the directional and non-directional light sources.

Validation

In the final part of the experiment, the subject evaluated the paper samples on the six point scale for gloss and performed the visual task on one of the six samples of paper, selected at random. The subject also judged the quality visual conditions in this part. The validation part of the experiment was conducted in offices in Durland Hall. Measurements of illuminance and contrast were also made.

INFORMED CONSENT AND INSTRUCTIONS PAPER GLOSS

This experiment is designed to study ''The Effect of Veiling Reflection in Papers''.

Your task will be very simple. You will be given six samples of paper with printed text, and asked to judge the papers on the basis of gloss. During this experiment, you will rest your chin on the support, and the papers will be placed on the table in front of you at a fixed location. For example, if you feel that a particular sample is very strong in gloss, circle the number close to your judgment, on the sheet, as shown below:

0. No Gloss
1. Hardly Noticeable
2. Low
3. Medium
4. Strong
5. Extremely Strong

There will be no risk in this experiment. However, you are free to stop your participation at any time. Naturally, I would prefer that you continue until the end so that I can get all the data. If you have any questions, now or later, feel free to ask.

Now if you are ready for the experiment, please sign the informed consent statement form.

Thanks for your cooperation.

Figure 11. Instructions given to the subjects.

INFORMED CONSENT AND INSTRUCTIONS PERFORMANCE TASK

This experiment is designed to study ''The Effect of Veiling Reflection in Papers.''

Your task will be very simple. You will be seated at the Lighting booth, which can be set at different levels of illumination. The task to be performed is a 16 x 16 matrix of broken rings, wherein the broken part is oriented in one of the eight directions. You will identify all the broken rings in a particular orientation for five light settings and six samples of paper. You will have to make a pencil mark across the identified rings. This experiment will be performed in a fixed amount of time, at the end of which you will be asked to stop. In case you complete earlier, please go to the top and start checking all over again. The penalty for missing a broken ring is one point, and two points for marking a wrong ring.

In the third part of the experiment, you will evaluate the overall quality of visual conditions for five light settings. During the part, do not bother to read the printed text on the paper samples. For example, if you feel that a particular light setting provides very poor visual conditions, circle the number close to your judgment as shown below

1. Completely Inadequate
2. Very Poor
3. Poor
4. Average
5. Good
6. Very Good
7. Excellent

There will be no risk in this experiment. However, you are free to stop your participation at any time. Naturally, I would prefer that you continue until the end so that I can get all the data. If you have any questions, now or later, feel free to ask.

Now, if you are ready for the experiment, please sign the informed consent statement form given by the experimenter.

If you have any comments about the procedure or the experiment, please feel free to inform the experimenter about the same.

Thanks for your cooperation.

Figure 12. Instructions given to subjects.

Experimental Design

The independent variables in the experiment were the light field compositions light position and the type of paper. The dependent variables in the subjective evaluation part were the subjective rating of paper gloss and visual conditions and in the performance task part, it was the number of rings correctly marked. This was then converted as a percentage of all rings, deducting one point for every ring not marked and two points for every incorrectly marked ring (i.e., ring with broken part not in the specified orientation). Random number tables were used for randomization of light positions, paper samples and lighting conditions.

Subjects

Twenty one subjects, all male, served in this experiment. All of them were students, enrolled in various colleges of Kansas State University. The age of the subjects varied from 20 years to 30 years with a mean of 25 years. Two of the 21 subjects wore eye-glasses. Subject took an average of forty five minutes to do the whole experiment.

RESULTS

The subjective reactions of the subjects on the degree of gloss of the six paper samples for three positions of the light source are given in Appendix B.

Table 5 presents the mean gloss indices for each of the papers and lighting positions averaged over seven subjects. An analysis of variance was carried out for this dependent variable, gloss index, as shown in Table 6. The results indicate significant differences among papers and interaction of light source position and paper. No significant difference is indicated between light source positions. Further analysis by Duncan's multiple range test and Fisher's LSD test at $\alpha = 0.05$, indicate which means are significantly different. The results of Duncan's and Fisher's tests are shown in Tables 7 and 8 respectively. Figures 13, 14, and 15 show the variation in paper gloss index for different paper types at light positions 0^{o}, 45^{o} and 90^{o}, respectively. Figure 16 shows the overall variation among paper samples in gloss.

The subjective evaluations of the quality of visual conditions and performance scores on the visual task for thirty samples by each subject are given in Appendix C. Table 9 presents the mean ratings by the subjects of the quality of visual conditions. Analysis of variance of subjective evaluation of quality of visual conditions in shown in Table 10. The results indicate significant differences among light field compositions, paper type, interaction of position and light field composition and the position and paper type interaction. Further analysis by Duncan's multiple range test at $\alpha = 0.05$, indicates which results are significantly different. The results of Duncan's test are shown in Tables 11, 12, and 13, while Figures 17 and 18 shows the variation. The

Table 5. Mean Ratings by the Subjects when Evaluating Paper Samples on Basis of Gloss

Directional Light Source Position	Paper Type*	Gloss Index[1]
	A	4.4286
	B	3.8571
0°	C	2.5714
	D	2.1429
	E	0.5714
	F	0.5714
	Mean Gloss Index	2.3571
	A	4.5714
	B	3.2857
45°	C	2.4286
	D	1.8571
	E	0.2857
	F	0.7143
	Mean Gloss Index	2.1904
	A	3.4286
	B	2.7143
90°	C	2.5714
	D	2.8571
	E	1.8571
	F	0.8571
	Mean Gloss Index	2.3809
	Overall Mean Index	2.3095

*
A. Kromekote Cast Coated One Side Paper
B. Dull Coated Offset Enamel Paper
C. Coated Offset Enamel Paper
D. Erasable Bond Paper
E. Handmade Embossed Finish Offset Paper
F. Sulphite Bond Paper

[1] Gloss was rated on a scale from 0 to 5 with a central position of 3.

Table 6. Analysis of Variance of Paper Gloss Evaluation

Dependent Variable Paper Gloss

Source	DF	Mean Square	F	Significance Level
Light Position	2	0.4524	0.87	0.4218
Error	18	1.2143		
Paper	5	37.29	71.84	0.0001*
Position * Paper	10	2.3	4.43	0.0001*

* Significant difference at $\alpha = 0.05$

Table 7. Duncan's Multiple Range Test at $\alpha = 0.05$ for Gloss Index. Degrees of Freedom = 90

Dependent Variable: Paper Gloss

Paper Type*	Mean Gloss Index	Grouping			
A	4.1423	A			
B	3.2857		B		
C	2.5238			C	
D	2.2857			C	
E	0.9048				D
F	0.7143				D

Means with the same letter are not significantly different.

*
A. Kromekote Cast Coated One Side Paper
B. Dull Coated Offset Enamel Paper
C. Coated Offset Enamel Paper
D. Erasable Bond Paper
E. Handmade Embossed Finish Offset Paper
F. Sulphite Bond Paper

Table 8. Fisher's LSD Test at $\alpha = 0.05$ for Gloss Index

Dependent Variable: Paper Gloss

Light Source Position	Paper Type*	Mean Gloss Index	Grouping			
	A	4.4287	A			
	B	3.8571	A			
0^{o}	C	2.5714		B		
	D	2.1429		B		
	E	0.5714			C	
	F	0.5714			C	
	A	4.5714	A			
	B	3.2857		B		
45^{o}	C	2.4286			C	
	D	1.8571			C	
	E	0.2857				D
	F	0.7143				D
	A	3.4286	A			
	B	2.7143	A	B		
90^{o}	C	2.5714		B	C	
	D	2.8571	A	B		
	E	1.8571			C	
	F	0.8571				D

* A. Kromekote Cast Coated One Side Paper
B. Dull Coated Offset Enamel Paper
C. Coated Offset Enamel Paper
D. Erasable Bond Paper
E. Handmade Embossed Finish Offset Paper
F. Sulphite Bond Paper

Table 9. Mean Ratings by the Subjects of the Quality of Visual Conditions.

Directional Light Source Position	Light Field Composition Overhead (footcandles)	Directional	Mean Quality
	0	100	3.9286
	25	75	4.1667
0^{o}	50	50	4.2381
	75	25	4.7143
	100	0	5.2381
	0	100	4.0952
	25	75	4.3810
45^{o}	50	50	4.7619
	75	25	4.8810
	100	0	4.8810
	0	100	4.6190
	25	75	4.2143
90^{o}	50	50	4.4286
	75	25	4.2143
	100	0	3.9762

[1] Refers to the Subjective Evaluation of Quality of Visual Conditions on a One to Seven Scale Ranging From Completely Inadequate to Excellent Conditions.

Table 10. Analysis of Variance of Subjective Evaluation of Visual Conditions

Dependent Variable: Evaluation of Visual Conditions

Source	D.F.	Mean Square	F	Significance Level
Light Position	2	5.04	0.5	0.0009
Error	18	10.16		
Light Field Composition	4	5.67	5.34	0.0003*
Paper Type	5	12.39	11.68	0.0001*
Light * Paper	20	0.878	0.83	0.6798
Position * Light	8	6.68	6.3	0.0001*
Position * Light * Paper	40	1.13	5.34	0.3735
Position * Paper	10	5.66	1.06	0.0001

* Significant Difference at $\alpha = 0.05$.

Table 11. Duncan's Multiple Range Test at $\alpha = 0.05$ for Evaluation of Visual Conditions

Dependent Variable: Mean Quality

Light Field Composition Overhead (Footcandles)	Directional	Mean Quality*	Grouping	
0	100	4.2143	A	
25	75	4.2540	A	
50	50	4.4762	A	B
75	25	4.6032		B
100	0	4.6984		B

Means with the same letter are not significantly different.

* Refers to Subjective Evaluation of the Quality of Visual Conditions on a One to Seven Scale ranging From Completely Inadequate to Excellent Conditions.

Table 12. Duncan's Multiple Range Test of $\alpha = 0.05$ for Evaluation of Visual Conditions

Dependent Variable: Mean Quality

Paper Type[1]	Mean Quality*	Grouping	
A	4.3143	B	
B	3.9810		C
C	4.400	B	
D	4.3048	B	
E	4.9238	A	
F	4.7714	A	

Means with the Same Letter are not Significantly Differeent.

* Refers to Subjective Evaluation of the Quality of Visual Conditions on a One to Seven Scale ranging From Completely Inadequate to Excellent Conditions.

1
A. Kromekote Cast Coated One Side Paper
B. Dull Coated Offset Enamel Paper
C. Coated Offset Enamel Paper
D. Erasable Bond Paper
E. Handmade Embossed Finish Offset Paper
F. Sulphite Bond Paper

Table 13. Duncan's Multiple Range Test at $\alpha = 0.05$ for Light Source Positions

Dependent Variable: Mean Quality

Directional Light Source Position	Mean Quality[1]	Grouping
0°	4.4572	A
45°	4.6000	A
90°	4.29	A

1 Refers to Subjective Evaluation of the Quality of Visual Conditions on a One to Seven Scale Ranging From Completely Inadequate to Excellent Conditions.

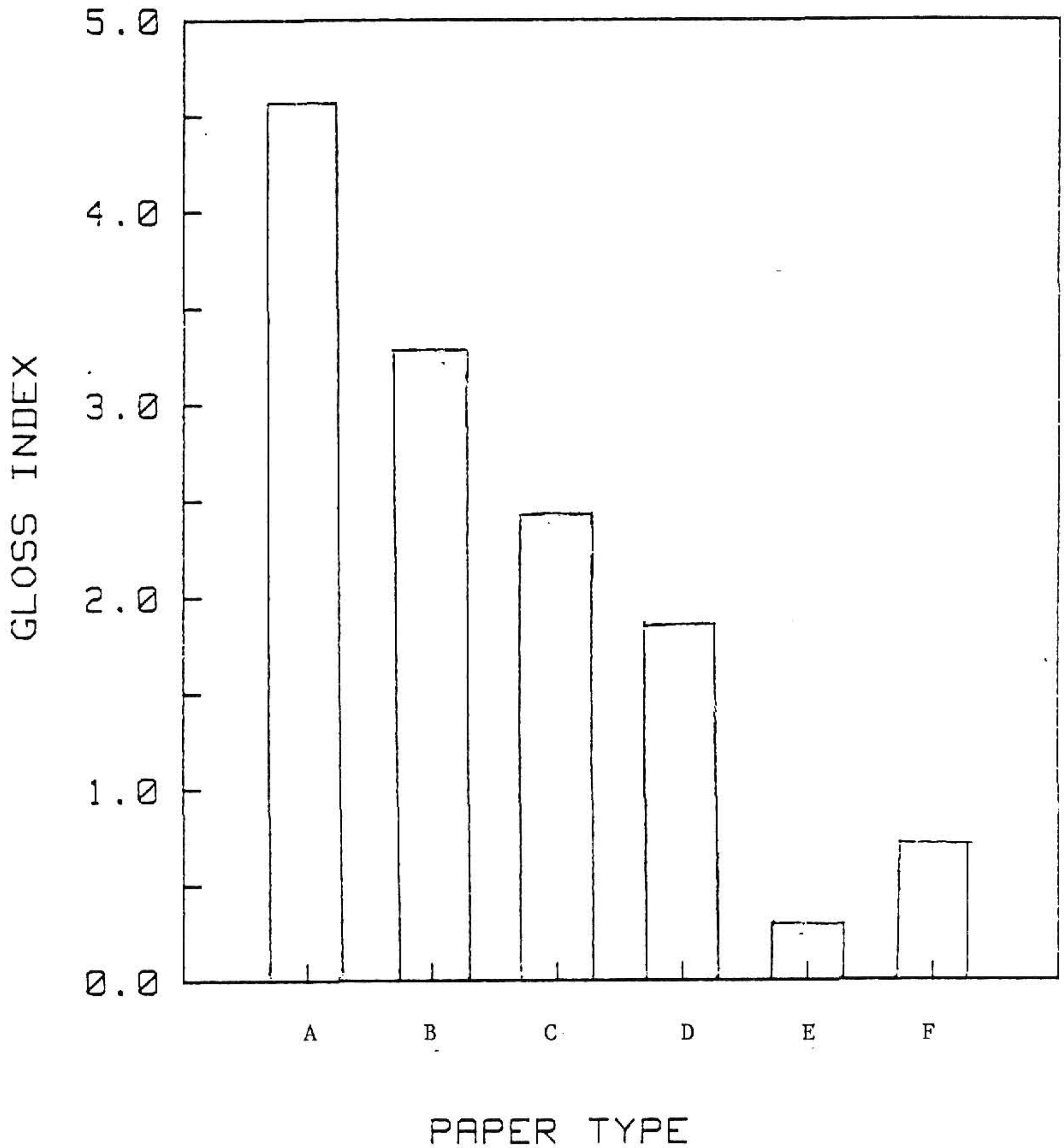


Figure 13. Mean Gloss Index vs Paper Type for light position, 0 .

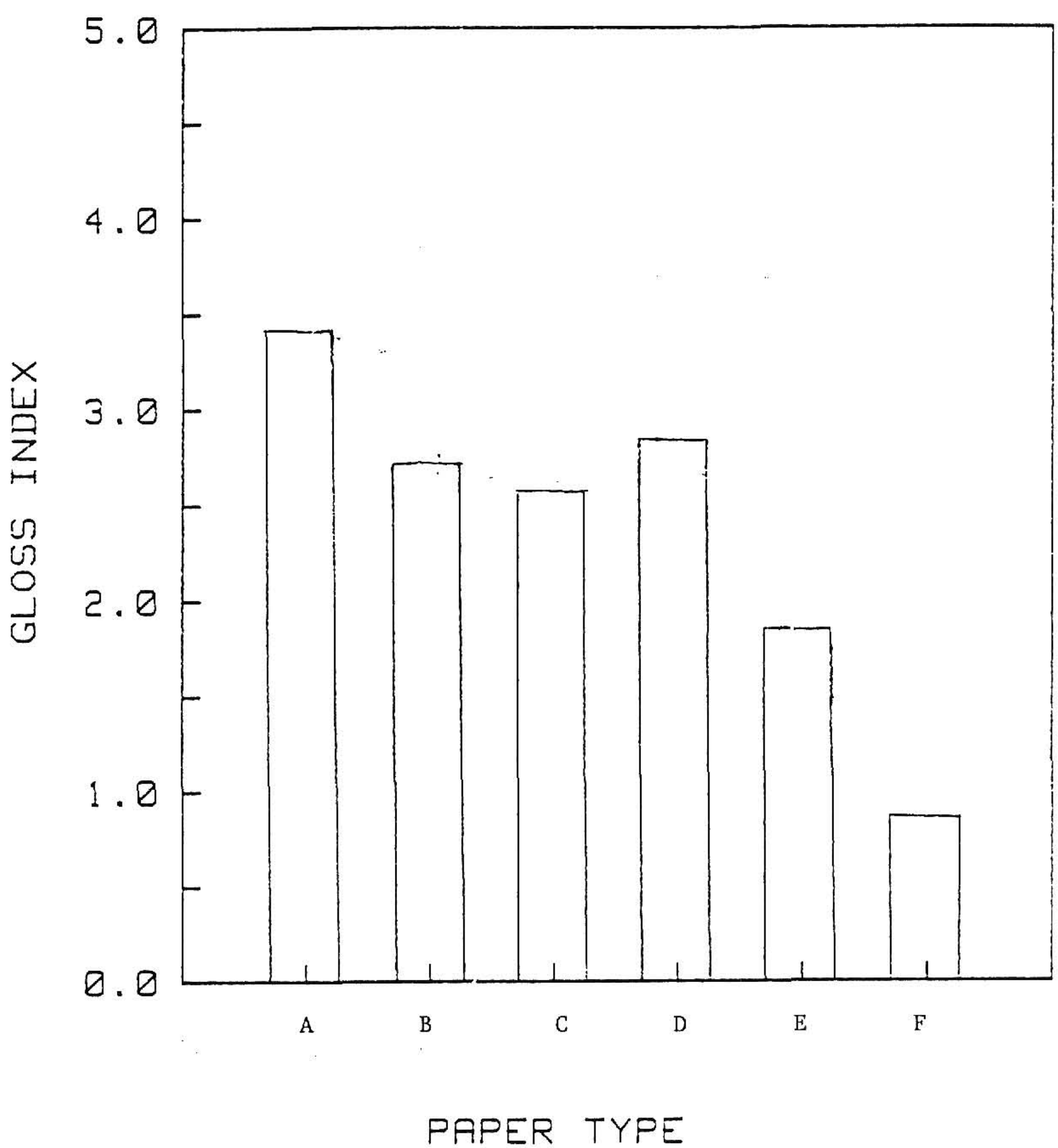


Figure 14. Mean Gloss Index vs. Paper Type for light position, 45°.

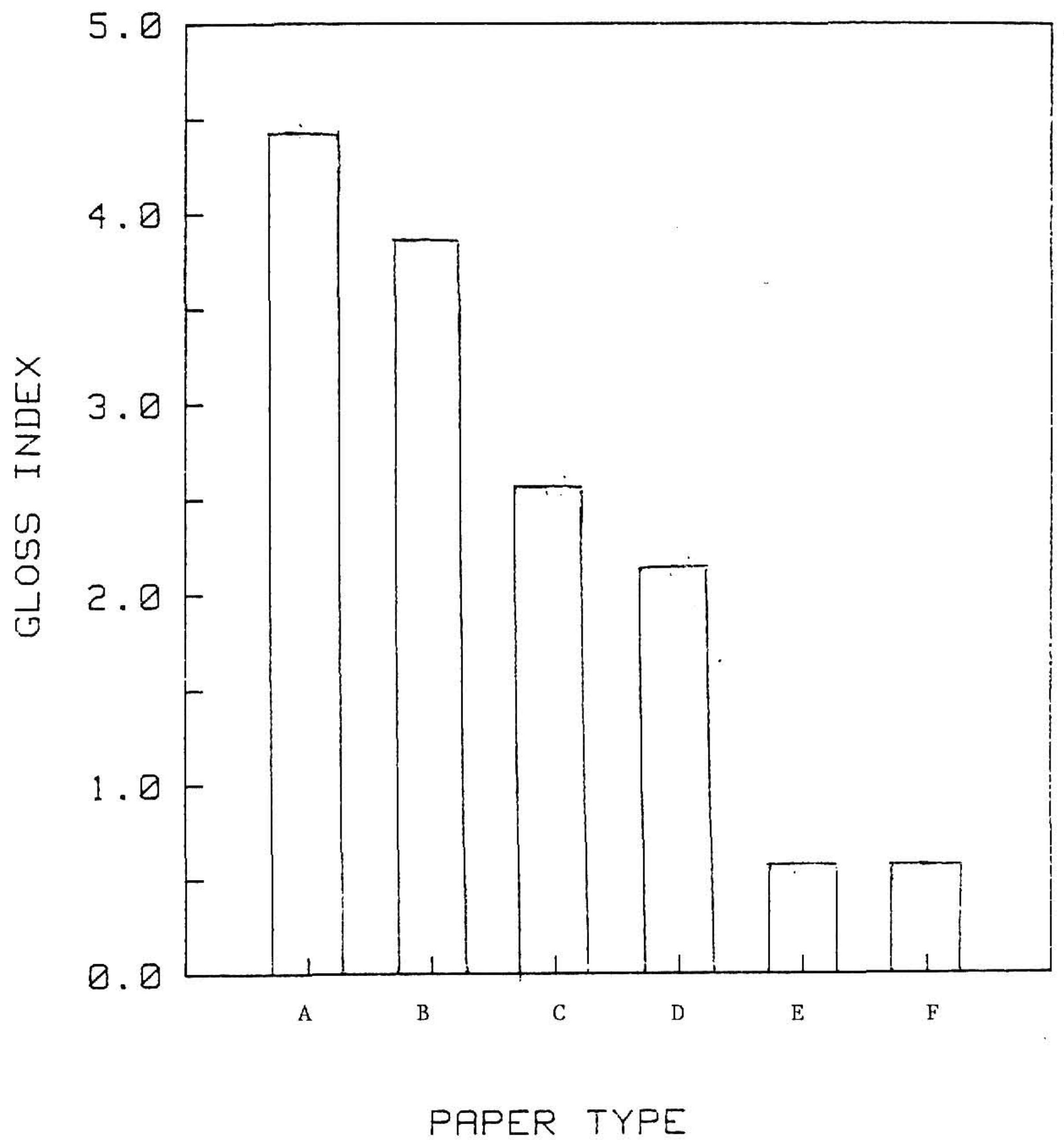


Figure 15. Mean Gloss Index vs. Paper Type for light position, 90°.

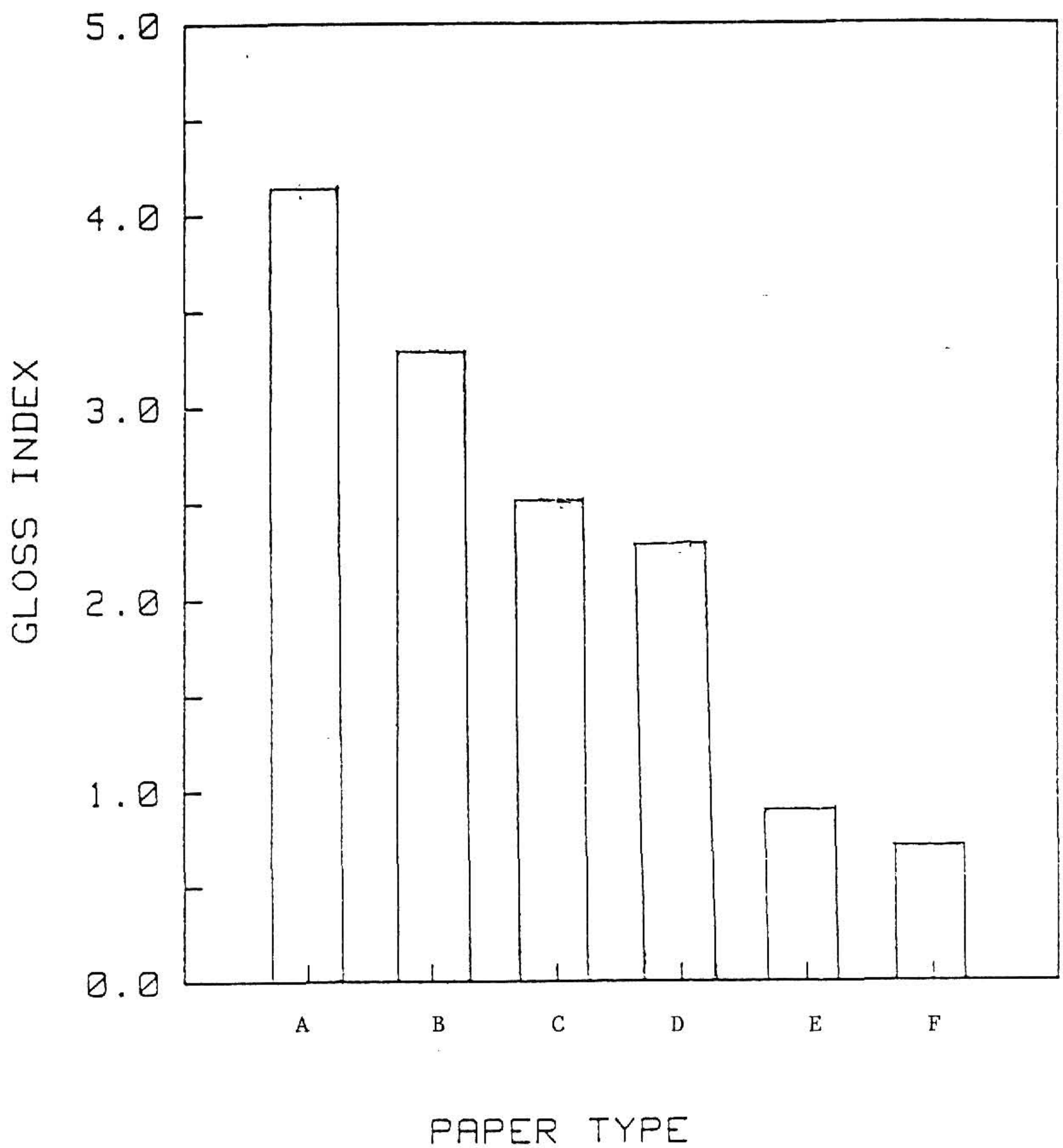
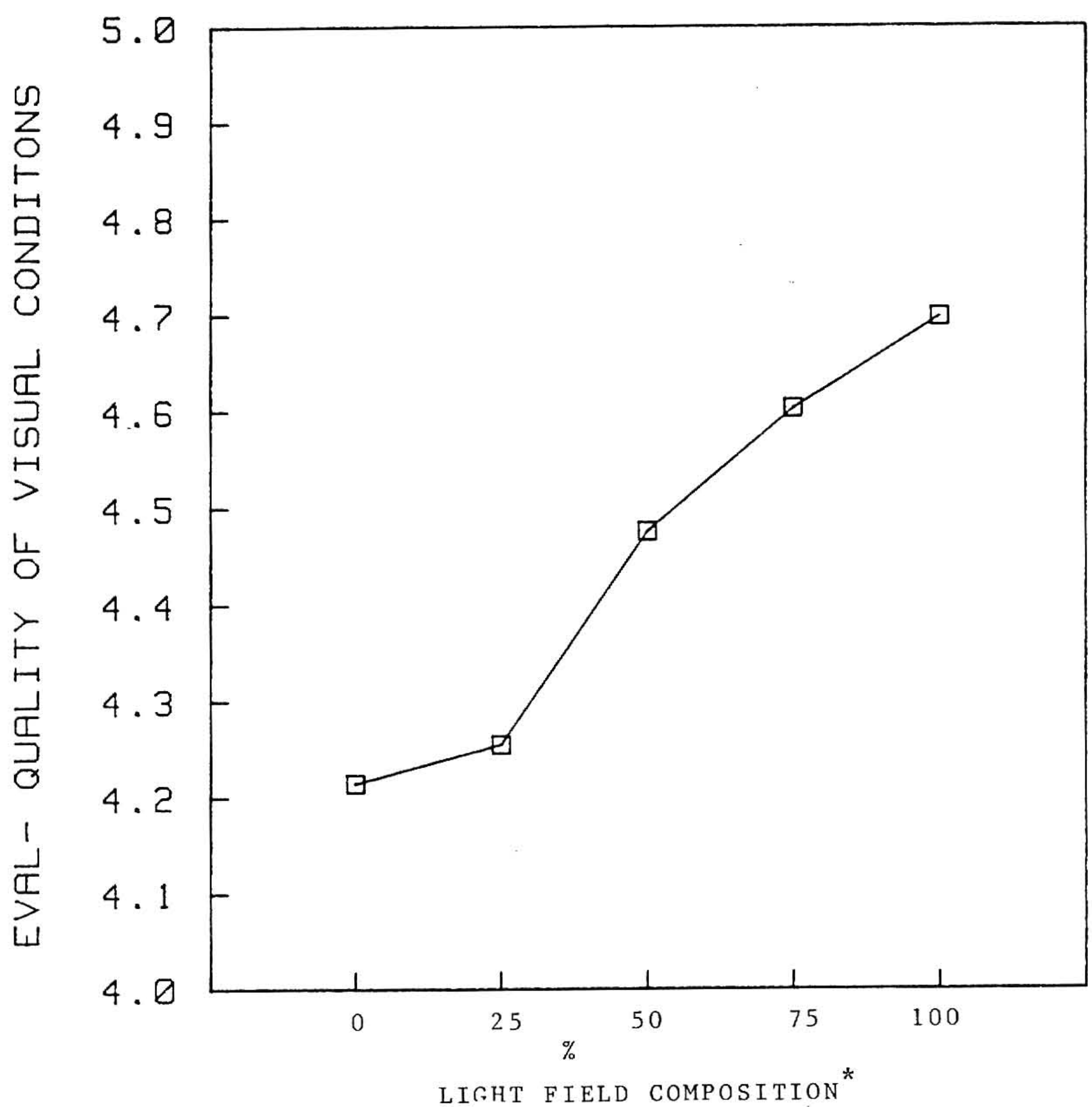


Figure 16. Mean Gloss Index vs. Paper Type.



* refers to percentage contributed from directional light source.

Figure 17. Evaluation of Visual Conditions vs. Light Field Composition.

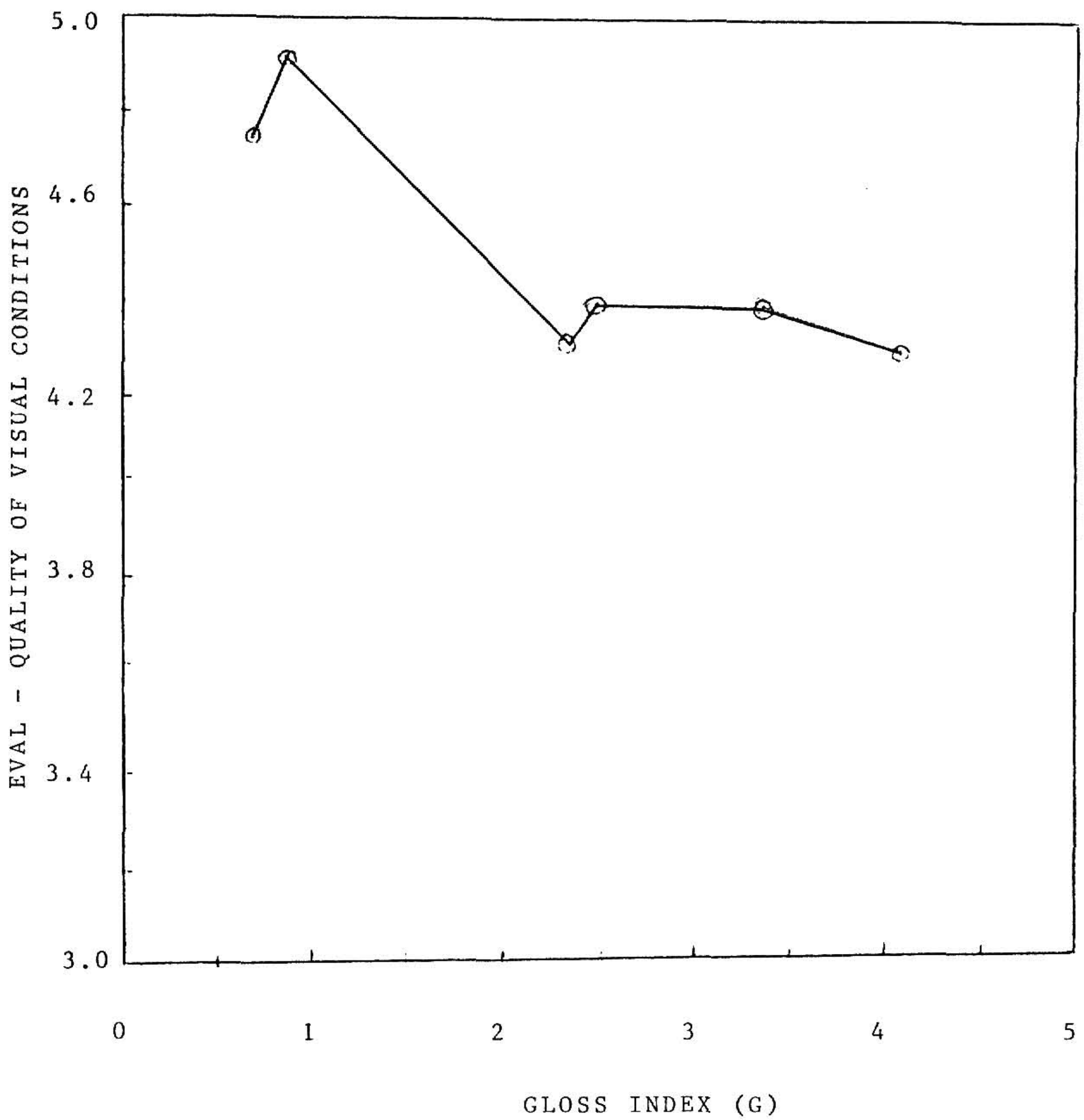


Figure 18. Evaluation of Visual Conditions vs. Paper Gloss.

interaction variables were tested using Fisher's (LSD) test $\alpha = 0.05$. Results of Fisher's test are shown in Tables 14 and 15. In the case of the interaction variables, they were tested by fixing one of the variables, while comparing the other. Figures 19, 20, 21, and 22 show the variation among the variables which show significant differences.

Table 16 shows the evaluation of the quality of visual conditions and illumination level for twenty one subjects in the "validation study". Figures 23 and 24 are plots between mean quality and ESI obtained from the light booth and "validation study" respectively.

The mean performance by the subjects on the Landolt Visual Task is reported in Table 17. An analysis of variance was done on the performance scores. The results of the analysis are shown in Table 18. Results indicate that none of the variables was significantly different at $\alpha = 0.05$, but Duncan's test shows that there were significant differences among paper samples. This is shown in Table 19. The performance score was correlated with ESI and had a correlation coefficient of 0.64, with the regression equation as follows:

Performance (%) = 46.89 + 0.07 * ESI,

where ESI is expressed in footcandles. The plot of Performance versus ESI is shown in Figure 25.

An analysis of variance was performed on ESI to test the effects of light field composition and directional light source positions, as shown in Table 20. The results indicate significant differences among light positions, but none amongst the different light field compositions. Further analysis by Duncan's test at $\alpha = 0.05$ indicates which results are significantly different as shown in Table 21.

Table 14. Fisher's LSD Test at $\alpha = 0.05$ for the Evaluation of Visual Conditions

Dependent Variable: Mean Quality.

Position is Fixed.

Directional Light Source Position	Light Field Composition Overhead (Footcandles)	Light Field Composition Directional (Footcandles)	Mean Quality[1]	Grouping[2]
	0	100	3.929	C
	25	75	4.167	C
0^{o}	50	50	4.238	C
	75	25	4.714	B
	100	0	5.238	A
	0	100	4.095	B
	25	75	4.381	A B
45^{o}	50	50	4.762	A
	75	25	4.881	A
	100	0	4.881	A
	0	100	4.619	A
	25	75	4.214	A B
90^{o}	50	50	4.429	A
	75	25	4.214	A B
	100	0	3.976	B

1 Refers to the Subjective Evaluation of Quality of Visual Conditions on a One to Seven Scale ranging From Completely Inadequate to Excellent Conditions.

2 Means with the Same Letter are not Significantly Different.

Table 15. Fisher's LSD Test at $\alpha = 0.05$ for the Evaluation of Visual Conditions

Dependent Variable: Mean Quality

Position is fixed

Directional Light Source Position	Paper Type*	Mean Quality[2]	Grouping[2]
	A	4.029	C
	B	3.429	B
0°	C	4.371	B
	D	4.314	B
	E	5.343	A
	F	5.257	A
	A	4.571	B C
	B	4.257	C
45°	C	4.429	B C
	D	4.286	C
	E	5.057	A
	F	5.0	A B
	A	4.343	A
	B	4.257	A
90°	C	4.4	A
	D	4.314	A
	E	4.371	A
	F	4.057	A

1 Refers to the Subjective Evaluation of Quality of Visual Conditions on a One to Seven Scale ranging From Completely Inadequate to Excellent Conditions.

2 Means with the Same Letter are not Significantly Different.

* A. Kromekote Cast Coated One Side Paper
B. Dull Coated Offset Enamel Paper
C. Coated Offset Enamel Paper
D. Erasable Bond Paper
E. Handmade Embossed Finish Offset Paper
F. Sulphite Bond Paper

Table 16. Evaluation of Visual Conditions in ''Validation Study''

Subject #	Illumination (Footcandles)	Evaluation of Quality Paper #* A	B	C	D	E	F	Mean Quality[1]
1	53	6	5	5	4	4	3	4.5
2	74	6	5	4	3	3	3	4.0
3	65	5	5	3	4	3	3	3.83
4	50	4	4	4	4	3	3	3.67
5	65	6	5	5	4	3	3	4.33
6	35	4	5	3	3	3	2	3.33
7	67	5	3	4	4	3	3	3.67
8	65	4	4	3	3	2	2	4.67
9	65	4	4	3	3	2	2	3.0
10	46	7	3	5	3	4	3	4.17
11	40	4	5	4	3	3	3	3.67
12	125	6	4	4	3	3	2	3.67
13	77	4	5	3	2	3	2	3.17
14	90	5	4	4	3	2	2	3.33
15	100	4	4	3	2	2	3	3.0
16	65	4	4	3	2	2	1	2.67
17	105	6	4	4	3	2	2	3.5
18	77	5	3	2	3	3	2	3.5
19	40	6	4	3	2	2	3	3.33
20	40	5	3	3	2	2	1	2.67
21	40	4	3	4	3	4	3	3.5

[1] Refers to the Subjective Evaluation of Quality of Visual Conditions on a One to Seven Scale ranging From Completely Inadequate to Excellent Conditions.

* A. Kromekote Cast Coated One Side Paper
B. Dull Coated Offset Enamel Paper
C. Coated Offset Enamel Paper
D. Erasable Bond Paper
E. Handmade Embossed Finish Offset Paper
F. Sulphite Bond Paper

Table 17. Mean Performance Score (%) of Subjects on Landolt Visual Task

Direction Light Source Position	Light Field Composition (Footcandles) Overhead	Directional	Mean Performance[1] (%)
0°	0	100	46.259
	25	75	46.3269
	50	50	45.8812
	75	25	48.8964
	100	0	45.6679
45°	0	100	48.6948
	25	75	50.7750
	50	50	48.8440
	75	25	51.6231
	100	0	49.6331
90°	0	100	49.2059
	25	75	53.6421
	50	50	50.2609
	75	25	51.9509
	100	0	50.7605

[1] Refers to score on the Landolt Visual Task, as percent of rings correctly marked.

Table 18. Analysis of Variance of Performance Score on Landolt Visual Task.

Dependent Variable: Performance

Source of Variation	D.F.	Mean Square	F	Significance Level
Light Position	2	1164.65	0.66	0.5275
Error	18	1757.18		
Light Field Composition	4	191.11	1.34	0.2542
Paper Type	5	293.46	2.06	0.0687
Light * Paper	20	105.21	0.74	0.7883
Position * Light	8	34.12	0.24	0.9826
Position * Paper	10	129.21	0.91	0.5278
Position * Light * Paper	40	96.23	0.67	0.9379

Table 19. Duncan's Multiple Range Test at $\alpha = 0.05$ for Performance

Paper Type[1]	Mean Performance (%)	Grouping*	
A	51.020	A	
B	46.397		B
C	48.442	A	B
D	49.052	A	B
E	50.012	A	
F	50.445	A	

* Means with the Same Letter are not Significantly Different.

1

A. Kromekote Cast Coated One Side Paper
B. Dull Coated Offset Enamel Paper
C. Coated Offset Enamel Paper
D. Erasable Bond Paper
E. Handmade Embossed Finish Offset Paper
F. Sulphite Bond Paper

Table 20. Analysis of Variance of Equivalent Sphere Illumination

Dependent Variable: ESI

Source of Variation	D.F.	Mean Square	F	Significance Level
Error	8	180.74		
Light Position	2	2312.43	12.79	0.0032*
Light Field Composition	4	130.16	0.72	0.6017

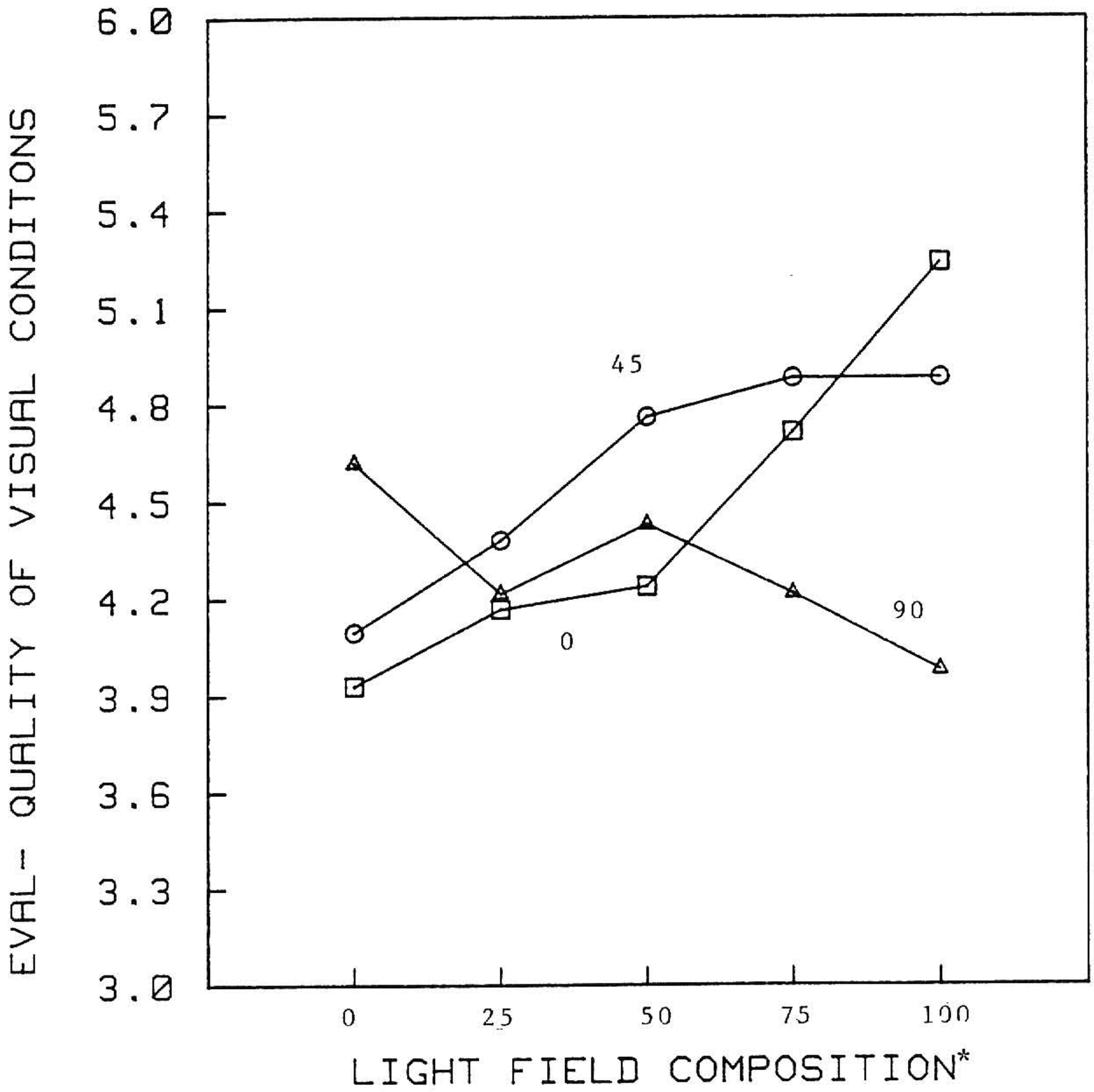
* Significantly Different at $\alpha = 0.05$

Table 21. Duncan's Multiple Range Test at $\alpha = 0.05$ for ESI

Dependent Variable: Performance

Direction Light Source Position	ESI (Footcandles)	Grouping
0°	9.216	A
45°	41.307	B
90°	50.062	B

Means with the Same Letter Are Not Significantly Different.



* refers to percentage contribution from directional light source.

Figure 19. Evaluation of Visual Conditions vs. Light Field Composition at three light positions.

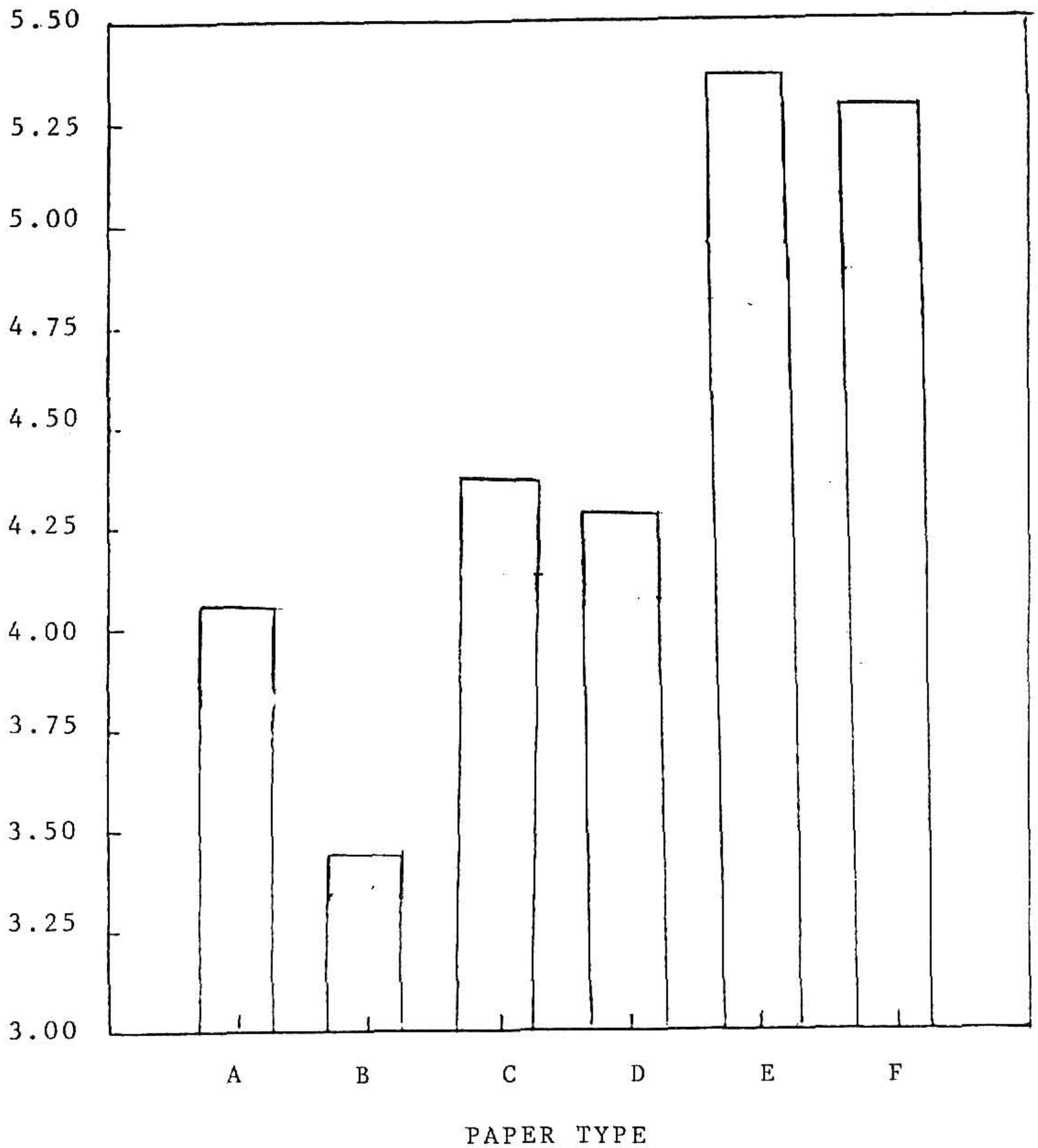


Figure 20. Quality of Visual Conditions vs. Paper Type for light position, 0°.

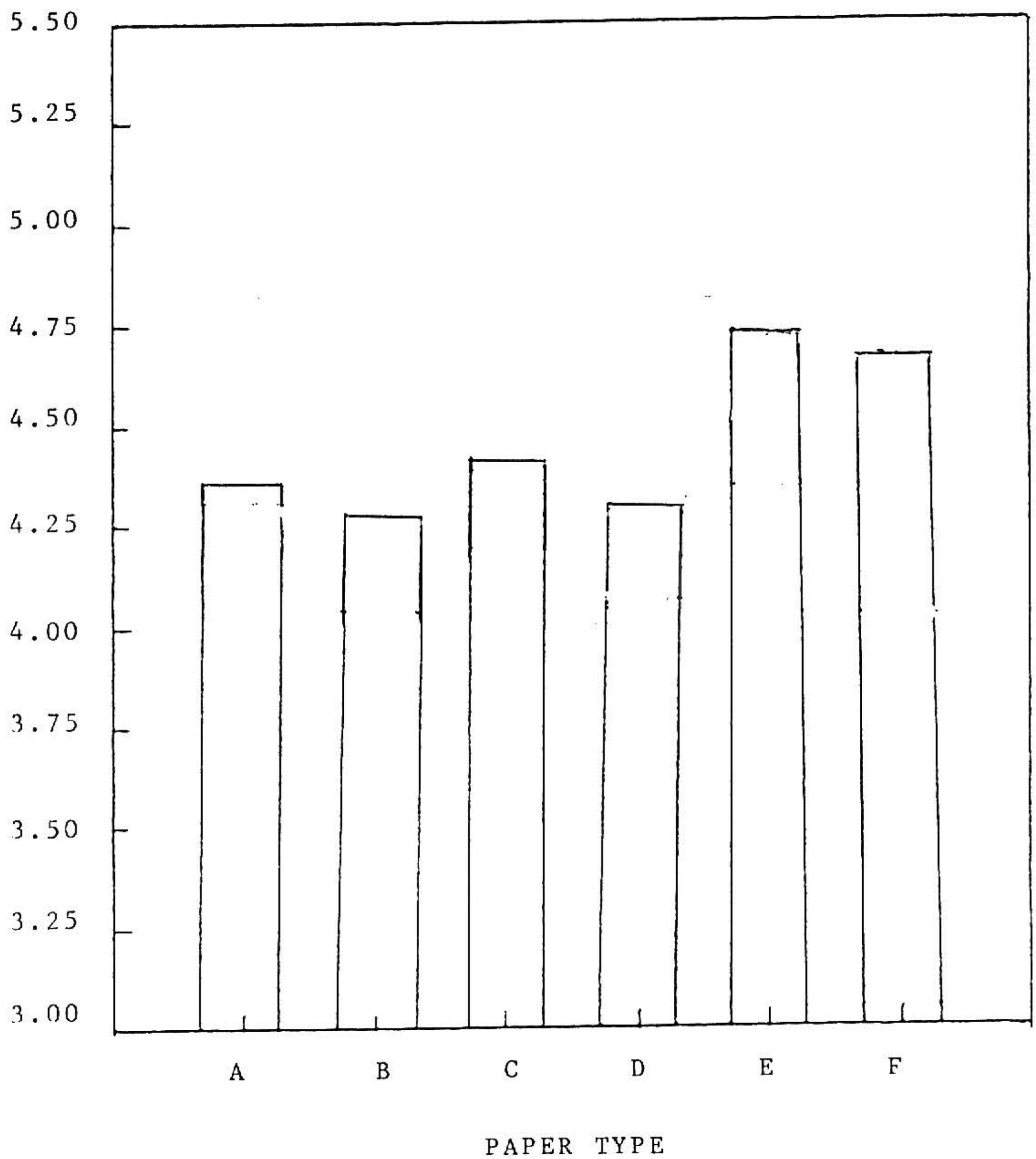


Figure 21. Quality of Visual Conditions vs. Paper Type for light position, 45°.

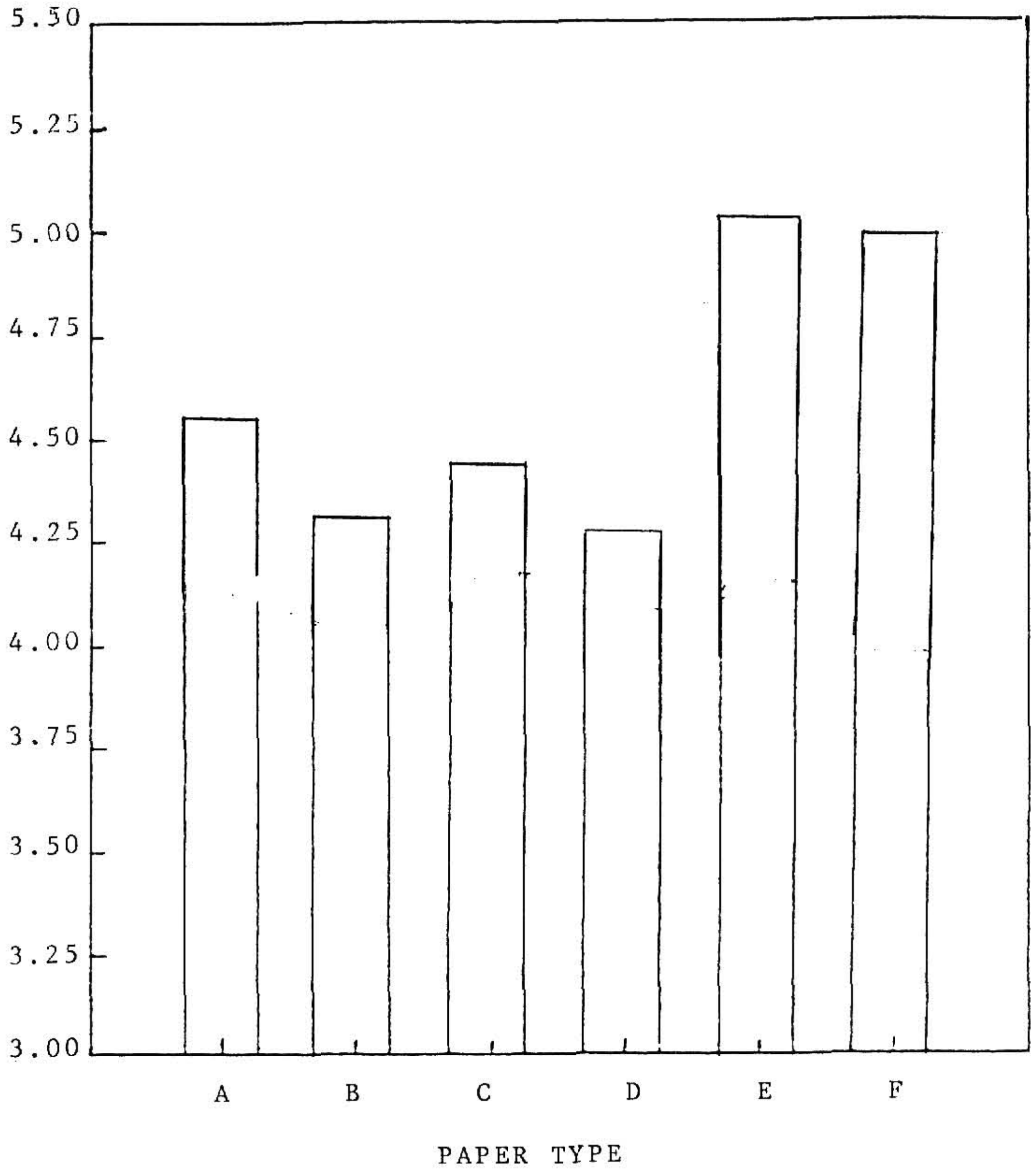


Figure 22. Quality of Visual Conditions vs. Paper Type for light position, 90°.

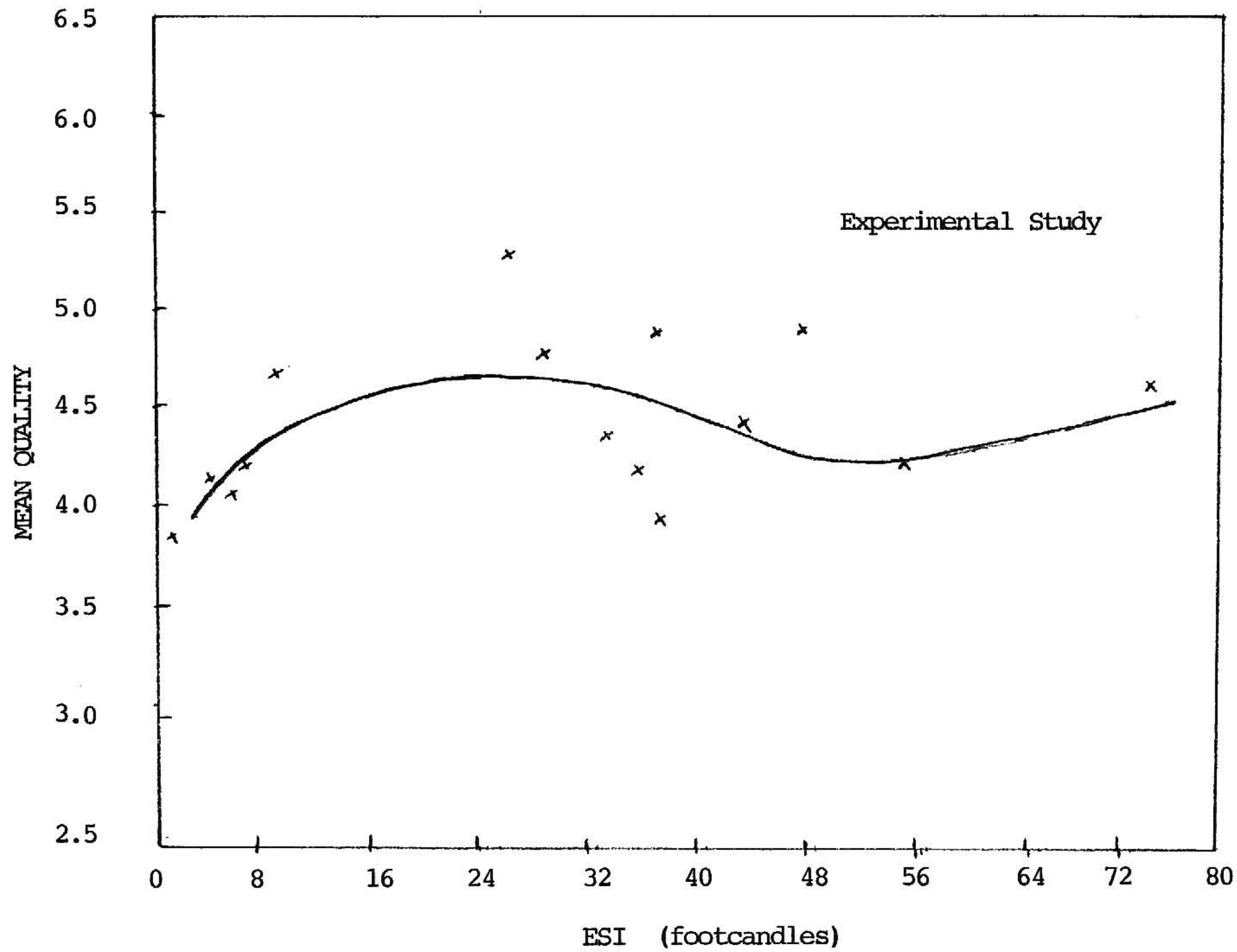


Figure 24. Mean Quality vs. ESI for experimental study

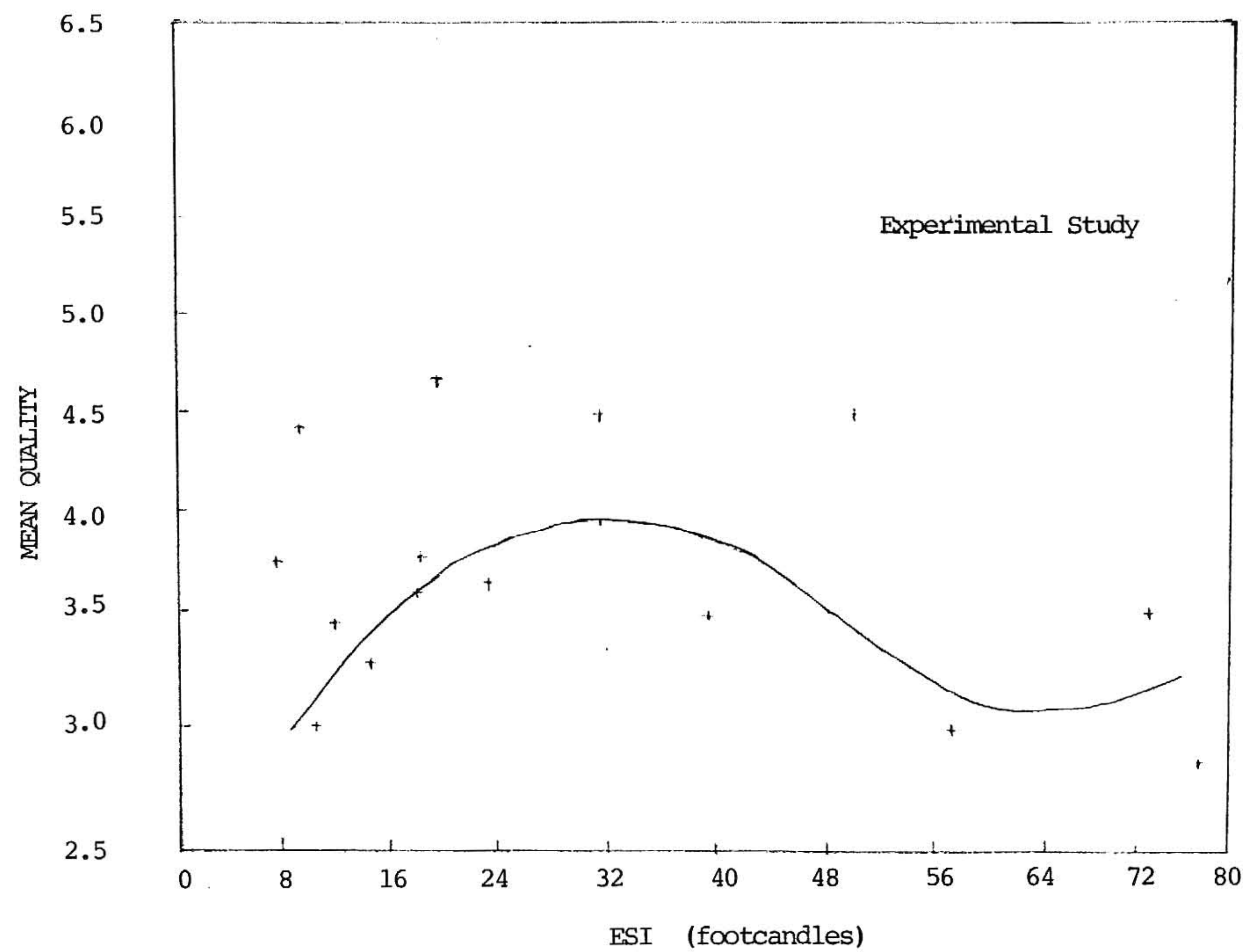


Figure 23. Mean Quality vs. ESI for experimental study

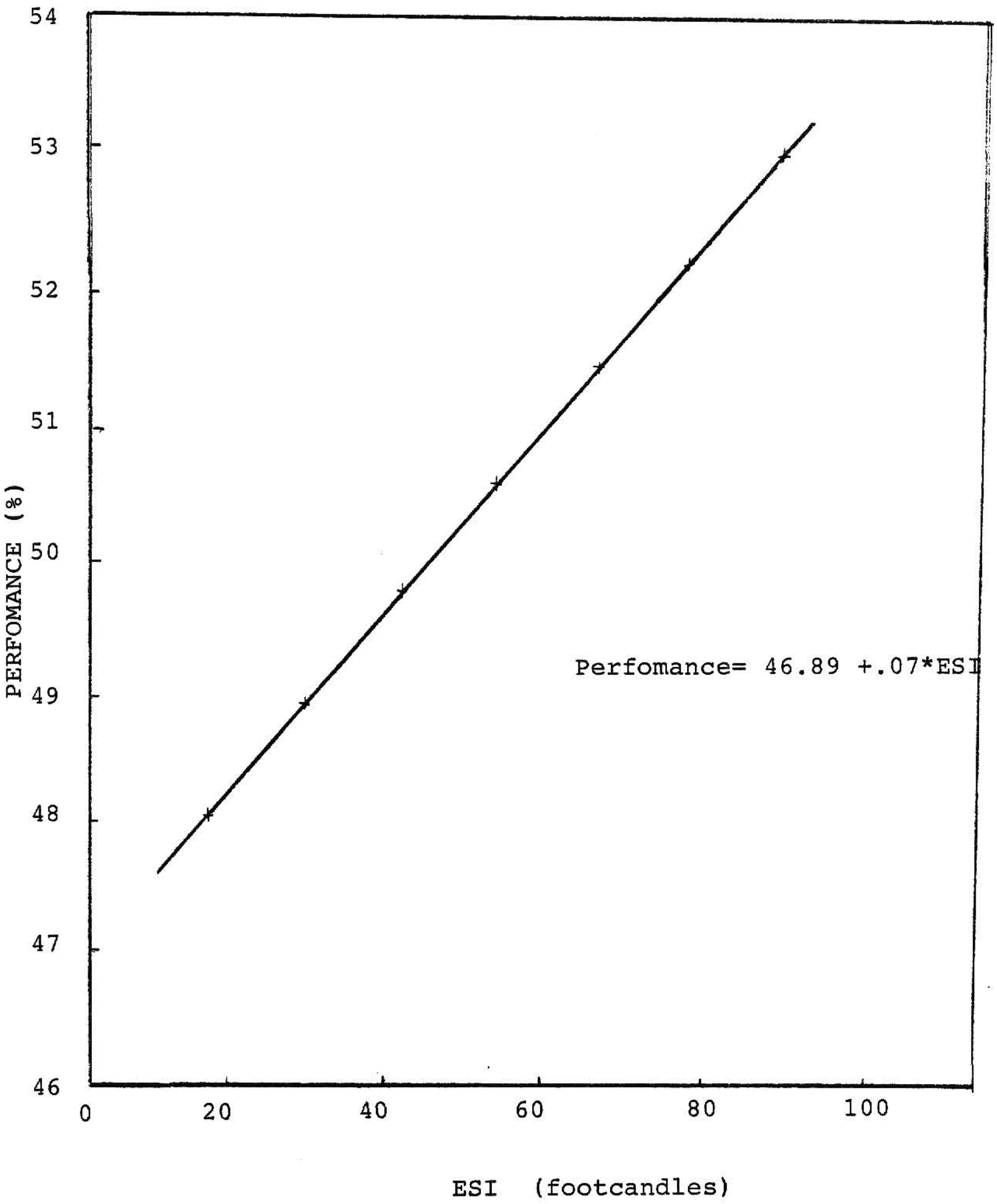


Figure 25. Perfomance Versus ESI

The gloss index G, was correlated with the maximum factor ξ and the following models were attempted to obtain the best fit.

Linear Model:

$$G = 0.579 + 1.43\,\xi$$

Correlation Coefficient (r) = 0.28

Logarithmic Model:

$$G = 2.0 + 1.76\ \ln(\xi)$$

Correlation Coefficient (r) = 0.17

Second Order Polynomial Model:

$$G = 12.9 - 15.66\,\xi + 5.49\,\xi^2$$

Correlation Coefficient (r) = 0.46

Third Order Polynomial Model:

$$G = 95.79 - 192.65\,\xi + 126.9\,\xi^2 - 26.57\,\xi^3.$$

Correlation Coefficient (r) = 0.55.

Fourth Order Polynomial Model:

$$G = 1426.6 - 4170\,\xi + 4493\,\xi^2 - 2104\,\xi^3 + 360\,\xi^4.$$

Correlation Coefficient (r) = 0.72.

Fifth Order Polynomial Model:

$$G = -64.69.0 + 26050\,\xi - 41140\,\xi^2 + 31820\,\xi^3 - 12028\,\xi^4 + 1772.47\,\xi^5.$$

Correlation Coefficient (r) = 0.73.

The above models were tested at a significance level of 0.05.

DISCUSSION

Paper Gloss

The mean ratings of paper gloss are presented in Table 5. Results of the analysis of variance procedure for paper gloss judgment is shown in Table 6. These results indicate that these were significant differences among paper types and the interaction of light position and paper. The mean gloss index was plotted against paper type for each of the three light source positions [Figures 13, 14, and 15]. The graphs indicate for all the three light positions, the papers had the same gloss indices, indicating that light from the offending zone [0^{o} position] as compared to the other two positions, did not cause differences in gloss judgment. It should be understood that, though the analysis of variance result indicates differences in the interaction of light position and paper, it is really the effect of paper type that causes this difference.

Results of analysis by Duncan's (multiple range) test at $\alpha = 0.05$, is shown in Table 7. Table 8 presents the results of Fisher's LSD test for the interaction variable. It was found that paper type affected gloss judgment as expected and shown earlier by Reitmaier (1979), confirming the point that subjects were clearly able to differentiate among paper samples of varying gloss. However, since this procedure was carried out at a constant illumination of 100 footcandles, it is not possible to conclude that gloss can be effectively judged under any lighting condition.

Quality of Visual Conditions

Table 10, shows the results of the analysis of variance for evaluation of the quality of visual conditions. The results indicate significant differences among light field compositions, paper type, directional light source position and the interaction of position and light field composition and of position and paper type. These results follow the directional hypothesis set at the beginning of this study.

Duncan's multiple range test was performed on the first three of the five variables -- light field composition, paper type and light position (Table 11, 12, and 13). The results indicate that, as the percentage contribution of the directional light source to the total illumination increased from 0% to 100%, the quality of visual conditions decreased. The plot in Figure 17 indicates this trend. Figure 18 shows the relationship between paper types, represented by the mean gloss indices and mean visual quality. It is seen that at a gloss index value of 0.9, the quality of visual conditions is best with a value of 4.9 (on a one to seven scale, ranging from completely inadequate to excellent visual conditions) and shows a downward trend thereafter. This indicates that to have better quality of visual conditions, paper gloss has to be kept at a minimum. Though the analysis of variance results indicated no significant differences among light positions. Duncan's test indicates that there were differences as shown in Table 13.

Figure 19 is a plot of light field composition versus quality of visual conditions for each of the three directional light source positions. For the light position of 0^{o} (in front of the observer), quality of visual conditions improved with lower contribution from the offending zone, as expected. On the other hand, for the 90^{o} position of the directional light source, the quality of visual conditions dropped with decreasing contribution from the directional source. The reason is that, the light source was not in the offending zone anymore and Figures 20, 21, and 22 shown the variation in the evaluation of visual conditions for different paper types at three light positions -- 0°, 45° and 90°. It should be noted that there was a wide variation ranging from 3.4 to 4.3 for the 0° position, only 4.25 and 5.3 and 4.0 to 4.4 for the 45° and 90° positions respectively. It can be concluded that the quality of visual conditions was affected by paper type to a great extent only when the directional light source was in the offending zone. Figures 23 and 24 show the variation in mean quality with ESI in the experimental and validation studies respectively.

Performance Task

The mean performance score on the Landolt Visual Task is presented in Table 17. The analysis of variance results are shown in Table 18. These results indicate that none of the variables were significantly different, but Duncan's test shows there were significant differences among paper types (Table 19). The performance versus paper type graph (Figure 25) shows that subjects performed best on Kromekote Cast Coated one side paper, which had the highest gloss index of 4.14, among the papers. This contradicts the findings of Reitmaier, wherein higher performance scores were obtained on papers with lower gloss index. The lowest performance scores were obtained on papers with lower gloss index. The lowest performance score of 46.4% was obtained for the dull coated offset enamel paper which had a gloss index of 3.3. Hence, it cannot be concluded whether paper gloss has any effect on performance of the visual task from this study.

In the hypothesis set before this research, it was expected that performance on the visual tasks would decrease with increasing contribution of illumination from the directional light source. However, this was not the case, since the analysis of variance shows no significant difference for light field composition. This result is contradictory to the findings of Reitmaier, who indicated that performance was affected by light field composition. It is felt that the overall illumination of 100 footcandles used in the previous and present study is too high to detect any differences in performance.

Overall illumination of 65 footcandles or lower seems to be a better level to maintain the booth at, since the Illumination Engineering Society sets this as a standard for reading tasks.

Equivalent Sphere Illumination

Figures 23 and 24 show that the "validation study" does not reinforce the findings of the experiment concerning the relationship between mean quality of visual conditions and ESI. While the plot for the "validation study" indicates that quality improves with increase in ESI, the experimental curve does not indicate any such trend.

The correlation between ESI and performance score was of the linear form.

Performance (%) = 46.89 + 0.07 * ESI where ESI is expressed in footcandles with a correlation coefficient of 0.63. This does not make sense, because of the high intercept value, which implies that even with negligible ESI values it is possible to perform the Landolt task reasonably well.

The analysis of variance on ESI is shown in Table 20, while the results of Duncan's test on the significant variable, light position is shown in Table 21. Light field composition had no effect on ESI, but it should be noted that the interaction of light field composition and light position could not be tested. The values of ESI computed for the fifteen combinations of light field compositions and light position are given in Table 2. This indicates that the percentage contribution of the directional source affected ESI only in the 0^{o} position (offending zone) -- lower percent conribution increasing the equivalent sphere illumination.

Hence, to obtain high ESI values, the directional light source should be placed in the non-offending zone where ESI will not be affected by light field composition.

<u>Correlation of Gloss Index and Maximum Factor</u>

The maximum factor, as defined in the introduction is

$= \beta_{max} \quad \beta_{oo} = \beta(V_1 = 25^{o}) \quad \beta\ (V_1 = 0^{o})$ where β is the luminance factor and $\beta = L(V_1) \quad L_W$, where

$L(V_1)$ = Luminance of the paper sample for the angle of incidence of light, 25^{o}

L_W = Luminance of a diffuse reference standard

Reitmaier found that a linear relationship existed between the gloss index G and the maximum factor as follows

$G = 0.52\ (1 - \quad),$

with a correlation coefficient of 0.98.

However, the present research shows that the best fit between the two variables is polynomial model of the fourth order as follows:

$G = 1426.6 - 4170 \quad + 4493 \quad ^{2} - 2104 \quad ^{3} + 360 \quad ^{4}$

Correlation coefficient = 0.72.

The linear model from the research which was $G = 0.579 + 1.43 \quad$, only had a correlation coefficient of 0.28. Since the data from the study by Reitmaier is not available, it is difficult to understand if a linear model was generated for simplicity or for other reasons.

It is clear from the discussion that more research is needed for lower levels of illumination especially between 40 and 65 footcandles and different light field compositions.

Further studies could also be carried out for a variety of visual displays-penciled tasks, typewritten task, etc., on different types of paper. It is also necessary to perform further validation studies to make such experiments representative of real life situations.

CONCLUSIONS

The main objective, to correlate the physically measured and judged quality of lighting was accomplished. Some conclusions can be drawn from this research.

1. The hypothesis that performance increased with lower contribution from the directional light source was not confirmed.
2. ESI was found to be dependent on the light source position but not on the light field composition.
3. The hypothesis that the quality of lighting (subjectively evaluated) decreased as the maximum contribution from the offending zone increased, was confirmed.
4. The relationship between judged paper gloss and the physically measured maximum factor was found to be a polynomial model of the fourth order.
5. The quality of visual condition was found to be unaffected by the directional light source position.
6. The hypothesis that paper gloss affected the quality of visual conditions was confirmed, for the offending zone.
7. The "validation study" did not reinforce the findings of the experiment concerning the relationship between mean quality and ESI.
8. A linear relationship was established between ESI and performance scores on the Landolt visual task.

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APPENDIX A.

ILLEGIBLE DOCUMENT

THE FOLLOWING DOCUMENT(S) IS OF POOR LEGIBILITY IN THE ORIGINAL

THIS IS THE BEST COPY AVAILABLE

KANSAS STATE UNIVERSITY VM/SP CMS

S T A T I S T I C A L   A N A L Y S I S   S Y S T E M

14:58 THURS

OBS	SUB	POS	PAPER	GLOSS
1	1	3	1	2
2	1	3	2	2
3	1	3	3	3
4	1	3	4	4
5	1	3	5	3
6	1	3	6	1
7	2	2	1	4
8	2	2	2	3
9	2	2	3	2
10	2	2	4	2
11	2	2	5	[illegible]
12	2	2	6	0
13	3	1	1	5
14	3	1	2	5
15	3	1	3	4
16	3	1	4	2
17	3	1	5	1
18	3	1	6	2

KANSAS STATE UNIVERSITY VM/SP CMS DATE

19	4	3	1	3
20	4	3	2	2
21	4	3	3	2
22	4	3	4	2
23	4	3	5	1
24	4	3	6	2
25	5	1	1	4
26	5	1	2	3
27	5	1	3	3
28	5	1	4	3
29	5	1	5	1
30	5	1	6	0
31	6	2	1	4
32	6	2	2	3
33	6	2	3	2
34	6	2	4	2
35	6	2	5	1
36	6	2	6	1
37	7	2	1	5
38	7	2	2	3
39	7	2	3	3
40	7	2	4	1
41	7	2	5	0
42	7	2	6	1
43	9	1	1	5
44	8	1	2	4
45	9	1	3	2
46	8	1	4	3

KANSAS STATE UNIVERSITY VM/SP CMS DATE

47	9	1	5	0
48	8	1	6	0
49	9	3	1	5
50	9	3	2	4
51	9	3	3	3
52	9	3	4	2
53	9	3	5	1
54	9	3	6	0
55	10	1	1	4

S T A T I S T I C A L   A N A L Y S I S   S Y S T E M

14:58 THURSD

OBS	SUB	POS	PAPER	GLOSS
56	10	1	2	4
57	10	1	3	1
58	10	1	4	1
59	10	1	5	0
60	10	1	6	0
61	11	3	1	1
62	11	3	2	2
63	11	3	3	1
64	11	3	4	3
65	11	3	5	2
66	11	3	6	0
67	12	2	1	5
68	12	2	2	4
69	12	2	3	3
70	12	2	4	2

KANSAS STATE UNIVERSITY V4/SP CMS DATE

71	12	2	5	0
72	12	2	6	1
73	13	2	1	4
74	13	2	2	3
75	13	2	3	2
76	13	2	4	2
77	13	2	5	0
78	13	2	6	1
79	14	1	1	4
80	14	1	2	4
81	14	1	3	3
82	14	1	4	3
83	14	1	5	1
84	14	1	6	2
85	15	3	1	4
86	15	3	2	4
87	15	3	3	3
88	15	3	4	3
89	15	3	5	2
90	15	3	6	0
91	16	1	1	4
92	16	1	2	4
93	16	1	3	3
94	16	1	4	2
95	16	1	5	1
96	16	1	6	0
97	17	2	1	5
98	17	2	2	4

KANSAS STATE UNIVERSITY VM/SP CMS DATE

99	17	2	3	3
100	17	2	4	2
101	17	2	5	1
102	17	2	6	0
103	18	3	1	4
104	18	3	2	3
105	18	3	3	3
106	19	3	4	2
107	18	3	5	1
108	18	3	6	1
109	19	2	1	5
110	19	2	2	3
OBS	SUB	POS	PAPER	GLOSS
111	19	2	3	2
112	19	2	4	2
113	19	2	5	0
114	19	2	6	1
115	20	1	1	5
116	20	1	2	3
117	20	1	3	2
118	20	1	4	1
119	20	1	5	0
120	20	1	6	0
121	21	3	1	5
122	21	3	2	2
123	21	3	3	3
124	21	3	4	4
125	21	3	5	3
126	21	3	6	2

APPENDIX B.

OBS	SUB	POS	LIGHT	PAPER	PERF	EVAL
1	1	3	1	1	55.88	5
2	1	3	1	2	43.75	4
3	1	3	1	3	46.88	5
4	1	3	1	4	46.67	4
5	1	3	1	5	56.25	5
6	1	3	1	6	46.67	4
7	1	3	2	1	56.67	5
8	1	3	2	2	65.00	4
9	1	3	2	3	71.79	6
10	1	3	2	4	62.16	6
11	1	3	2	5	47.06	4
12	1	3	2	6	59.46	5
13	1	3	3	1	53.13	4
14	1	3	3	2	56.67	4
15	1	3	3	3	50.00	5
16	1	3	3	4	70.00	5
17	1	3	3	5	40.63	5
18	1	3	3	6	65.63	5
19	1	3	4	1	59.38	4
20	1	3	4	2	37.50	5
21	1	3	4	3	56.67	5
22	1	3	4	4	56.25	5
23	1	3	4	5	50.00	5
24	1	3	4	6	61.76	6
25	1	3	5	1	46.15	5
26	1	3	5	2	70.00	6
27	1	3	5	3	68.75	6
28	1	3	5	4	66.67	6
29	1	3	5	5	53.85	5
30	1	3	5	6	66.67	5
31	2	2	1	1	58.82	4

KANSAS STATE UNIVERSITY VM/SP CMS   CATE 1

32	2	2	1	2	56.25	6
33	2	2	1	3	53.13	3
34	2	2	1	4	60.00	4
35	2	2	1	5	58.82	5
36	2	2	1	6	65.63	5
37	2	2	2	1	81.08	6
38	2	2	2	2	64.11	4
39	2	2	2	3	43.59	4
40	2	2	2	4	87.55	4
41	2	2	2	5	53.13	4
42	2	2	2	6	40.54	5
43	2	2	3	1	53.13	5
44	2	2	3	2	43.75	4
45	2	2	3	3	85.00	5
46	2	2	3	4	59.38	5
47	2	2	3	5	30.00	5
48	2	2	3	6	50.00	5
49	2	2	4	1	68.75	5
50	2	2	4	2	68.75	4
51	2	2	4	3	50.00	4
52	2	2	4	4	56.67	3
53	2	2	4	5	90.00	5
54	2	2	4	6	64.10	5
55	2	2	5	1	80.00	4
56	2	2	5	2	36.67	4

S T A T I S T I C A L   A N A L Y S I S   S Y S T E M   13:45 FRIDAY,

OBS	SUB	POS	LIGHT	PAPER	PERF	EVAL

KANSAS STATE UNIVERSITY VM/SP CMS DATE

57	2	2	5	3	70.59	3
58	2	2	5	4	75.63	3
59	2	2	5	5	72.97	5
60	2	2	5	6	68.75	4
61	3	1	1	1	51.35	3
62	3	1	1	2	36.67	2
63	3	1	1	3	28.13	3
64	3	1	1	4	35.90	3
65	3	1	1	5	29.13	6
66	3	1	1	6	50.00	5
67	3	1	2	1	59.46	4
68	3	1	2	2	35.29	3
69	3	1	2	3	44.12	3
70	3	1	2	4	50.00	4
71	3	1	2	5	55.00	5
72	3	1	2	6	34.38	5
73	3	1	3	1	43.75	3
74	3	1	3	2	75.00	3
75	3	1	3	3	20.00	4
76	3	1	3	4	75.00	4
77	3	1	3	5	43.75	6
78	3	1	3	6	35.90	6
79	3	1	4	1	72.97	5
80	3	1	4	2	38.24	5
81	3	1	4	3	40.63	4
82	3	1	4	4	43.75	7
83	3	1	4	5	25.64	6
84	3	1	4	6	43.75	6

KANSAS STATE UNIVERSITY VM/SP CMS DATE I

85	3	1	5	1	40.00	7
86	3	1	5	2	34.38	5
87	3	1	5	3	32.35	6
88	3	1	5	4	56.25	6
89	3	1	5	5	65.00	7
90	3	1	5	6	62.16	7
91	4	3	1	1	50.00	3
92	4	3	1	2	48.72	5
93	4	3	1	3	75.00	6
94	4	3	1	4	43.75	4
95	4	3	1	5	56.25	3
96	4	3	1	6	38.46	4
97	4	3	2	1	43.75	5
98	4	3	2	2	46.15	5
99	4	3	2	3	75.00	4
100	4	3	2	4	46.67	3
101	4	3	2	5	62.50	3
102	4	3	2	6	78.38	5
103	4	3	3	1	82.35	3
104	4	3	3	2	50.00	5
105	4	3	3	3	43.33	4
106	4	3	3	4	45.95	3
107	4	3	3	5	55.00	5
108	4	3	3	6	56.25	4
109	4	3	4	1	75.00	3
110	4	3	4	2	70.00	3
111	4	3	4	3	43.33	2
112	4	3	4	4	51.35	3

S T A T I S T I C A L   A N A L Y S I S   S Y S T E M   13:45 FRIDAY,

KANSAS STATE UNIVERSITY VM/SP CMS DATE :

OBS	SUB	POS	LIGHT	PAPER	PERF	EVAL
113	4	3	4	5	68.75	5
114	4	3	4	6	43.75	3
115	4	3	5	1	67.65	4
116	4	3	5	2	51.35	3
117	4	3	5	3	55.88	5
118	4	3	5	4	33.33	2
119	4	3	5	5	65.00	5
120	4	3	5	6	55.88	3
121	5	1	1	1	35.29	4
122	5	1	1	2	64.86	4
123	5	1	1	3	50.00	4
124	5	1	1	4	27.03	3
125	5	1	1	5	40.63	4
126	5	1	1	6	31.20	3
127	5	1	2	1	56.25	4
128	5	1	2	2	43.75	4
129	5	1	2	3	31.25	4
130	5	1	2	4	37.55	4
131	5	1	2	5	30.77	4
132	5	1	2	6	60.00	4
133	5	1	3	1	29.13	5
134	5	1	3	2	40.00	4
135	5	1	3	3	37.50	5
136	5	1	3	4	37.34	4
137	5	1	3	5	43.75	4

KANSAS STATE UNIVERSITY VM/SP CMS DATE

138	5	1	3	6	40.63	4
139	5	1	4	1	60.00	4
140	5	1	4	2	70.00	4
141	5	1	4	3	43.59	5
142	5	1	4	4	65.63	4
143	5	1	4	5	46.67	5
144	5	1	4	6	29.41	4
145	5	1	5	1	50.00	6
146	5	1	5	2	30.00	5
147	5	1	5	3	29.41	4
148	5	1	5	4	53.33	4
149	5	1	5	5	30.67	5
150	5	1	5	6	43.24	5
151	6	2	1	1	55.00	2
152	6	2	1	2	43.75	4
153	6	2	1	3	65.63	5
154	6	2	1	4	35.29	2
155	6	2	1	5	38.46	3
156	6	2	1	6	43.75	5
157	6	2	2	1	50.00	5
158	6	2	2	2	40.63	3
159	6	2	2	3	40.00	3
160	6	2	2	4	50.00	3
161	6	2	2	5	43.33	5
162	6	2	2	6	59.46	6
163	6	2	3	1	50.00	4
164	6	2	3	2	32.35	4
165	6	2	3	3	53.33	5
166	6	2	3	4	65.00	4

KANSAS STATE UNIVERSITY VM/SP CMS DATE 1

167	6	2	3	5	38.46	5
168	6	2	3	6	53.13	6

S T A T I S T I C A L A N A L Y S I S S Y S T E M 13:45 FRIDAY, D:

OBS	SUB	PCS	LIGHT	PAPER	PERF	EVAL
169	6	2	4	1	56.25	6
170	6	2	4	2	33.33	3
171	6	2	4	3	35.29	4
172	6	2	4	4	55.00	4
173	6	2	4	5	51.35	5
174	6	2	4	6	45.00	4
175	6	2	5	1	48.65	3
176	6	2	5	2	47.06	3
177	6	2	5	3	43.75	3
178	6	2	5	4	56.25	3
179	6	2	5	5	64.36	6
180	6	2	5	6	43.75	4
181	7	2	1	1	30.00	3
182	7	2	1	2	50.00	3
183	7	2	1	3	25.00	3
184	7	2	1	4	37.50	3
185	7	2	1	5	95.00	3
186	7	2	1	6	56.25	3
187	7	2	2	1	41.18	6
188	7	2	2	2	25.00	4
189	7	2	2	3	50.00	4
190	7	2	2	4	36.67	4

191	7	2	2	5	23.08	5
192	7	2	2	6	32.43	4
193	7	2	3	1	41.03	4
194	7	2	3	2	40.54	6
195	7	2	3	3	40.54	4
196	7	2	3	4	30.00	3
197	7	2	3	5	40.63	4
198	7	2	3	6	35.00	4
199	7	2	4	1	41.18	4
200	7	2	4	2	41.18	4
201	7	2	4	3	50.00	4
202	7	2	4	4	30.00	6
203	7	2	4	5	35.00	5
204	7	2	4	6	65.00	5
205	7	2	5	1	32.43	6
206	7	2	5	2	46.88	5
207	7	2	5	3	37.84	7
208	7	2	5	4	35.82	6
209	7	2	5	5	46.15	5
210	7	2	5	6	65.63	6
211	8	1	1	1	43.75	2
212	8	1	1	2	44.12	1
213	8	1	1	3	53.85	3
214	8	1	1	4	46.88	3
215	8	1	1	5	71.88	6
216	8	1	1	6	55.88	6
217	8	1	2	1	50.00	2
218	8	1	2	2	69.23	3
219	8	1	2	3	50.00	3

A1 KANSAS STATE UNIVERSITY VM/SP CMS CAT

220	8	1	2	4	75.00	2
221	3	1	2	5	62.50	7
222	8	1	2	6	59.46	6
223	8	1	3	1	70.00	3
224	3	1	3	2	51.35	3
S T A T I S T I C A L A N A L Y S I S S Y S T E M 13:45 FRIDAY						
OBS	SUB	POS	LIGHT	PAPER	PERF	EVAL
225	8	1	3	3	59.38	5
226	8	1	3	4	56.41	4
227	3	1	3	5	71.88	5
228	8	1	3	6	71.08	6
229	8	1	4	1	50.00	4
230	8	1	4	2	50.00	4
231	8	1	4	3	44.12	5
232	8	1	4	4	48.65	4
233	8	1	4	5	52.94	6
234	9	1	4	6	95.00	7
235	6	1	5	1	43.33	5
236	8	1	5	2	66.67	6
237	9	1	5	3	50.00	6
238	8	1	5	4	60.00	6
239	9	1	5	5	65.63	7
240	9	1	5	6	55.00	6
241	9	3	1	1	45.95	5
242	5	3	1	2	56.76	4
243	9	3	1	3	52.94	5

244	9	3	1	4	60.00	5
245	9	3	1	5	46.83	3
246	9	3	1	6	65.63	3
247	9	3	2	1	80.00	4
248	9	3	2	2	61.54	4
249	9	3	2	3	53.13	4
250	9	3	2	4	81.25	5
251	9	3	2	5	63.33	5
252	9	3	2	6	59.38	3
253	9	3	3	1	56.67	4
254	9	3	3	2	59.38	5
255	9	3	3	3	100.00	4
256	9	3	3	4	38.46	4
257	9	3	3	5	43.75	4
258	9	3	3	6	56.25	3
259	9	3	4	1	68.25	4
260	9	3	4	2	52.94	4
261	9	3	4	3	47.06	6
262	9	3	4	4	85.00	6
263	9	3	4	5	47.06	4
264	9	3	4	6	56.67	4
265	9	3	5	1	68.25	4
266	9	3	5	2	48.72	4
267	9	3	5	3	66.67	5
268	9	3	5	4	46.88	4
269	9	3	5	5	51.35	4
270	9	3	5	6	53.13	4
271	10	1	1	1	75.68	3
272	10	1	1	2	70.00	3

A1 KANSAS STATE UNIVERSITY VM/SP CMS CAT

STATISTICAL ANALYSIS SYSTEM 13:45 FRIDAY

OBS	SUB	POS	LIGHT	PAPER	PERF	EVAL
273	10	1	1	3	37.50	2
274	10	1	1	4	34.38	3
275	10	1	1	5	55.00	6
276	10	1	1	6	78.13	4
277	10	1	2	1	46.15	2
278	10	1	2	2	62.16	1
279	10	1	2	3	23.53	4
280	10	1	2	4	26.67	4
281	10	1	2	5	37.50	6
282	10	1	2	6	63.33	4
283	10	1	3	1	50.00	5
284	10	1	3	2	30.00	3
285	10	1	3	3	43.59	4
286	10	1	3	4	39.24	4
287	10	1	3	5	48.72	6
288	10	1	3	6	65.63	5
289	10	1	4	1	64.75	6
290	10	1	4	2	38.24	3
291	10	1	4	3	80.00	4
292	10	1	4	4	68.75	3
293	10	1	4	5	55.00	5
294	10	1	4	6	46.15	5
295	10	1	5	1	37.50	7
296	10	1	5	2	75.68	4

297	10	1	5	3	59.46	4
298	10	1	5	4	38.24	6
299	10	1	5	5	59.38	5
300	10	1	5	6	40.63	5
301	11	3	1	1	50.00	4
302	11	3	1	2	65.00	5
303	11	3	1	3	53.85	4
304	11	3	1	4	40.63	4
305	11	3	1	5	40.63	5
306	11	3	1	6	53.13	5
307	11	3	2	1	60.00	5
308	11	3	2	2	29.73	4
309	11	3	2	3	52.94	4
310	11	3	2	4	75.00	4
311	11	3	2	5	60.00	5
312	11	3	2	6	47.06	4
313	11	3	3	1	43.59	5
314	11	3	3	2	53.13	5
315	11	3	3	3	50.00	4
316	11	3	3	4	59.38	5
317	11	3	3	5	29.73	5
318	11	3	3	6	46.15	4
319	11	3	4	1	59.38	3
320	11	3	4	2	23.33	5
321	11	3	4	3	43.33	4
322	11	3	4	4	46.88	5
323	11	3	4	5	56.25	4
324	11	3	4	6	52.94	3
325	11	3	5	1	53.13	3

326	11	3	5	2	43.75	2
327	11	3	5	3	75.00	3
328	11	3	5	4	46.15	3
329	11	3	5	5	51.35	4
330	11	3	5	6	47.06	2
331	12	2	1	1	53.97	6
332	12	2	1	2	54.05	6
333	12	2	1	3	58.97	7
334	12	2	1	4	43.33	3
335	12	2	1	5	50.00	4
336	12	2	1	6	58.97	7

OBS	SUB	POS	LIGHT	PAPER	PERF	EVAL
337	12	2	2	1	46.88	4
338	12	2	2	2	56.25	5
339	12	2	2	3	61.54	7
340	12	2	2	4	50.00	5
341	12	2	2	5	64.86	7
342	12	2	2	6	50.00	3
343	12	2	3	1	59.38	7
344	12	2	3	2	56.25	7
345	12	2	3	3	70.00	6
346	12	2	3	4	53.13	7
347	12	2	3	5	34.38	4
348	12	2	3	6	62.50	7
349	12	2	4	1	56.25	7

350	12	2	4	2	53.13	5
351	12	2	4	3	56.25	6
352	12	2	4	4	61.76	7
353	12	2	4	5	52.94	6
354	12	2	4	6	46.67	6
355	12	2	5	1	40.67	4
356	12	2	5	2	45.00	3
357	12	2	5	3	46.67	5
358	12	2	5	4	55.00	3
359	12	2	5	5	58.82	6
360	12	2	5	6	69.23	7
361	13	2	1	1	46.67	6
362	13	2	1	2	43.75	5
363	13	2	1	3	32.35	2
364	13	2	1	4	33.33	5
365	13	2	1	5	51.28	3
366	13	2	1	6	41.03	1
367	13	2	2	1	55.00	4
368	13	2	2	2	40.00	3
369	13	2	2	3	67.57	4
370	13	2	2	4	43.24	3
371	13	2	2	5	40.63	4
372	13	2	2	6	50.00	4
373	13	2	3	1	34.38	4
374	13	2	3	2	46.67	5
375	13	2	3	3	37.84	2
376	13	2	3	4	65.00	3
377	13	2	3	5	34.38	6
378	13	2	3	6	70.27	5

OBS	SUB	POS	LIGHT	PAPER	PERF	EVAL
379	13	2	4	1	31.25	5
380	13	2	4	2	21.62	4
381	13	2	4	3	43.72	6
382	13	2	4	4	61.70	5
383	13	2	4	5	50.00	6
384	13	2	4	6	46.68	4
385	13	2	5	1	30.00	6
386	13	2	5	2	41.18	6
387	13	2	5	3	50.00	5
388	13	2	5	4	56.25	7
389	13	2	5	5	37.00	6
390	13	2	5	6	28.13	6
391	14	1	1	1	43.33	3
392	14	1	1	2	34.38	2

OBS	SUB	POS	LIGHT	PAPER	PERF	EVAL
393	14	1	1	3	43.75	6
394	14	1	1	4	43.75	3
395	14	1	1	5	67.75	7
396	14	1	1	6	62.16	7
397	14	1	2	1	45.00	4
398	14	1	2	2	40.63	3
399	14	1	2	3	50.00	7
400	14	1	2	4	41.18	7
401	14	1	2	5	44.12	5
402	14	1	2	6	68.75	7

403	14	1	3	1	43.75	4
404	14	1	3	2	44.12	3
405	14	1	3	3	46.72	4
406	14	1	3	4	31.25	5
407	14	1	3	5	40.63	5
408	14	1	3	6	51.35	6
409	14	1	4	1	40.63	4
410	14	1	4	2	51.35	5
411	14	1	4	3	34.38	4
412	14	1	4	4	55.00	5
413	14	1	4	5	52.94	6
414	14	1	4	6	40.00	6
415	14	1	5	1	35.90	6
416	14	1	5	2	43.33	4
417	14	1	5	3	60.00	6
418	14	1	5	4	41.03	5
419	14	1	5	5	43.33	6
420	14	1	5	6	43.33	6
421	15	3	1	1	35.00	4
422	15	3	1	2	16.67	4
423	15	3	1	3	23.33	4
424	15	3	1	4	25.00	3
425	15	3	1	5	26.47	3
426	15	3	1	6	45.95	4
427	15	3	2	1	26.47	3
428	15	3	2	2	35.90	2
429	15	3	2	3	34.38	3
430	15	3	2	4	33.33	2
431	15	3	2	5	31.25	2

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432	15	3	2	6	26.47	2
433	15	3	3	1	41.03	3
434	15	3	3	2	37.50	5
435	15	3	3	3	29.41	3
436	15	3	3	4	31.25	3
437	15	3	3	5	50.00	3
438	15	3	3	6	34.38	4
439	15	3	4	1	35.00	4
440	15	3	4	2	43.24	3
441	15	3	4	3	35.90	2
442	15	3	4	4	40.00	6
443	15	3	4	5	37.50	3
444	15	3	4	6	46.00	3
445	15	3	5	1	33.88	3
446	15	3	5	2	31.25	3
447	15	3	5	3	12.63	3
448	15	3	5	4	34.38	2

STATISTICAL ANALYSIS SYSTEM 13:45 FRIDAY

OBS	SUB	POS	LIGHT	PAPER	PERF	EVAL
449	15	3	5	5	18.75	3
450	15	3	5	6	26.67	3
451	16	1	1	1	50.00	4
452	16	1	1	2	50.00	3
453	16	1	1	3	32.43	4
454	16	1	1	4	55.00	3
455	16	1	1	5	38.24	5

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456	16	1	1	6	33.33	4
457	16	1	2	1	32.35	2
458	16	1	2	2	31.25	2
459	16	1	2	3	20.00	5
460	16	1	2	4	43.75	4
461	16	1	2	5	59.38	5
462	16	1	2	6	60.00	6
463	16	1	3	1	46.38	3
464	16	1	3	2	32.35	2
465	16	1	3	3	40.00	3
466	16	1	3	4	33.33	5
467	16	1	3	5	40.63	4
468	16	1	3	6	46.88	4
469	16	1	4	1	26.67	4
470	16	1	4	2	30.00	4
471	16	1	4	3	43.24	4
472	16	1	4	4	65.00	5
473	16	1	4	5	45.00	4
474	16	1	4	6	37.50	4
475	16	1	5	1	53.13	5
476	16	1	5	2	34.38	4
477	16	1	5	3	48.72	4
478	16	1	5	4	43.33	4
479	16	1	5	5	33.24	4
480	16	1	5	6	35.90	5
481	17	2	1	1	46.67	5
482	17	2	1	2	43.75	5
483	17	2	1	3	50.00	5
484	17	2	1	4	38.25	4

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485	17	2	1	5	45.95	4
486	17	2	1	6	33.33	4
487	17	2	2	1	55.00	4
488	17	2	2	2	31.25	2
489	17	2	2	3	45.95	5
490	17	2	2	4	40.63	5
491	17	2	2	5	50.00	5
492	17	2	2	6	60.00	6
493	17	2	3	1	68.75	6
494	17	2	3	2	37.50	5
495	17	2	3	3	40.00	3
496	17	2	3	4	31.25	3
497	17	2	3	5	41.03	5
498	17	2	3	6	44.12	5
499	17	2	4	1	50.00	4
500	17	2	4	2	51.35	5
501	17	2	4	3	41.03	6
502	17	2	4	4	40.63	3
503	17	2	4	5	55.00	5
504	17	2	4	6	52.94	6

S T A T I S T I C A L   A N A L Y S I S   S Y S T E M   13:45 FRIDAY

OBS	SUB	POS	LIGHT	PAPER	PERF	EVAL
505	17	2	5	1	17.99	3
506	17	2	5	2	34.38	4
507	17	2	5	3	43.12	4
508	17	2	5	4	43.33	4

509	17	2	5	5	51.35	5
510	17	2	5	6	35.90	5
511	18	3	1	1	61.54	7
512	18	3	1	2	46.67	6
513	19	3	1	3	59.38	6
514	19	3	1	4	43.24	6
515	18	3	1	5	62.50	7
516	18	3	1	6	48.72	6
517	19	3	2	1	61.54	7
518	18	3	2	2	58.82	4
519	18	3	2	3	54.05	6
520	18	3	2	4	51.35	6
521	18	3	2	5	43.33	4
522	18	3	2	6	62.50	5
523	19	3	3	1	51.28	6
524	19	3	3	2	51.28	4
525	18	3	3	3	62.50	6
526	18	3	3	4	56.25	6
527	19	3	3	5	59.38	5
528	18	3	3	6	61.76	6
529	19	3	4	1	56.67	7
530	19	3	4	2	55.88	6
531	18	3	4	3	60.00	5
532	18	3	4	4	43.75	5
533	18	3	4	5	70.00	7
534	18	3	4	6	70.00	4
535	18	3	5	1	53.13	5
536	18	3	5	2	71.88	6
537	18	3	5	3	55.88	6

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538	18	3	5	4	45.95	6
539	18	3	5	5	65.00	6
540	18	3	5	6	56.25	5
541	19	2	1	1	56.76	3
542	19	2	1	2	36.67	3
543	19	2	1	3	46.15	4
544	19	2	1	4	70.00	4
545	19	2	1	5	40.00	5
546	19	2	1	6	36.67	5
547	19	2	2	1	85.00	3
548	19	2	2	2	43.75	3
549	19	2	2	3	80.00	4
550	19	2	2	4	59.46	4
551	19	2	2	5	53.13	5
552	19	2	2	6	40.63	6
553	19	2	3	1	55.88	3
554	19	2	3	2	56.25	4
555	19	2	3	3	43.75	4
556	19	2	3	4	56.25	4
557	19	2	3	5	62.50	7
558	19	2	3	6	48.72	6
559	19	2	4	1	53.85	3
560	19	2	4	2	53.13	3

S T A T I S T I C A L   A N A L Y S I S   S Y S T E M   13:45 FRIDAY

OBS	SUB	POS	LIGHT	PAPER	PERF	EVAL
561	19	2	4	3	65.63	4

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562	19	2	4	4	60.00	7
563	19	2	4	5	70.59	7
564	19	2	4	6	50.00	5
565	19	2	5	1	53.13	6
566	19	2	5	2	47.06	5
567	19	2	5	3	59.46	6
568	19	2	5	4	41.03	7
569	19	2	5	5	55.88	7
570	19	2	5	6	59.38	6
571	20	1	1	1	37.50	3
572	20	1	1	2	35.14	4
573	20	1	1	3	56.25	6
574	20	1	1	4	41.03	6
575	20	1	1	5	38.24	5
576	20	1	1	6	34.38	4
577	20	1	2	1	30.00	5
578	20	1	2	2	37.36	3
579	20	1	2	3	40.63	4
580	20	1	2	4	43.75	4
581	20	1	2	5	50.00	5
582	20	1	2	6	43.75	5
583	20	1	3	1	34.38	4
584	20	1	3	2	47.06	3
585	20	1	3	3	35.29	4
586	20	1	3	4	50.00	4
587	20	1	3	5	41.03	5
588	20	1	3	6	41.03	5
589	20	1	4	1	40.63	3
590	20	1	4	2	31.25	3

591	20	1	4	3	54.05	6
592	20	1	4	4	45.00	5
593	20	1	4	5	55.00	5
594	20	1	4	6	28.13	6
595	20	1	5	1	53.13	3
596	20	1	5	2	25.00	5
597	20	1	5	3	33.33	4
598	20	1	5	4	45.00	4
599	20	1	5	5	23.33	5
600	20	1	5	6	33.33	6
601	21	3	1	1	70.00	6
602	21	3	1	2	56.25	4
603	21	3	1	3	50.00	5
604	21	3	1	4	56.25	5
605	21	3	1	5	50.00	5
606	21	3	1	6	50.00	5
607	21	3	2	1	50.00	4
608	21	3	2	2	50.00	5
609	21	3	2	3	40.00	4
610	21	3	2	4	50.00	3
611	21	3	2	5	65.00	4
612	21	3	2	6	40.63	5
613	21	3	3	1	68.75	6
614	21	3	3	2	47.06	5
615	21	3	3	3	0.00	3
616	21	3	3	4	23.33	4

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OBS	SUB	POS	LIGHT	PAPER	PERF	EVAL
617	21	3	3	5	56.25	5
618	21	3	3	6	44.12	5
619	21	3	4	1	50.00	3
620	21	3	4	2	35.14	4
621	21	3	4	3	56.25	4
622	21	3	4	4	40.54	4
623	21	3	4	5	50.00	2
624	21	3	4	6	43.24	3
625	21	3	5	1	46.15	2
626	21	3	5	2	43.75	2
627	21	3	5	3	33.24	3
628	21	3	5	4	46.15	4
629	21	3	5	5	65.00	5
630	21	3	5	6	34.38	3

ACCNT

****CRBD NARAIN, ARVIND

RESIDENT TIME 1.15 MIN

CLASS A

1.17000 * 1.00 UNITS

INUTES 0.99754 * 1.00 UNITS

2.16754 UNITS $2.17

IC 0.01962 * 1.00 UNITS

INTED 0.03456 * 1.00 UNITS

'S 0.09300 * 1.00 UNITS

0.14718 UNITS $0.15

TOTAL COST $2.32

SS

APPENDIX C.

D R A F T

OPERATORS MANUAL

Series 1000

CONTRAST/ESI METER

Smith, Hinchman & Grylls Associates, Inc.
455 West Fort Street
Detroit, Michigan 48226

INTRODUCTION

The Series 1000 Contrast/ESI Meter is designed to provide for the easy measurement of contrast. This is accomplished by temporarily modifying the angular response to light of any common illuminance meter with good cosine correction. The result is a meter than can measure, at a given location, the luminances that a standard visual display would have, were it at the same location. From these luminances the display contrast is easily determined.

The Series 1000 Contrast/ESI Meter consists of a base and adaptor plate for positioning an illuminance meter probe, and two transmittance-modifying cylinders.

The cylinders have transmittance patterns that mimic the bi-directional reflectances of a particular standard visual display. Thus, an illuminance meter, when used with the cylinders, responds to light in the same way that a standard visual display responds. The cylinders include the effect of the standard body shadow.

DEFINITION OF TERMS

Standard Visual Display

Any number of standard physical objects which are used in typical school and office situations to convey visual information. These physical objects have had their bi-directional reflectances measured and are currently used in many of the commercially available contrast predicting computer programs. Standard visual displays include:

- Number 2 pencil on white paper
- IBM Selectric typing on bond paper
- Xerographic copy
- Drafting on mylar
- Felt tip pen on white paper
- Ball point pen on white paper
- Black offset printing on semi-matte paper

Each standard visual display and viewing angle is represented by a pair of cylinders.

Flux Contrast, C

The contrast exhibited by a standard visual display:

$$C = \frac{L_b - L_t}{L_b}$$

Where L_b = Background luminance

L_t = Task luminance

Background Luminance, L_b

The luminance exhibited by the immediate background material of the visual display. This is usually the luminance of the paper on which the writing, printing, or typing appears.

Task Luminance, L_t

The luminance exhibited by the task, that is, the actual printing, writing or typing, combined with some paper or background material on which it appears.

Luminance Difference, ΔL

The difference in background and task luminance exhibited by the visual display:

$$\Delta L = L_b - L_t$$

$$C = \frac{L_b - L_t}{L_b} = \frac{\Delta L}{L_b}$$

USE OF THE METER TO MEASURE CONTRAST

1) Placement and Orientation of Base

The location of contrast measurements is determined by centering the base of the Contrast/ESI Meter over the desired location. A circular hole is provided for this purpose.

Visual display luminances are particular to viewing direction. The viewing direction for contrast measurements using the Contrast/ESI Meter is determined by the azimuthal orientation given to the cylinders. The handle on the base is toward the back of the hypothetical observer, and thus the viewing direction will be directly opposite that of the handle.

2) Locating Illuminance Meter Probe

Adaptor plates are provided for the proper centering and alignment of the illuminance meter probe. The adaptor plate is placed into the base.

The illuminance probe is placed on the adaptor plate, with its lead wire or handle passing through the hole provided in the wall of the base.

In addition to centering the probe, the adaptor plate provides the vertical alignment necessary for the probe optical horizon to coincide with the Contrast/ESI Meter measurement horizon.

3) Making L_b and L Measurements

The cylinder for measuring background luminance is placed on the base so that the two handles coincide. This cylinder is marked "B". A measurement is made with this cylinder in place. The quantity measured will be called R_b.

The background cylinder is removed and the cylinder for measuring luminance difference is then placed on the base so that the two handles coincide. The cylinder is marked "D". A measurmenet is made with this cylinder in place. The quantity measured will be called R_d.

Note that the base must be in the same position and orientation for both measurements.

Each cylinder has an individually determined calibration constant. The two measurements, R_b and R_d, are converted to luminances with these calibrating constants, K_b and K_d.

If the illuminance meter is calibrated for LUX (lumens/meter^2) then the two luminances in candelas/meter^2 are given by:

$L_b = K_b \times R_b$ (R_b in LUX) K_b = 1.0284
For "B" cylinder
Serial No. B-0615101

$\Delta L = K_d \times R_d$ (R_d in LUX) K_d = .1959
For "D" cylinder
Serial No. D-0615101

If the illuminance meter is calibrated for footcandles (lumens/foot^2), then the luminances in candelas/meter^2 are given by:

$$L_b = K_b \times R_b \times 10.76 \qquad (R_b \text{ in footcandles})$$

$$\Delta L = K_d \times R_d \times 10.76 \qquad (R_d \text{ in footcandles})$$

4) Determining Contrast

The contrast of the standard visual display for the location and viewing direction chosen is non-dimensional and is determined from:

$$C = \frac{\Delta L}{L_b}$$

5) Determining Contrast Rendering Factor

Contrast Rendering Factor (CRF) is defined as the ratio of visual display contrast in the real lighting environment to the visual display contrast in a photometric sphere. That is,

$$CRF = \frac{C}{C_o}$$

The contrasts the visual displays exhibit in a photometric sphere are constants that have been determined and are listed in Table 1 for the various visual displays.

Table 1

	C_o	βb
Number 2 Pencil	.1675	.858
Typing	.1258	.906
Xerography	.1388	.870
Drafting	.4296	.832
Felt Tip	.5199	.823
Ball Point	.2572	.859
Offset Printing	.1411	.865

All viewing angles are 25°.

Table 1 also lists the reflectances, β_b, that the visual display backgrounds exhibit in a photometric sphere. These are used for equivalent sphere illumination determination.

6) Changing Viewing Direction

If more than one viewing direction is to be investigated at the same location, then both the "B" and "D" cylinders can be rotated so that they face another viewing direction. The cylinders can be rotated on the base to viewing directions that are $\pm 30^\circ$, $\pm 45^\circ$, $\pm 60^\circ$, and $\pm 90^\circ$ from the direction established by the orientation of the base. These angles are marked on the cylinders and detents are provided for easy location of these orientations.

Note that <u>both</u> cylinders must have the same position on the base when the R_b and R_d measurements are made. The handles on the cylinders will no longer coincide with the handle on the base when the cylinders are rotated.

DETERMINING EQUIVALENT SPHERE ILLUMINATION (ESI)

ESI is a measure of visual display visibility. The ESI at a particular point in a real lighting environment is that level of illuminance produced by a photometric sphere which would produce a visibility equivalent to that produced on the display by the real lighting environment. ESI is a function of display contrast, C, and background luminance, L_b. It is calculated using the Relative Contrast Sensitivity (RCS) function of luminance. See IESNA 1981 Lighting Handbook, Reference Volume, Page 9-60 through 9-63. ESI is calculated from

$$\text{ESI (LUX)} = \frac{\pi}{\beta_b}\left[\frac{.568558}{\dfrac{2.19572}{x + \log(\text{CRF})} - 1}\right]^5$$

where

$$x = \left[\frac{2.19572}{1 + \dfrac{1}{1.75885\ [(L_b)^{.2}]}}\right]$$

This equation assumes that L_b is in candela/meter^2. Or,

$$\text{ESI (Footcandles)} = \frac{\text{ESI (LUX)}}{10.76}$$

DISCOMFORT GLARE EFFECTS OF VEILING REFLECTIONS IN PAPERS

by

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ABSTRACT

The purpose of this research was to relate the physically measured and judged quality of lighting. The physical variables were Equivalent Sphere Illumination, Maximum Factor, Light Field Composition, and Directional Light Source position. Lighting quality was subjectively evaluated on the basis of paper gloss, quality of visual conditions and performance on the Landolt Visual task.

Results of this study show that paper gloss affected the quality of visual conditions only when the directional light source was placed in front of the observer (0^{o} position). The relationship between judged paper gloss and the physical variable, maximum factor was found to be a polynomial model of the fourth order.

The hypothesis that lighting quality deteriorates as the maximum contribution from the offending zone (0^{o} position of directional light source) increases was confirmed. It was also found that light position had no effect on the evaluation of visual conditions.

Performance on the Landolt Visual task was found not to be affected by light field composition. This was attributed to the high level of overall illuminance (100 foot candles). A linear relationship was established between performance score and ESI. It was found that ESI was affected only by the directional light position and not the light composition. Results also indicate that the relationship between ESI and mean quality was not confirmed by the "Validation Study". Futher research on this topic is needed at lower levels of illumination especially between 40 and 65 footcandles and different light field compositions.