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Date 5/19/81

CORRELATION BETWEEN MAXIMUM DENSITY AND LOG EXPOSURE RANGE OF QUALITY PRINTS

by

David A. Baer

A thesis submitted in partial fulfillment
of the requirements for the degree of
Bachelor of Science in the School of
Photographic Arts and Sciences in the
College of Graphic Arts and Photography
of the Rochester Institute of Technology

May, 1981

Signature of the Author..
Photographic Science
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Supervisor, Undergraduate Research

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Submitted to the
Photographic Science and Instrumentation Division
in partial fulfillment of the requirements
for the Bachelor of Science degree
at the Rochester Institute of Technology

ABSTRACT

An investigation was made to determine the correlation between the maximum density and log exposure range of photographic paper when making "quality" prints. The 1966 ANSI log exposure range formula assumes that papers which have the same log exposure range but differ in maximum density will print the same negative successfully. It has been shown with 27 judges that when the 1966 ANSI log exposure range formula is used the maximum density has an effect on the effective log exposure range such that papers which have the same log exposure range but differ in maximum density will not print the same negative successfully. Effective log exposure range factors were determined so that papers of different maximum density could be compared more readily.

ACKNOWLEDGMENTS

I would first like to thank the following organizations: Ilford, Inc., Eastman Kodak Company, and Agfa-Gevaert, Inc. for their generous donations of photographic paper. The technical assistance of the following instructors was greatly appreciated: Al Rickmers, Tom Iten, John Carson, and Leslie Stroebel.

I would now like to especially thank Richard Byer, my research adviser, who helped me with his time, patience, and knowledge.

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INTRODUCTION

When buying photographic paper, it is important to identify the paper by certain characteristics. These include the "grade", surface, weight, tone, speed, etc. One of the most important characteristics that photographers need is the grade of paper[1] (Appendix A).

The ANSI PH2.2 standard of 1966[2] for photographic paper indicates that the grading of papers would be based on the log exposure range (LER). For instance, a paper that has a LER within the range of 0.95-1.15 would be considered "medium".[3] It is the LER (ANSI 1966) which donates the useful part of the paper's characteristic curve which is used to make a good print. Since the paper "grade" is important to know when choosing paper, it is important that the grades are designated the best way possible by having the appropriate LER assigned to a given paper. It was hypothesized that the LER that was obtained from the 1966 ANSI PH2.2 formula[4] (Appendix A) would have to be multiplied by a correction factor for the purpose of being able to compare the LER of papers which have different maximum densities. This was due to the fact that the maximum density may affect what the "effective LER" should be.

In this study the following two things will be looked at: 1. To determine if the maximum density of photographic paper has an effect on the LER as defined by the 1966 ANSI formula.[5] 2. To determine what the effective LER equations should be for various Dmax in order to compare what the LER is for papers of different Dmax. If the Dmax does not affect what the effective LER is, the effective LER equations will all be (1.0) (LER) at all maximum densities.

BACKGROUND

Studies by Nelson and Jones[6,7] were done to find a way of determining which grade of paper would be used with a given negative. In their study, a plot of the log exposure scale (LER) of the paper versus the density range of the negative was given. By knowing the density range of the negative, one could determine the appropriate LER that would predict the grade of paper that should be used.

Nelson and Jones concluded that the sensitometric exposure scale (Appendix B) was the most suitable basis for the derivation of paper grade numbers.[8] Nelson and Jones claimed that if two papers had the same sensitometric exposure scale but different maximum densities, the result of printing the same negative on both of these papers would yield the same result in the quality of the photograph.

Both the sensitometric exposure scale and the 1966 ANSI LER indicate the useful part of the paper's characteristic curve. The sensitometric exposure scale is based on the log exposure interval between two points on the paper's characteristic curve. One point is on the toe and is equal to 0.10 $\bar{G}$ and the other is on the shoulder and equal to 1.0 $\bar{G}$, in which $\bar{G}$ is the average slope of the line that connects these points. The two points on the curve that define the 1966 ANSI LER formula are located at 0.04 above base + fog density, and at (0.9)(maximum density). The log exposure interval between these two points represents the LER.

The question was raised by the ANSI PH2-46 Subcommittee, which was charged with revising/rewriting the 1966 R(1972) PH2.2 standard, that the LER of a paper calculated by the 1966 R(1972) PH2.2 formula may not be valid when comparing papers of different maximum density (Dmax). It was hypothesized that the LER that was obtained from the 1966 PH2.2 formula would have to be multiplied by a correction factor for the purpose of being better able to compare the LER of papers which have different Dmax. For instance, if a paper had a Dmax of 2.0, the correction factor for this paper would be different than the correction factor for a paper that had a lower Dmax of the same LER.

R.J. Byer of Dupont Photo Products, a member of the ANSI PH2-46 Subcommittee, prepared a hypothesized chart of Dmax versus the LER correction factors which is shown below.[9]

Table 1. Hypothesized Chart of LER Correction Factors For Various Dmax

Dmax	LER Correction Factor
2.1	0.95
2.0	1.00
1.8	1.05
1.6	1.10
1.4	1.20
1.2	1.30

Table 1 is based on a Dmax of 2.0 needing no correction factor. At the other maximum densities the paper's LER needs to be multiplied by the LER correction factor in order to compare these papers. Byer's chart is based on a limited study, and he has suggested that a more rigorous study be done which would indicate how the LER of a paper is related to its Dmax. Two ideas have therefore been stated with respect to print quality: 1. As long as two papers have the same LER, the result of making prints with these papers with the same negative will be the same regardless of the maximum densities of the papers.[10]
2. Two papers which have the same LER but different Dmax may not necessarily print the same as determined by various judges using subjective evaluation. This in turn would necessitate a change of the LER value that is given for the two papers if the print quality is to be the same when printing the same negative. It has been hypothesized that if the LER (ANSI 1966) changes from a matte paper to a glossy paper due to its maximum density increasing, the matte paper would be rated a grade differently according to the ANSI standard of 1966,[11] and according to the standard by Nelson and Jones.[12] However, the papers should probably not be rated differently since they would print the same negative successfully.

EXPERIMENTAL

Photographing Subjects and Processing Film

Photographs were made of a variety of subjects under a number of lighting conditions. This was done in order to determine how the type of subject matter and lighting conditions influenced the way the Dmax of paper affected the LER (ANSI 1966). This was illustrated in Table 2.

Table 2. Photographing Subjects

Subject	Subject Letter	Lighting	Meter Setting
Barge	A	Outdoor front lit	50
Studio portrait	B	Electronic flash	16
Overcast outdoor portrait	C	Available outdoor light	50
Still life of fruit	D	Back lit tungsten light source with front reflector	32
Outdoor shopping center	E	Outdoor front lit	16
Outdoor view of house	F	Outdoor front lit	16
Outdoor portrait of female model	G	Outdoor front lit	50
Still life of glassware	H	Side lit by reflectors that received light from tungsten sources	50
Outdoor portrait of female model	I	Outdoor shade	50

The subjects listed in Table 2 were photographed using Eastman Kodak's Panatomic-X bulk film (35mm) using a Minolta SRT 101 35mm single lens reflex camera. The film was processed according to the manufacturer's instructions in D-76 (1:1) at 68°F for seven minutes. A sensitometric strip was exposed in a Kodak 101 sensitometer and taped onto the end of each roll of film that was developed for the purpose of obtaining the characteristic curve of each roll of film that was developed. The results were illustrated in Table 3.

Table 3. Data From Film Curves of Panatomic-X Film

Subject	Contrast Index	Exposure Index	Dmax	Base + Fog
Barge(A)	0.36	27	1.07	0.23
Studio portrait (B)	0.52	40	1.54	0.25
Overcast outdoor portrait (C)	0.52	46	1.51	0.23
Still life of fruit (D)	0.52	40	1.54	0.25
Outdoor shopping center (E)	0.54	40	1.52	0.24
Outdoor view of house (F)	0.52	43	1.52	0.25
Outdoor portrait of female model (G)	0.36	27	1.07	0.23
Still life of glassware (H)	0.54	46	1.51	0.24
Outdoor portrait of female model (I)	0.52	40	1.51	0.23

The film's characteristic curves were shown in Figure 1.

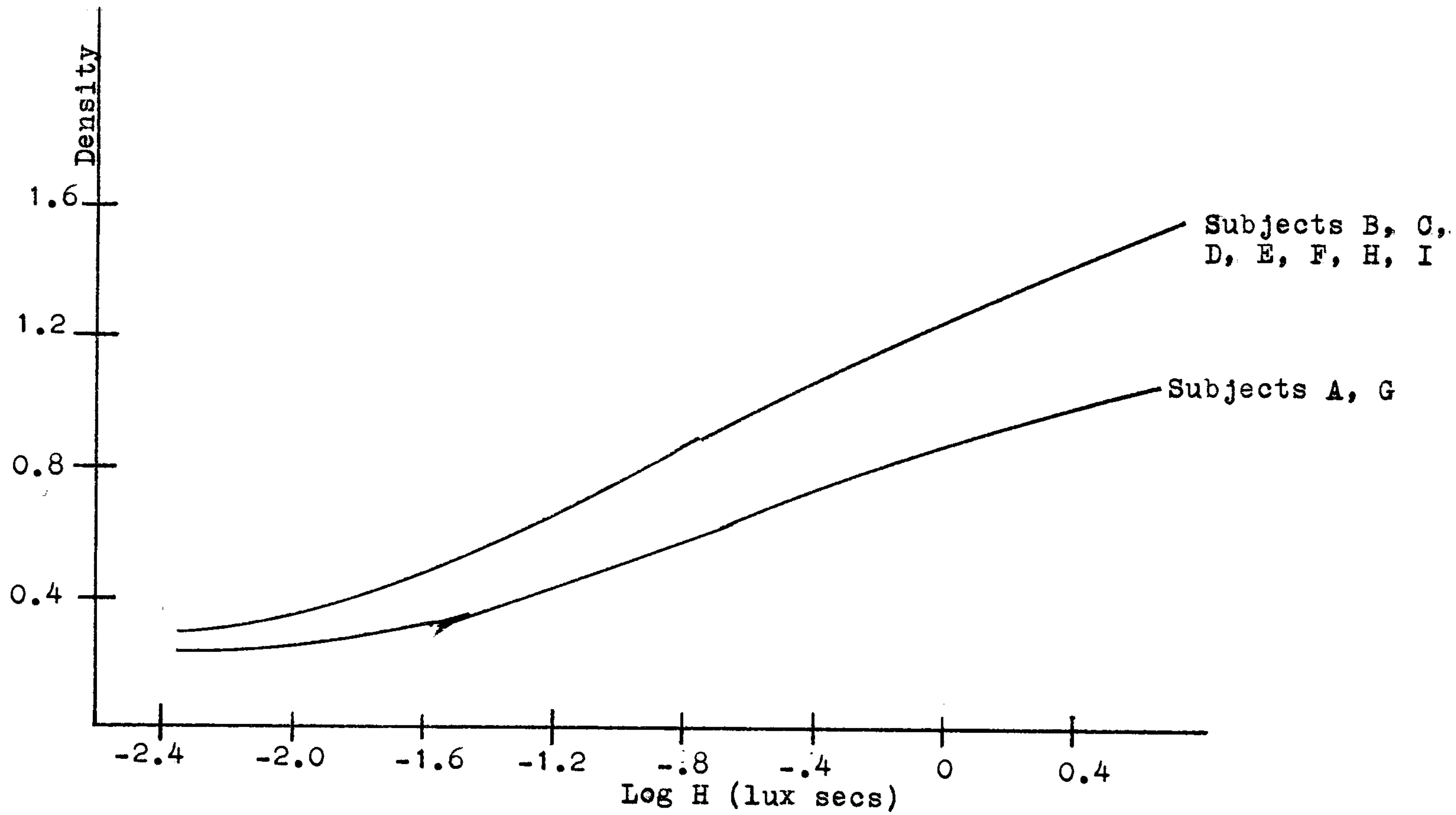

Figure 1. Film Curves for Panatomic-X Film

The densities for the characteristic curves were obtained from using a Macbeth TD-504 transmission densitometer. The contrast index, base + fog, and exposure index that were shown in Table 3 were obtained from the characteristic curves of the films. Contact prints were made of all of the subjects in order to determine what the optimum exposure was for each subject, which was based on the shadow detail that was present.

Testing Paper

Characteristic curves of Eastman Kodak's Kodabrome II RC paper for the glossy, lustre, and matte surfaces were done in order to determine what the maximum densities were and what the optimum development time should be. The same was done with Ilford's Galerie (glossy) paper which was ferrotyped and matte dried. These objectives were accomplished by contact printing a step tablet onto paper while the step tablet was being exposed to light. The light source was an Omega condenser enlarger. The Kodabrome paper was developed in D-72 (1:2) at $68^{o}F$ for 1 and 2 minutes, while the Galerie paper was developed for 1½ and 2 minutes under the same conditions.

It was determined that the optimum development time was at one minute and 10 seconds to one minute and 20 seconds for the Kodabrome and at two minutes for the Galerie paper. These processing times were chosen to obtain a maximum density with a minimum amount of development time. It was discovered that the maximum densities for the glossy and lustre Kodabrome paper only differed by about 0.1, so only the glossy and matte surface paper was used. The maximum density values for the paper were shown in Table 4.

Table 4. Maximum Densities of Photographic Paper

Paper	Dmax
Kodabrome II RC (lustre)	2.00
Kodabrome II RC (matte)	1.50-1.60
Kodabrome II RC (glossy)	1.99-2.12
Galerie (matte dried)	2.25-2.30
Galerie (ferrotyped)	2.20

Testing Equipment

The Pako ferrotype dryer was cleaned with Bon-Ami soap and tested for ferrotyping with Ilford's Ilfobrom glossy paper. Prior to placing the print on the dryer, the paper was first immersed in Pako's Pakosol ® solution according to the manufacturer's instructions, and placed on the dryer which was heated at 200°F. The result was a ferrotyped print that was very glossy.

The Omega condenser enlarger was tested for uniformity and the Macbeth RD-100 reflection densitometer was tested for precision and accuracy. The densitometer was tested with standard Macbeth reflection patches and found to be accurate and precise to within plus or minus 0.02 density units. The enlarger was tested by contact printing a step tablet along the edges and center of a piece of photographic paper which was processed. The edges of the paper corresponded to the edges of the enlarger's illumination from the negative carrier. The densities of the edges only differed by 0 - 12% from the densities of the center of the paper.

Printing Negatives

A series of 5 x 7 prints were made of the nine subjects using the Kodabrome II RC and Galerie paper. The prints varied in exposure and grade. The grades of the papers that were used for each subject were shown in Table 5. The F surface of the Kodabrome II RC paper corresponded to a glossy surface, while the N surface corresponded to a matte surface.

The height of the enlarger was kept constant with a constant F stop of F-8. Step tablet exposures were made by contacting the step tablet on the same photographic paper that was used to make the prints. In this way characteristic curves were obtained for each subject that was used so that day differences that might be present were determined. The Galerie paper was matte dried and ferrotyped.

Table 5. Printing Negatives

Subjects	Paper	Grades
Barge (A)	Kodabrome (F & N)	1,2,3
Studio portrait (B)	Kodabrome (F & N)	1,2,3
Overcast outdoor portrait (C)	Kodabrome (F & N)	2,3,4,5
Still life of fruit (D)	Kodabrome (F & N)	1,2,3
Outdoor shopping center (E)	Kodabrome (F & N)	1,2,3,4,5
	Galerie (matte dried)	1,2,3
	Galerie (ferrotyped)	1,2,3
Outdoor view of house (F)	Kodabrome (F & N)	1,2,3
Outdoor portrait of female model (G)	Kodabrome (F & N)	1,2,3
Still life of glassware (H)	Kodabrome (F & N)	1,2,3,4,5
	Galerie (matte dried)	1,2,3
	Galerie (ferrotyped)	1,2,3
Outdoor portrait of female model (I)	Kodabrome (F & N)	1,2,3,4,5
	Galerie (matte dried)	1,2,3
	Galerie (ferrotyped)	1,2,3

Judging of Prints

Twenty-seven judges from the various photo departments at the Rochester Institute of Technology (RIT) were selected to judge the prints. The majority of these judges were from the Pro Photo department. The judges included both faculty and students. Judges looked at the prints using a Macbeth viewing booth which had florescent tubes at 5000°K.

Each judge would pick the optimum three exposures for each grade and pick the first, second, and third best grade by using as many of the selected prints from picking the optimum print exposures for each of the grades. In this way the optimum print grade number was obtained for each subject. The optimum grades that were chosen by the judges corresponded to a LER (ANSI 1966) value. The order of print presentation to the judges was to show all of the subjects in one surface and then to show each of the subjects in another surface so that the memory of one surface would not influence the selection of the best grade for the other surface.

One of the judges was tested for constancy by having the judge look at the prints one day involving one set of conditions, and having the judge look at the prints another day involving another set of conditions. The first day none of the prints were cut, and the exposures were not presented in sequential order which forced the judge to look at two 5 x 7 prints on an 8 x 10 sheet of paper. The second day the prints were all cut and labeled and in sequential exposure order. The results for both conditions were the same in the selection of the best print except for subject F.

Three of the judges also matched print quality when going from a paper of one surface to another in order to determine the LER (ANSI 1966) correction factors. For instance, a judge was told to match the print quality of a matte paper for a given grade with a glossy paper with given grades. An example of this might be a glossy #1 grade would equal a matte #2 grade in print quality. The print comparisons were done with subjects E, H, and I.

Dmax and LER Values

Paper characteristic curves were made from the sensitometric strips that were contact printed along the edge of each print that was shown to the judges. Average density values were taken from all the curves for a given grade of paper for the purpose of obtaining an average characteristic curve. This was done for all of the grades of paper, and was shown in Figures 2 - 4. The numbers next to each of the curves corresponded to the grades of paper. Figure 4 showed the curves for the Galerie paper in which the matte dried paper curves had higher density values than the ferrotyped paper only at the higher density values. The matte dried paper curves had a 0.03 higher Dmax on the average for all three grades.

A summary of the Dmax and LER (ANSI 1966) values were given in Tables 6 - 9 for the Galerie and Kodabrome II RC paper. The dashed line (-) indicated that either none of the judges selected those contrast grades or those grades were not used to make prints for that subject. The average (mean) LER and Dmax values for all the grades of paper were shown in Table 10.

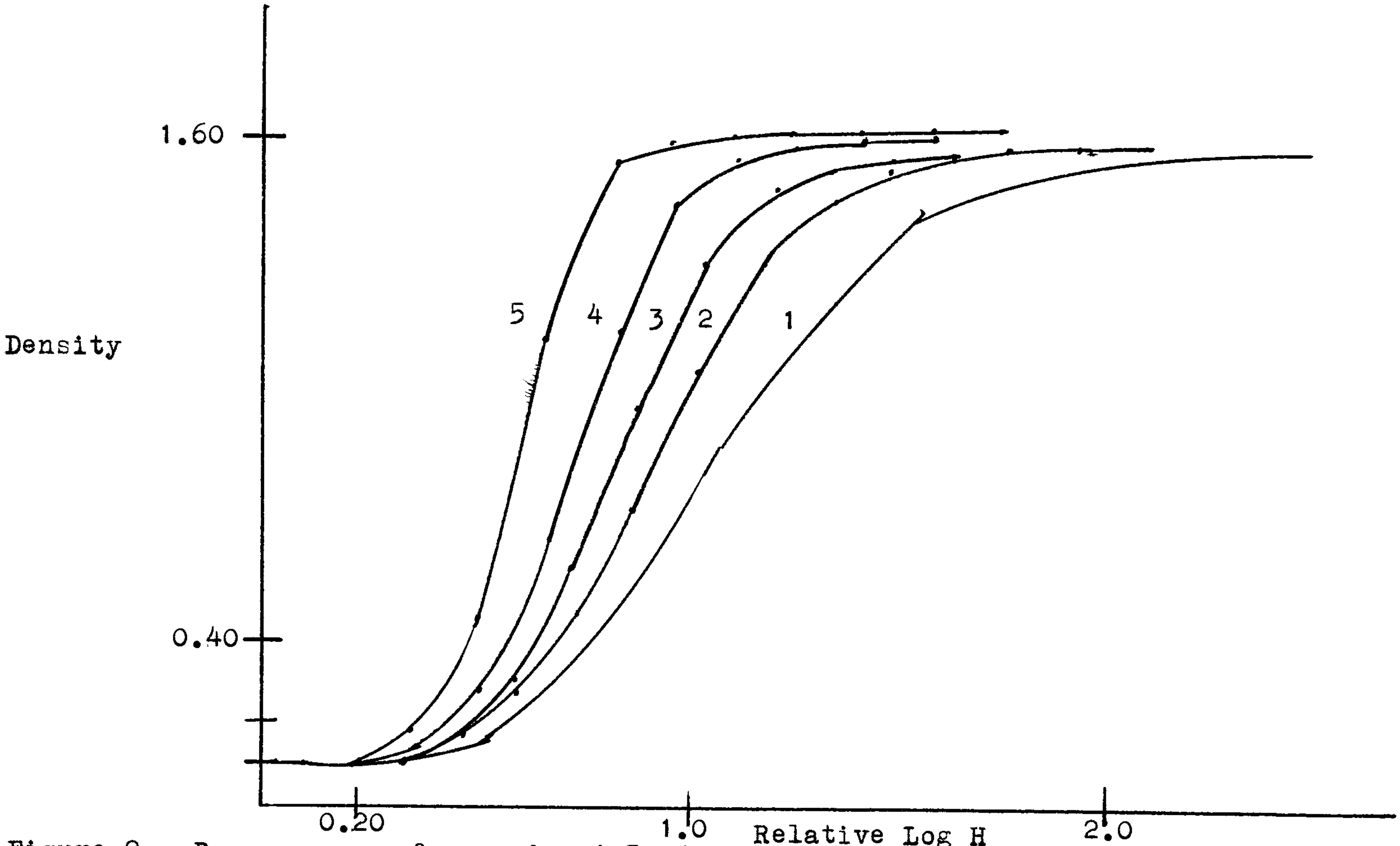

Figure 2. Paper curves for grades 1-5 of Kodabrome II RC (matte)

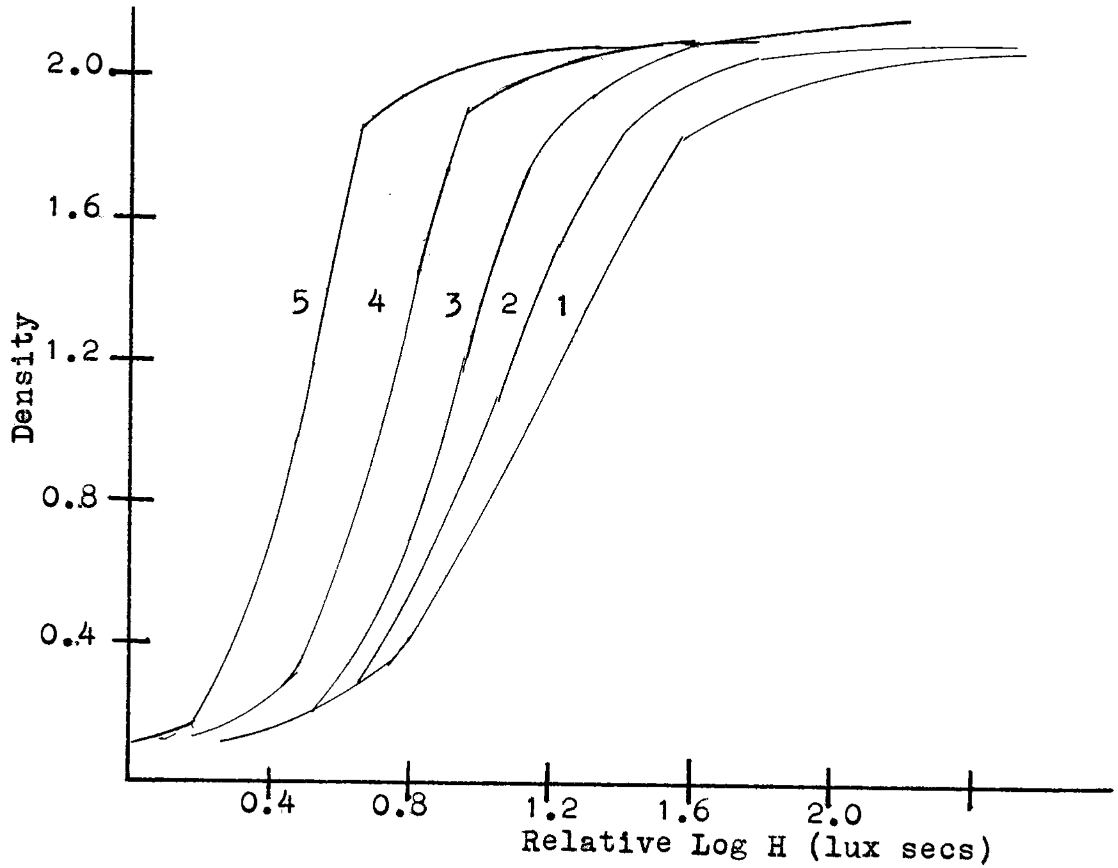

Figure 3. Paper Curves for Grades 1 - 5 of Kodabrome II RC (glossy)

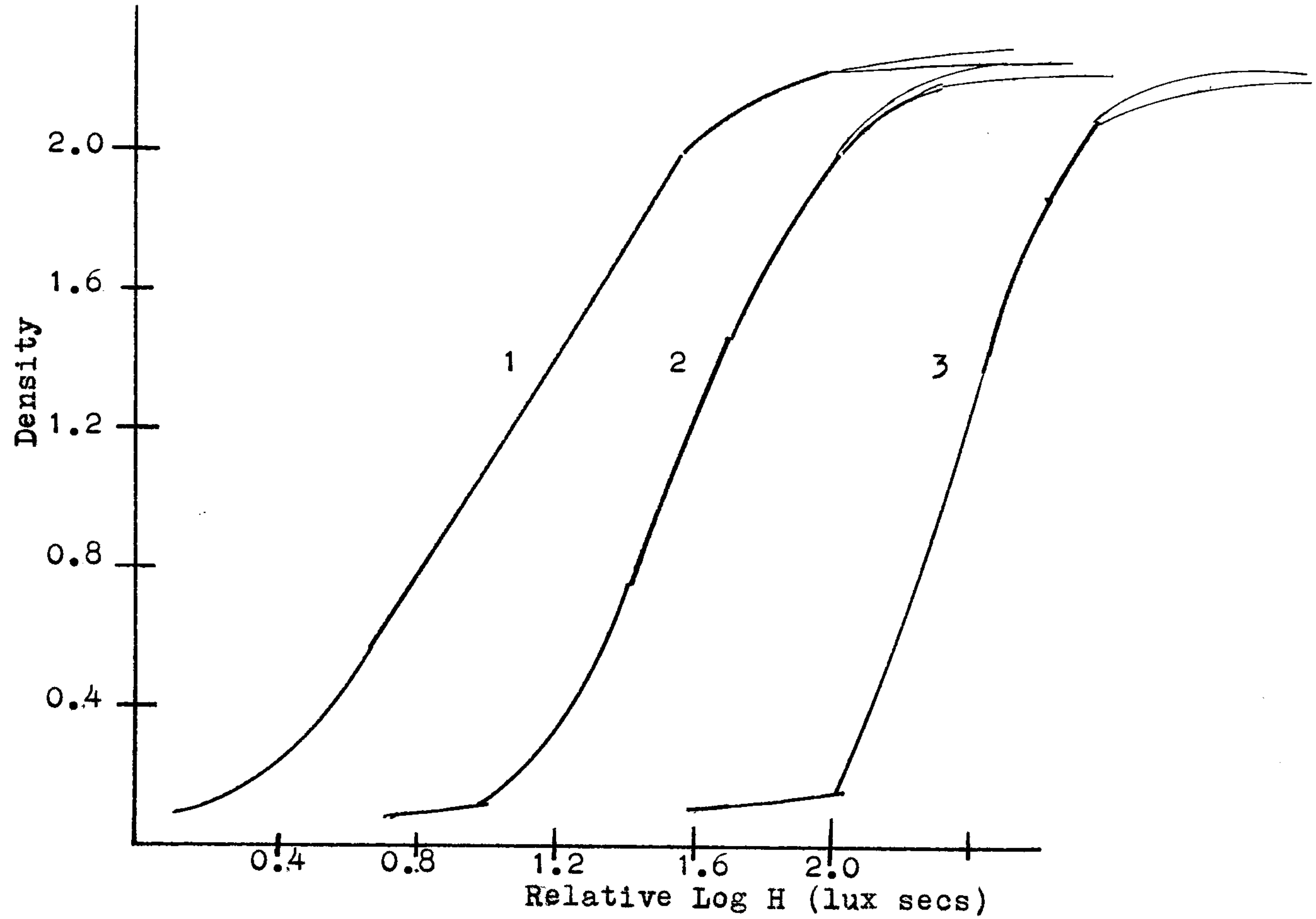

Figure 4. Paper Curves for Grades 1 - 3 of Galerie (matte dried) and Galerie (ferrotyped)

Table 6. LER Values for the Kodabrome II RC Matte and Glossy Surfaces

	LER Values for the Matte Surface					LER Values for the Glossy Surface				
	Grades					Grades				
Subject	1	2	3	4	5	1	2	3	4	5
Barge (A)	1.04	0.93	0.73	-	-	1.17	1.04	0.84	-	-
Studio portrait (B)	1.12	0.97	-	-	-	1.16	1.04	-	-	-
Overcast outdoor portrait (C)	-	-	0.79	0.63	-	-	-	0.84	0.71	-
Still life of fruit (D)	1.06	0.95	0.73	-	-	1.31	1.09	0.84	-	-
Outdoor shopping center (E)	1.08	0.91	0.74	0.62	0.49	1.16	1.04	0.84	0.72	0.55
Outdoor view of house (F)	1.08	0.97	0.74	-	-	1.17	1.03	0.87	-	-
Outdoor portrait of female model (G)	1.04	0.89	0.70	-	-	1.16	1.02	0.87	-	-
Still life of glassware (H)	1.16	0.91	0.76	0.63	0.52	1.25	1.03	0.84	0.72	0.55
Outdoor portrait of female model (I)	1.10	0.89	0.77	0.64	0.49	1.16	1.02	0.85	0.72	0.57

Table 7. Dmax Values for the Kodabrome II RC Matte and Glossy Surfaces

Subject	Dmax Values for the Matte Surface					Dmax Values for the Glossy Surface				
	Grades					Grades				
	1	2	3	4	5	1	2	3	4	5
Barge (A)	1.57	1.58	1.57	-	-	2.10	2.15	2.16	-	-
Studio portrait (B)	1.57	1.60	-	-	-	2.06	2.15	-	-	-
Overcast outdoor portrait (C)	-	-	1.59	1.61	-	-	-	2.18	2.14	-
Still life of fruit (D)	1.56	1.58	1.57	-	-	2.12	2.15	2.16	-	-
Outdoor shopping center (E)	1.55	1.59	1.58	1.61	1.63	2.12	2.15	2.16	2.15	2.09
Outdoor view of house (F)	1.55	1.60	1.58	-	-	2.06	2.15	2.19	-	-
Outdoor portrait of female model (G)	1.57	1.58	1.57	-	-	2.10	2.11	2.19	-	-
Still life of glassware (H)	1.58	1.58	1.58	1.62	1.63	2.12	2.15	2.18	2.15	2.12
Outdoor portrait of female model (I)	1.55	1.59	1.58	1.60	1.62	2.10	2.11	2.14	2.12	2.12

Table 8. LER Values for the Galerie Paper

Subject	Galerie (matte dried) Grades 1	Galerie (matte dried) Grades 2	Galerie (matte dried) Grades 3	Galerie (ferrotyped) Grades 1	Galerie (ferrotyped) Grades 2	Galerie (ferrotyped) Grades 3
Outdoor shopping center (E)	1.37	1.10	0.82	1.33	1.10	0.82
Still life of glassware (H)	1.30	1.10	0.76	1.33	1.11	0.74
Outdoor portrait of female model (I)	1.38	1.07	0.76	1.33	1.10	0.79

Table 9. Dmax Values for the Galerie Paper

Subject	Galerie (matte dried) Grades 1	Galerie (matte dried) Grades 2	Galerie (matte dried) Grades 3	Galerie (ferrotyped) Grades 1	Galerie (ferrotyped) Grades 2	Galerie (ferrotyped) Grades 3
Outdoor shopping center (E)	2.25	2.29	2.24	2.20	2.24	2.20
Still life of glassware (H)	2.25	2.31	2.25	2.24	2.30	2.21
Outdoor portrait of female model (I)	2.31	2.25	2.24	2.25	2.30	2.24

Table 10. Average LER (ANSI 1966) and Dmax Values (all grades)

	Average LER (ANSI 1966)					
	Grades					
Paper	1	2	3	4	5	Dmax
Kodabrome II RC (glossy)	1.19	1.04	0.85	0.72	0.56	2.13
Kodabrome II RC (matte)	1.08	0.93	0.75	0.63	0.50	1.58
Galerie (matte dried)	1.35	1.09	0.78	-	-	2.27
Galerie (ferrotyped)	1.33	1.10	0.78	-	-	2.24

Statistical Analysis

A. Histograms

After 16 judges had judged the prints, histograms were made showing the results of the optimum grades selected for each subject. Histograms were also done showing how many judges switched grades (optimum) when going from Kodabrome II RC (matte) to Kodabrome II RC (glossy), and when going from a Galerie print that was matte dried to one which was ferrotyped. A paired comparison test[13] showed that a significant number of judges did not change their optimum grade number when going from one surface to another for some of the subjects. These subjects included F, G, and I for the Kodabrome, and subjects E and I for the Galerie. This involved a two tailed test with an alpha value of 0.05. The other subjects were shown to 11 additional judges to determine if the Dmax had an effect on the choice of the optimum grade.

Histograms were also done comparing the results of photo instructors with those of photo science and technical photography instructors to see if there was any significant difference between the two groups. There were a total of five judges from each group. Once all the judges (faculty and students) viewed the prints, final histograms were made that represented the optimum grade selections of the Kodabrome and Galerie paper which involved all of the subjects. This was shown in Figures 5 - 7.

B. Hypothesis Testing of the Variance and Mean LER

Using the data from the final histograms, (Figures 5-7) and Tables 6 & 8, the average LER (ANSI 1966) selected by the judges was determined for all of the subjects with all of the papers that were used. This was done by first noting what LER (ANSI 1966) values corresponded to each grade of paper. The histograms were used to determine the frequency associated with the optimum grade selection to obtain the average LER (ANSI 1966). The variance associated with the judges' selection of grades (LER) was also determined based on the LER values.

An hypothesis test was done on the variances of the LER values that were selected by the judges for each subject with the glossy and matte surface Kodabrome paper. This was done to determine if the two paper surfaces were from the same population. This was done by using an F test. An hypothesis test for means was done to see if the mean LER (ANSI 1966) for the matte surface was significantly different than the glossy surface. Sample calculations for the hypothesis test for variances and means were shown in Appendix C. The hypothesis test for means was set up using an alpha value of 0.05 for a two tailed test for all the subjects that were tested. The results of these tests indicated if the Dmax of the paper had an effect on the LER (ANSI 1966).

C. Determining Effective LER Equations

Two sets of effective LER equations were determined to be able to compare papers which had different Dmax. The first set was based on the mean LER (ANSI 1966) values that were obtained from the judges' selections of optimum prints for each subject. This involved using subjects E, H, and I with both the Galerie and Kodabrome paper, while the other subjects were used only with the Kodabrome paper.

The second set of effective LER equations were based on the print comparisons that were done by the three judges. This was done by obtaining the LER (ANSI 1966) values that were selected by the judges using subjects E, H, and I with both the Galerie and Kodabrome paper. For example, if one judge thought that a glossy #1 grade equalled a matte surface #2 grade for a given subject, the two grades were converted to LER (ANSI 1966) values and recorded. If two of the judges selected the same LER (ANSI 1966) value for a given subject, those values were used. If all three judges differed in their selection, the average grade was determined and converted to its corresponding LER.

There were some cases in the print comparisons in which the judge thought that the correct print grade was somewhere in between the two grades that were presented to him. For instance, if a judge indicated that a glossy #1 paper equalled a matte grade number that was between grades 1 & 3, an appropriate LER value would need to be found that was located between what the LER values were for grades 1 and 3. This was done by adding the LER (ANSI 1966) values for grades 1 and 3 of the matte paper, and then dividing this total by 2 to obtain an approximate LER value that was between the LER values of grades 1 and 3.

The mean LER values were graphed with the LER values obtained from the print comparisons for all of the subjects and papers that were used. The result of this was a paper with one Dmax plotted against a paper of another Dmax. This was shown in Figures 8 - 14. Linear regression equations were determined for these graphs and were shown in Table 11. The correlation coefficient was also determined for all of the equations.

Effective LER equations were obtained by comparing the LER (ANSI 1966) values for the Kodabrome matte paper with all of the other paper surfaces. This was done by calculating the linear regression equations that related the Kodabrome matte paper to the other papers. This was done using the linear regression equations from the mean LER values for the subjects, and from the print comparisons that were done. For example, if the relationship between the Kodabrome matte and glossy surface paper was LER (matte) = (0.87)(LER (glossy)), this would be the effective LER equation for the Kodabrome glossy paper. Therefore, if the LER (ANSI 1966) of the Kodabrome glossy paper was 1.0, the effective LER would be 0.87. The effective LER equations shown in Table 13 were based on the Kodabrome matte paper (Dmax = 1.58) needing no correction factor so the effective LER equation was 1.0 LER (ANSI 1966). This was because the Kodabrome matte paper was selected as the one that all of the other papers would be compared with. In this way papers of different Dmax were compared in terms of the LER.

RESULTS

Histograms

The optimum grade numbers that were selected by the judges for all of the subjects were shown in the final histograms of Figures 5 - 7. The m's stand for the matte surface for the Kodabrome paper, and for the matte dried Galerie paper. The g's stand for the glossy surface Kodabrome paper, and for the ferrotyped Galerie paper.

Hypothesis Tests for Means and Variances

Table 11 indicated what the mean LER (ANSI 1966) and variance values were for all of the subjects using Kodabrome paper.based on the optimum grades chosen by the judges. Subject H had the highest variance for the matte surface, while subject D had the highest variance for the glossy surface.

The null hypothesis for the hypothesis test for the variance of the LER (ANSI 1966) was that the variance of the glossy Kodabrome paper was equal to the variance of the matte Kodabrome paper. The alternative hypothesis was the variances were not equal. The null hypothesis was accepted for all of the subjects except subject D using an alpha of 0.05. The hypothesis test for means showed that the mean LER (ANSI 1966) for the Kodabrome matte surface paper was significantly less than the

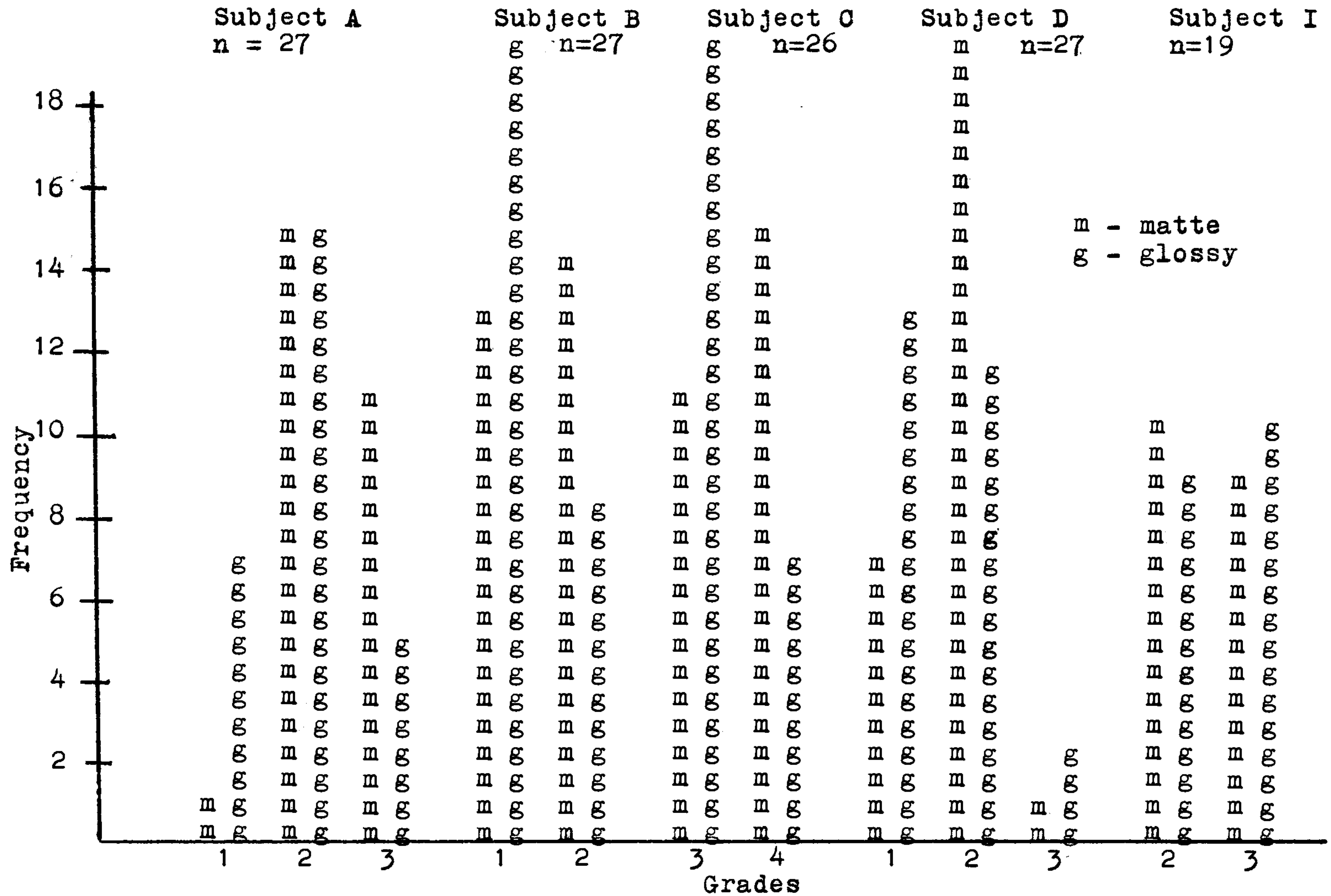

Figure 5. Histograms of the Optimum Grade Number Choice for the Kodabrome Matte and Glossy Surfaces

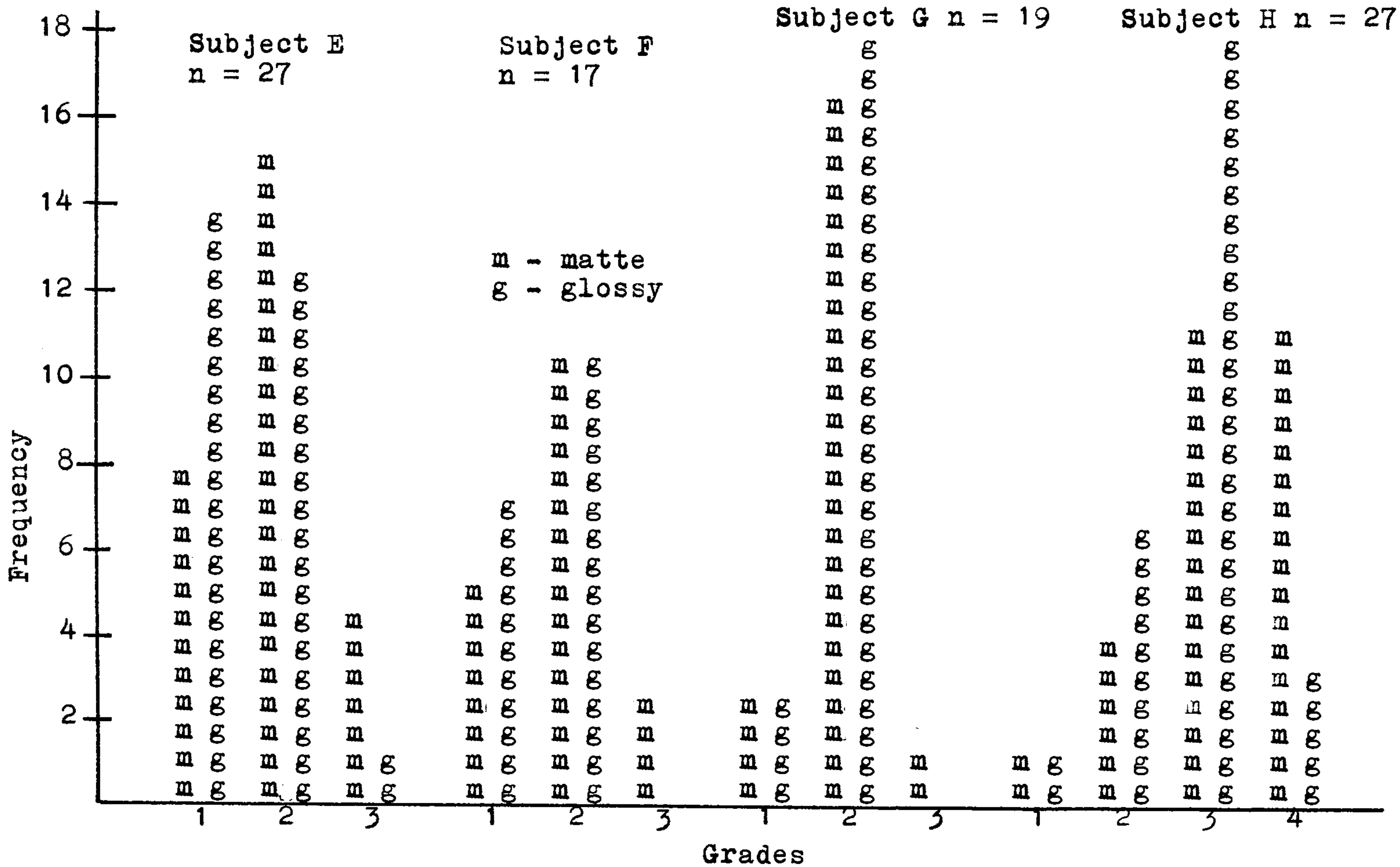

Figure 6. Histograms of the Optimum Grade Number Choice for the Kodabrome Matte and Glossy Surfaces

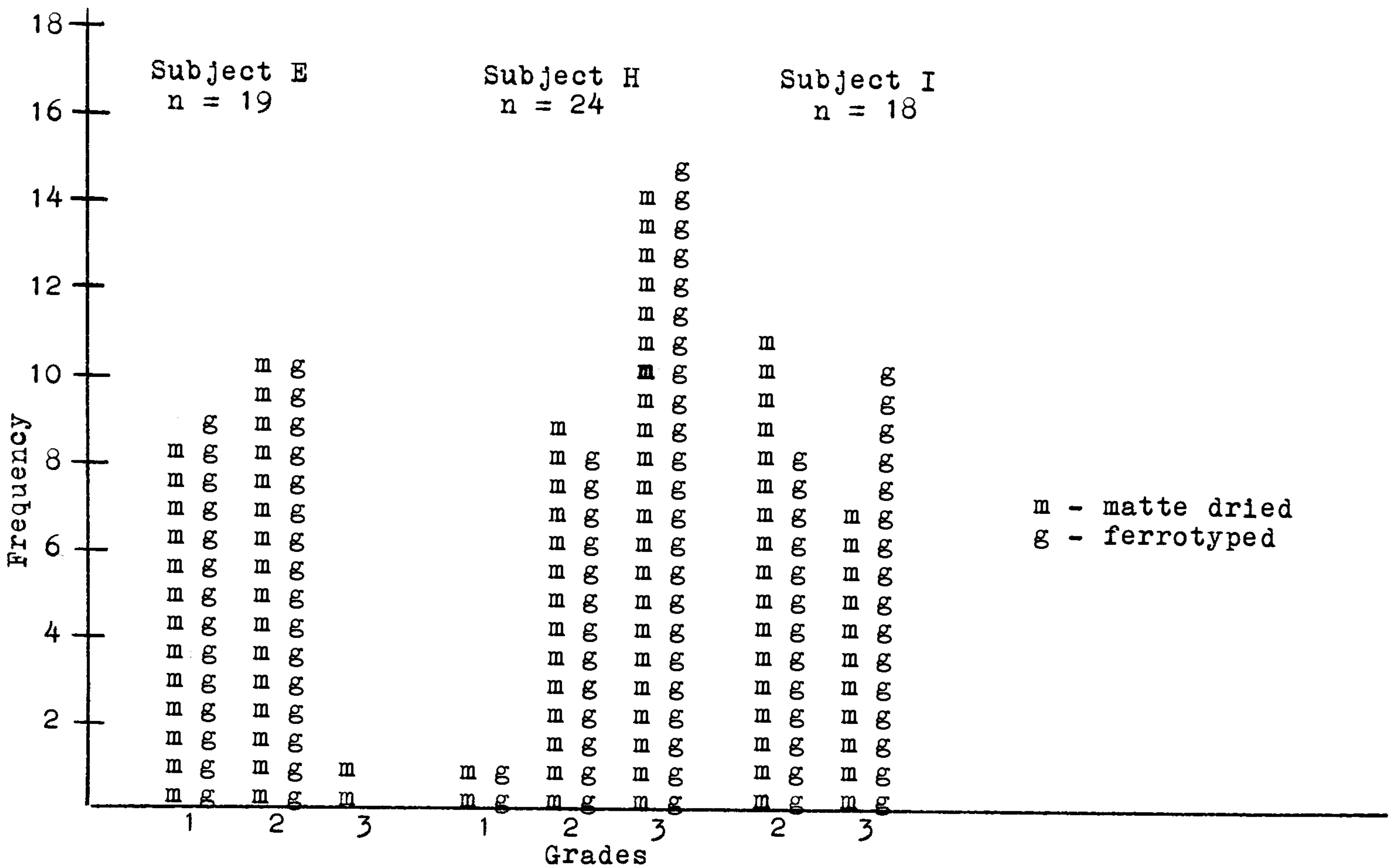

Figure 7. Histograms of the Optimum Grade Number Choice for the Galerie Matte dried and Ferrotyped Paper

Table 11. Mean LER (ANSI 1966) and Variance Values for the Kodabrome II RC Paper

Subject	Mean LER		Variance	
	Matte	Glossy	Matte	Glossy
Barge (A)	0.85	1.04	0.010	0.012
Studio portrait (B)	1.04	1.12	0.006	0.003
Overcast outdoor portrait (C)	0.70	0.80	0.007	0.003
Still life of fruit (D)	0.97	1.18	0.005	0.021
Outdoor shopping center (E)	0.94	1.10	0.013	0.006
Outdoor view of house (F)	0.975	1.09	0.010	0.005
Outdoor portrait of female model (G)	0.90	1.04	0.004	0.002
Still life of glassware (H)	0.74	0.88	0.016	0.014
Outdoor portrait of female model (I)	0.83	0.93	0.004	0.008

mean LER (ANSI 1966) for the glossy Kodabrome paper. This was true of all nine subjects that were used. This was determined by using an alpha value of 0.05 for a one tailed test. The mean LER values were based on the average LER that was selected by the judges for all of the subjects, which were taken from Table 11.

Effective LER Equations

The result of plotting the mean LER (ANSI 1966) values and the LER values from the print comparisons were shown in Figures 8 - 14. Each point that was plotted was labeled with the subject letter for identification. The Dmax that were given represent the average Dmax that was calculated for that particular paper surface.

The lines that were drawn on the graphs corresponded to the mean LER values, to the print comparison LER values, and to a linear one to one line which was used as a reference to indicate what the relationship would be if the Dmax did not have an effect on the LER (ANSI 1966). The linear regression equations that describe the plotted lines were shown in Table 12. All of the equations in Table 12 have correlation coefficients of 0.90 or above except for the equations which related the Dmax of 2.13 to the Dmax of 2.24 for part B, and the equation which related the Dmax of 1.58 to the Dmax of 2.13 when all of the subjects were used for part B (print comparisons). The worst relationship involved the relationship between the Dmax

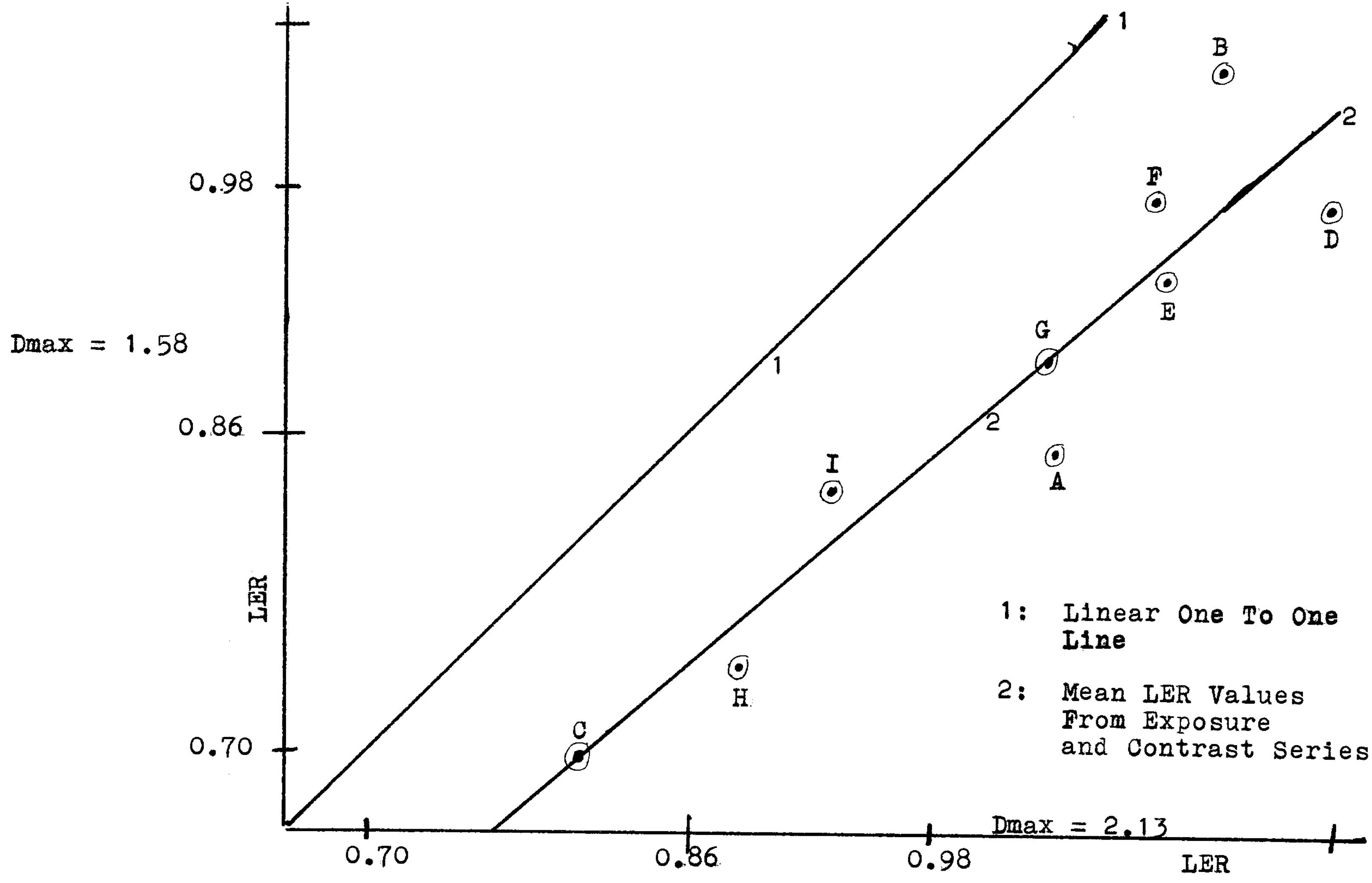

Figure 8. Comparing the LER (ANSI 1966) Values of the Glossy and Matte Kodabrome Paper

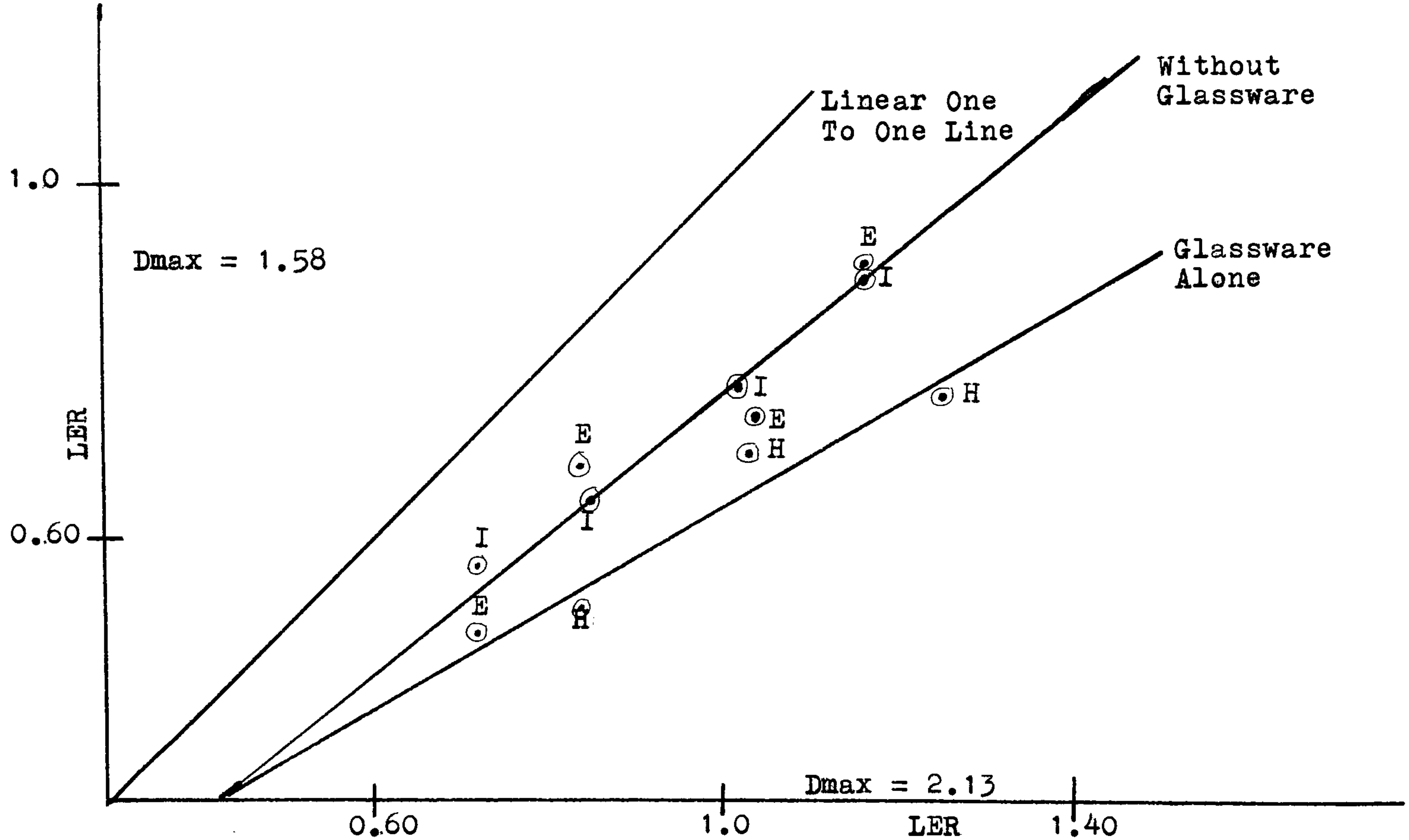

Figure 9. Comparing the LER (ANSI 1966) Values of the Glossy and Matte Kodabrome Paper Using the Print Comparisons

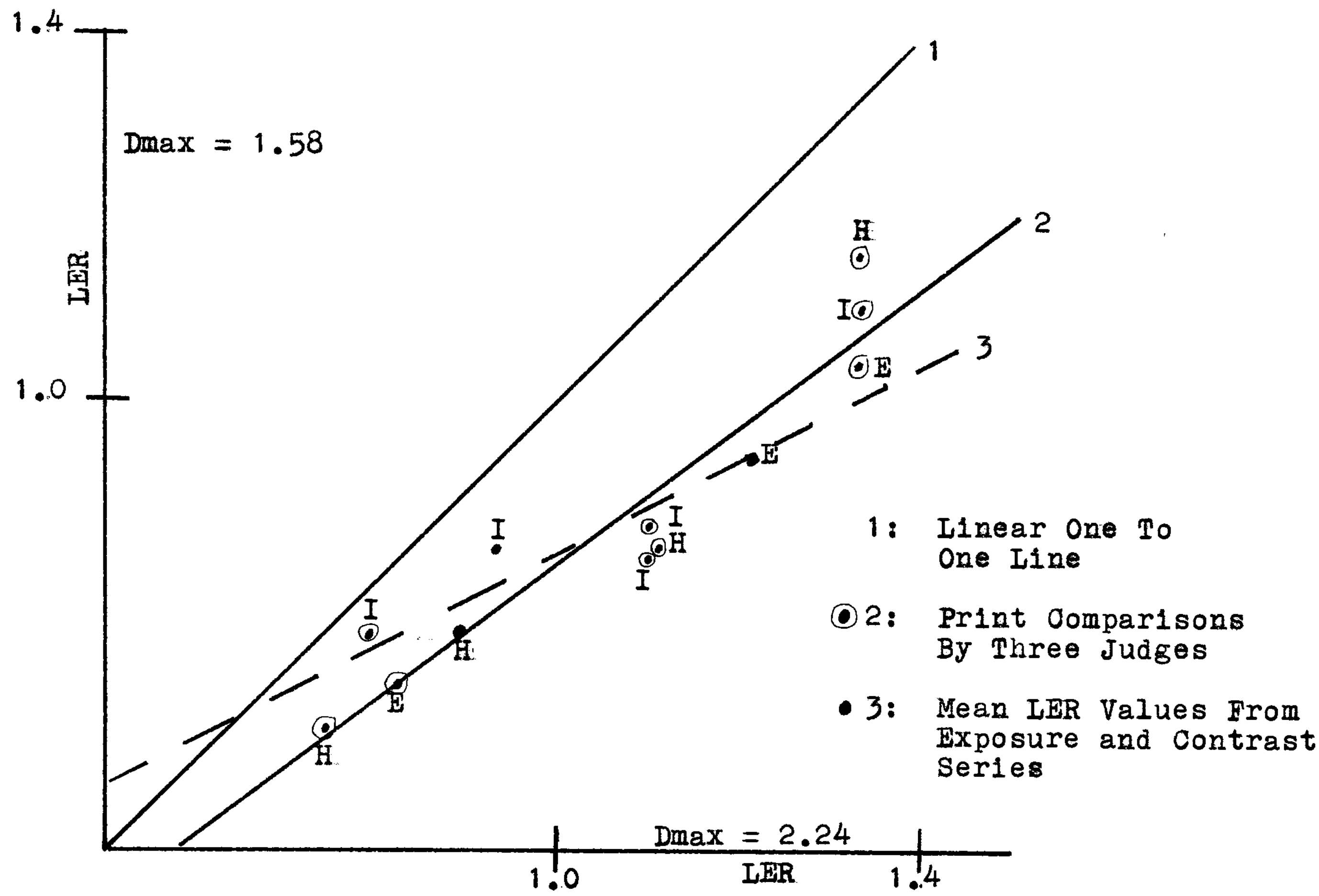

Figure 10. Comparing the LER (ANSI 1966) Values of the Matte Kodabrome Paper to the Ferrotyped Galerie Paper

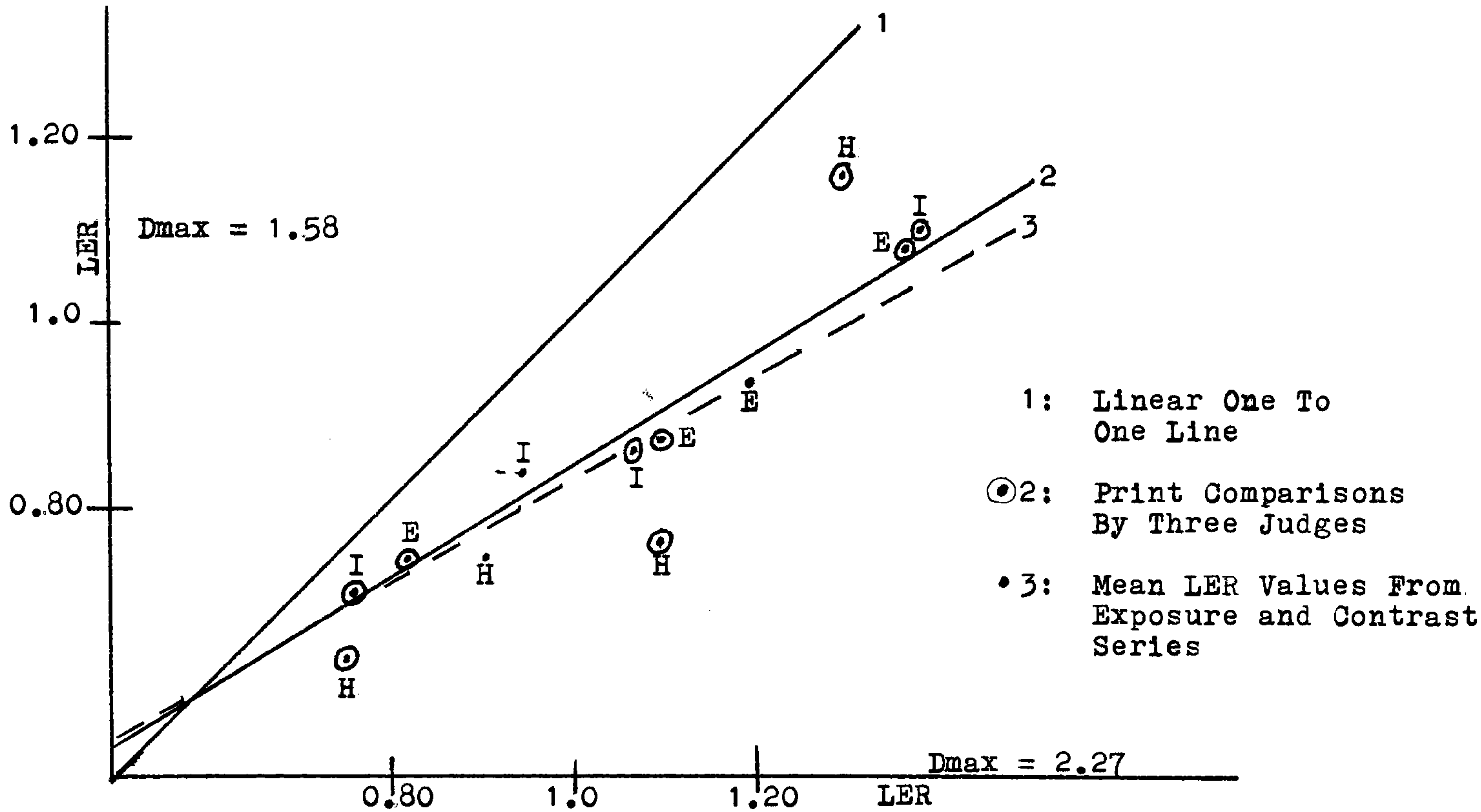

Figure 11. Comparing the LER (ANSI 1966) Values of the Matte Kodabrome Paper to the Matte Dried Galerie Paper

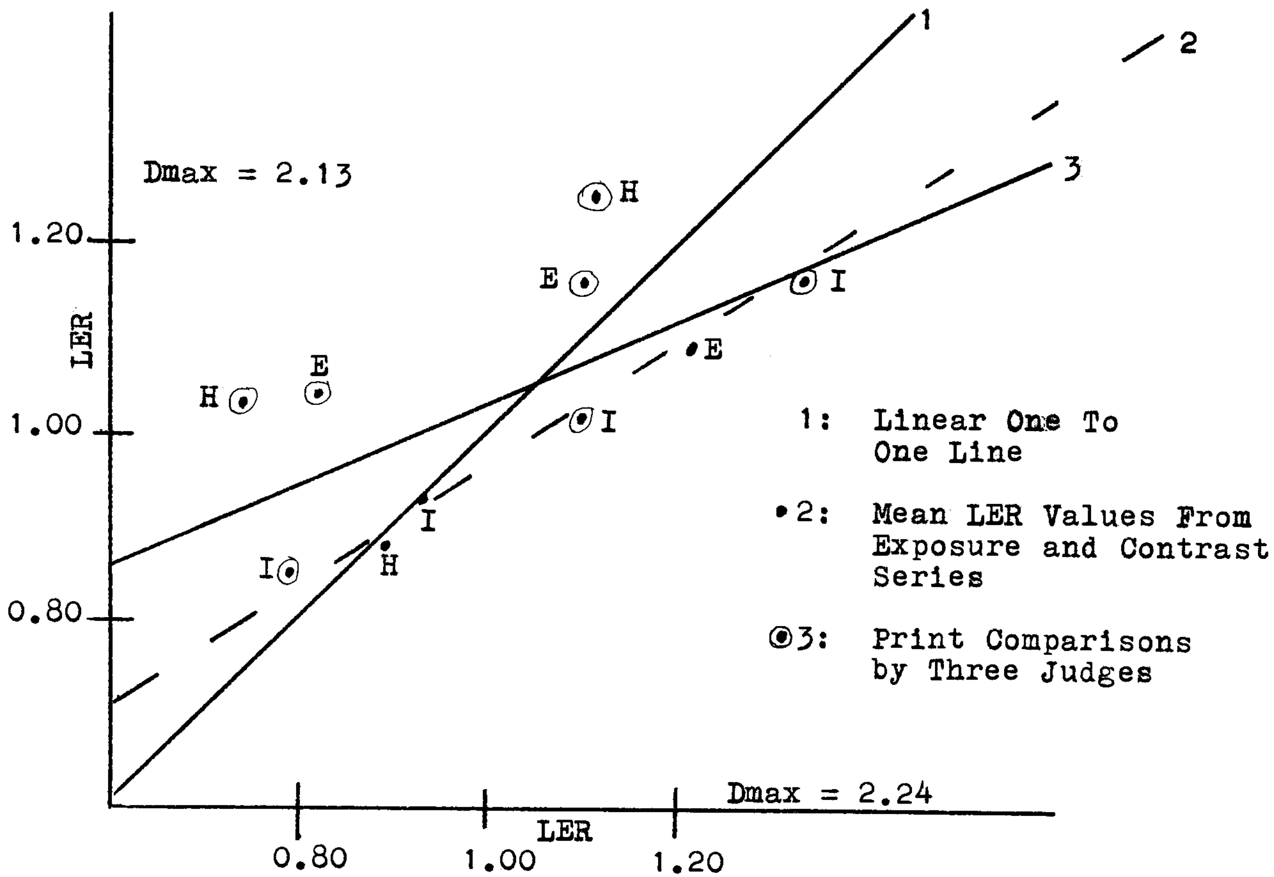

Figure 12. Comparing the LER (ANSI 1966) Values of the Glossy Kodabrome Paper to the Ferrotyped Galerie Paper

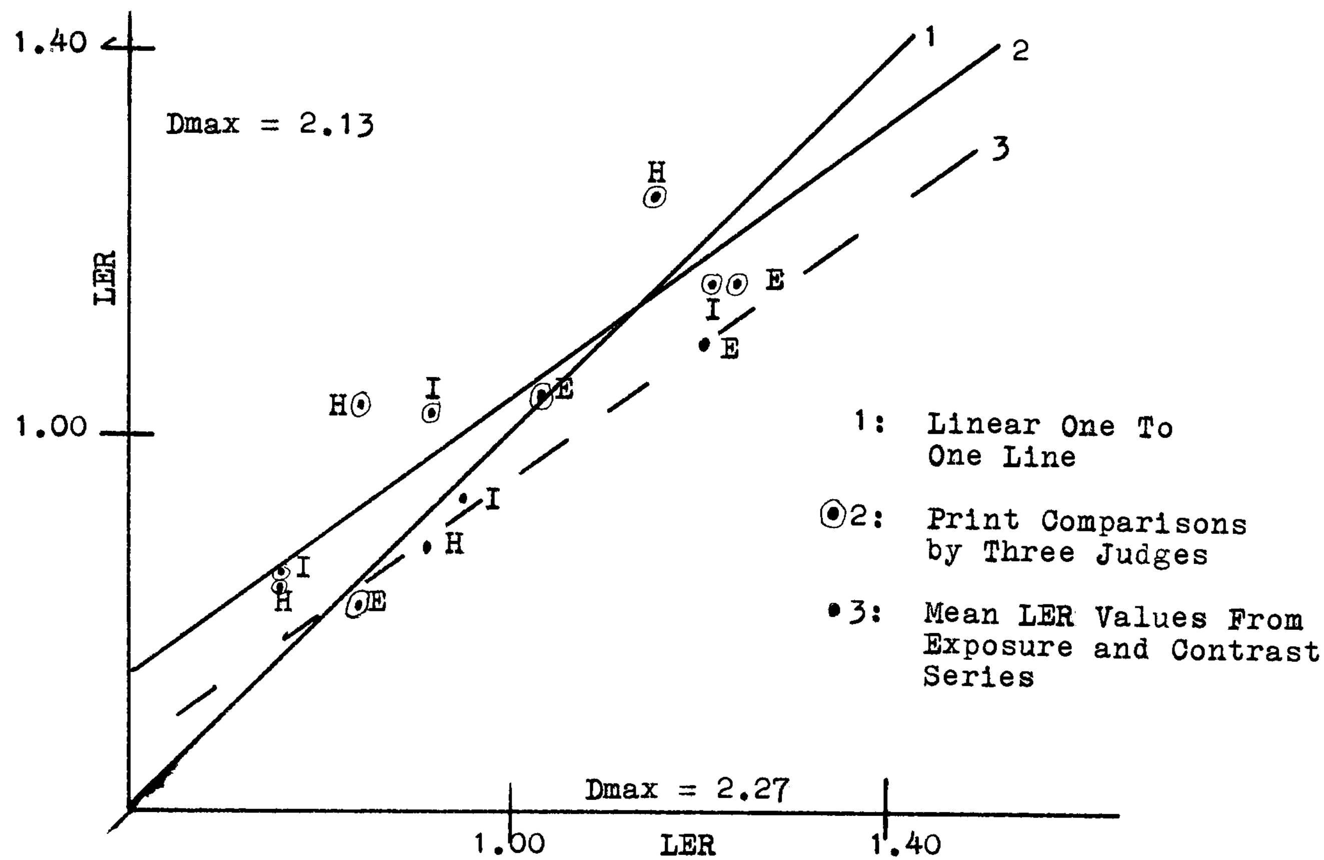

Figure 13. Comparing the LER (ANSI 1966) Values of the Glossy Kodabrome Paper to the Matte Dried Galerie Paper

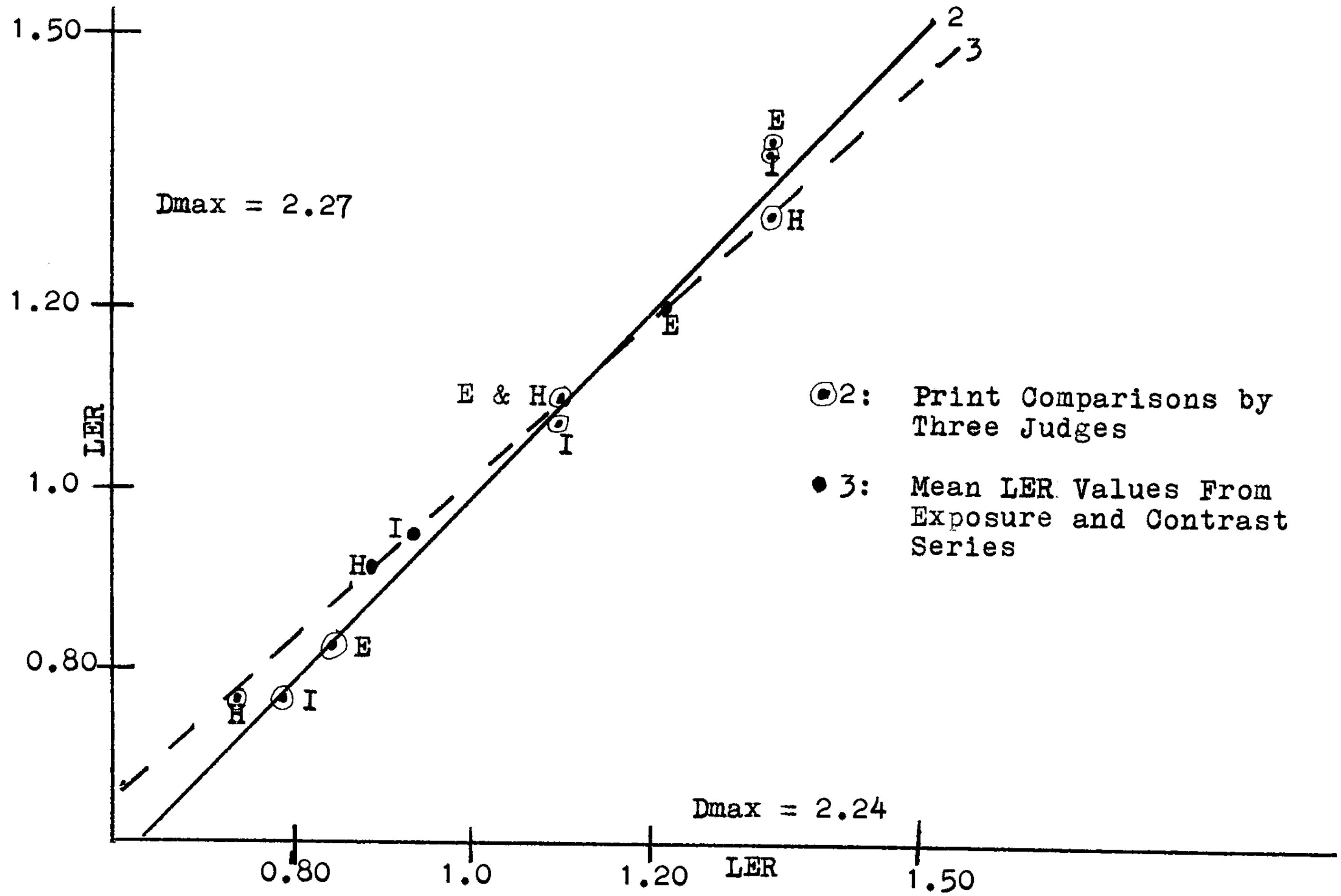

Figure 14. Comparing the LER (ANSI 1966) Values of the Matte Dried and Ferrotyped Galerie Paper

Table 12. Linear Regression Equations Describing LER (ANSI 1966) Relationships Between Papers for Figures 8 - 14.

A. Using the Mean LER (ANSI 1966) Values Calculated From the Selection of the Optimum LER (grade) Values

Figure	Dmax Averages	Equations	Subjects Used
8	1.58 - 2.13	LER(1.58) = (LER(2.13))(0.87)	All 9 subjects
10	1.58 - 2.24	LER(1.58) = (LER(2.24))(0.51) + 0.32	E, H, & I
11	1.58 - 2.27	LER(1.58) = (LER(2.27))(0.57) + 0.25	E, H, & I
12	2.13 - 2.24	LER(2.13) = (LER(2.24))(0.63) + 0.33	E, H, & I
13	2.13 - 2.27	LER(2.13) = (LER(2.27))(0.70) + 0.25	E, H, & I
14	2.27 - 2.24	LER(2.27) = (LER(2.24))(0.90) + 0.12	E, H, & I

B. Using the LER (ANSI 1966) Values From the Three Judges Doing Print Comparisons

Figure	Dmax Averages	Equations	Subjects Used
9	1.58 - 2.13	LER(1.58) = (LER(2.13))(0.65) + 0.07	All 9 subjects
9	1.58 - 2.13	LER(1.58) = (LER(2.13))(0.79) - 0.03	All subjects but H
10	1.58 - 2.24	LER(1.58) = (LER(2.24))(0.74) + 0.08	E, H, & I
11	1.58 - 2.27	LER(1.58) = (LER(2.27))(0.71) + 0.11	E, H, & I

Table 12 (continued)

Figure	Dmax Averages	Equations	Subjects Used
13	2.13 - 2.27	LER(2.13) = (LER(2.27))(0.74) + 0.30	E, H, & I
13	2.13 - 2.27	LER(2.13) = (LER(2.27))(0.71) + 0.30	E & I
12	2.13 - 2.24	LER(2.13) = (LER(2.24))(0.40) + 0.67	E, H, & I
12	2.13 - 2.24	LER(2.13) = (LER(2.24))(0.44) + 0.59	E & I
14	2.27 - 2.24	LER(2.27) = (LER(2.24))(1.05) - 0.06	E, H, & I

of 2.13 and 2.24 when subjects E, H, & I were used. This relationship had a correlation coefficient of only 0.68.

Effective LER equations were made which were based on a Dmax of 1.58 (Kodabrome (matte)) having an effective LER of 1.0 LER (ANSI 1966). This was done using the mean LER (ANSI 1966) values, and using the LER (ANSI 1966) values from the print comparisons and were shown in Table 13. When the Dmax of 2.13 and 1.58 were shown, this was based on using all nine subjects, while the other Dmax were based on using subjects E, H, & I except for the Dmax of 1.58 and 2.24 when using the LER values from doing print comparisons. These Dmax were based on subjects E and I only.

Table 13. Effective LER Equations

I. Using the Mean LER (ANSI 1966) Values Calculated From the Selection of the Optimum LER (grade) Values

Dmax	Effective LER
1.58	1.0 LER (ANSI 1966)
2.13	0.87 LER (ANSI 1966)
2.24	0.51 LER (ANSI 1966) - 0.32
2.27	0.57 LER (ANSI 1966) + 0.25

II. Using the LER (ANSI 1966) Values From the Three Judges Doing Print Comparisons

Dmax	Effective LER
1.58	1.0 LER (ANSI 1966)
2.13	0.79 LER (ANSI 1966) - 0.03
2.24	0.74 LER (ANSI 1966) + 0.08
2.27	0.71 LER (ANSI 1966) + 0.11

DISCUSSION OF RESULTS

When the hypothesis test of variance was applied to all of the subjects, only subject D had a significant variance difference between the glossy and matte surfaces of Kodabrome paper using a two tailed F test with an alpha of 0.05. Table 6 showed that the LER (ANSI 1966) for the glossy #1 Kodabrome paper was 1.31 for subject D. This value was quite different than the other LER values for the glossy #1 paper, which might have been due to the processing of that paper for that subject. This was probably the reason why the variances between the glossy and matte surface paper took place.

Subject H had the highest variance for the matte surface Kodabrome paper, while subject D had the highest variance for the glossy Kodabrome. This was shown in Table 11. Subject D probably had the high variance because the LER (ANSI 1966) was 1.31 for the glossy #1 paper as compared to a LER (ANSI 1966) of only 1.09 for the glossy #2 paper. Subject H was the only subject that was accepted as an optimum print in four different grades for the Kodabrome matte and glossy paper as was shown in Figure 6. The reasons for this high variability were probably due to the side lit lighting of the subject, and the type of subject matter that was chosen.

The hypothesis test for means showed that the maximum density had an effect on the LER (ANSI 1966) using a one tailed t test with an alpha value of 0.05. This was the case for all nine subjects. The mean LER (ANSI 1966) values for the glossy Kodabrome paper were therefore significantly higher than the mean LER values for the matte surface. Therefore, if the Kodabrome matte and glossy surface paper was to be compared in terms of the LER (ANSI 1966), effective LER equations (correction factors) must be used or another LER formula should be established.

The hypothesis test for means was based on the ANSI 1966 LER formula and was not based on the sensitometric log exposure scale as defined by Nelson and Jones in 1948.[14] Therefore, this test has not necessarily disproved Nelson and Jones hypothesis that the same negative will print successfully on the same paper as long as the log exposure scale (LER) was the same regardless of the Dmax.

When five photography instructors were compared with five instructors from the Photo Science and technical photography departments, there was no pattern to the results for all of the nine subjects that were presented to the instructors. However, in many cases it was shown that photography instructors prefer photographs which have higher contrast. This was probably due to the background of the instructors. If more judges had been used, the results of the optimum print selection between the two groups would probably have been more definite.

The selection of optimum prints was done by the faculty and students of the Rochester Institute of Technology. The majority of the judges were from the Pro Photo department. This was done to insure that the judges were experienced and knowledgable in the field of photography, and not people who were amateurs or who were not that familiar with photography.

When the LER (ANSI 1966) of papers were compared in Figures 8 - 14, it was shown that if the Dmax of the papers differed by 0.55 or more, the Dmax did affect the LER (ANSI 1966). This was illustrated when the regression lines for the mean LER values and the print comparisons were different than the linear one to one line, which would indicate that the Dmax did not affect the LER (ANSI 1966). However, when the Dmax that were compared differed by 0.11 or less, the Dmax did not necessarily affect the LER (ANSI 1966). This was shown when the plotted points were on both sides of the linear one to one line. When the Dmax of 2.27 was compared with the Dmax of 2.24 (Figure 14), the relationship was essentially a one to one relationship for both the print comparison line and the mean LER values line. This showed that when the Dmax were nearly the same, the LER (ANSI 1966) of one paper would have about the same

LER (ANSI 1966) as the other paper.

Subject H seemed to be a deviant from the other subjects in Figure 9. This was evident when the correlation coefficient was 0.87 for the print comparison line which involved subjects E, H, & I. The correlation coefficient was 0.97 when the line described only subjects E & I. This again showed that subject H seemed to be different from the other subjects due to the subject matter and lighting set up.

The most unusual graph was Figure 12 when the glossy Kodabrome paper was compared with the Galerie (ferrotyped) paper for the print comparison line. The correlation coefficient of this line was only 0.68 when subjects E, H, & I were taken into account. There were probably two reasons for this low correlation: 1. RC glossy paper was being compared to ferrotyped fiber based paper. 2. Only three judges were doing the print comparisons. The correlation coefficient for the mean LER (ANSI 1966) value line for Figure 12 was 0.991 which involved using 18 to 27 judges for each subject. The range of correlation coefficients was 0.93 to 0.99 for the mean LER values of Figures 8 - 14 and 0.68 - 0.99 for the print comparison lines.

Table 12 indicates all of the linear regression equations for Figures 8 - 14. In certain instances it might be better to describe the relationship between one Dmax and another by combining some of the equations that were listed in Table 12. For instance, the equation relating the Dmax of 1.58 and 2.24 for the mean LER (ANSI 1966) values could be combined with the equation relating the Dmax of 1.58 and 2.27 to form one equation since these equations were similiar and the difference in Dmax between 2.24 and 2.27 was not very large. By combining these two equations, a relationship between a Dmax of 1.58 and a range of Dmax from 2.24 to 2.27 could be described. The instances in which two equations could be combined, such as the example given, were shown in Table 12 by only single spacing between the desired equations.

Upon examination of the two sets of effective LER equations of Table 13, a noticeable difference was shown between using the mean LER (ANSI 1966) values and the print comparison values. These two sets of equations are different because they were determined from two different types of conditions as described on pages 24 - 26. The question then becomes which set of equations should be used? The correlation coefficients for the effective LER equations were 0.93 - 0.94 for the mean LER (ANSI 1966) values and 0.87 - 0.93 for the print comparisons. However, the print comparisons were only based on three judges as compared to 18 - 27 judges for the mean LER values. Therefore, in order to determine which set of effective LER equations should be used, it would first be necessary to have more people judge the prints by matching the quality of prints of one surface with the quality of prints of another surface so that more judges would be involved with print comparisons.

CONCLUSIONS

1. The Dmax has an effect on the LER (ANSI 1966).

2. Effective LER equations need to be applied to the LER (ANSI 1966) values or a new LER formula needs to be used if the objective is to have an ANSI standard which allows the comparison of papers with different Dmax.

FUTURE WORK

1. A larger number of Dmax values should be tested so that papers with other Dmax values can be compared in terms of the effective LER.
2. Additional testing of the Dmax and LER (ANSI 1966) should involve papers that have smaller increments between LER (ANSI 1966) values for various grades. This will help to improve the accuracy of the effective LER equations.
3. The correlation between the negative density range and the effective LER value should be explored.
4. People who are not very familiar with photography should be judges in order to see if the results depend on the type of judge that views the prints.
5. Another interesting study might be to under and over expose film and then under and over develop film that is being used to take pictures of subjects. A comparison could then be made between normal processing and exposure and abnormal processing and exposure to see what the differences would be in the effective LER equations.
6. More testing could be done in order to determine which method is the most effective for determining the effective LER equations. An example would be to compare the equations based on the mean LER (ANSI 1966) values and the print comparison values.

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[1] ANSI "Sensitometry of Photographic Papers,"ANSI PH2.2-1966 R(1972), p.14.

[2] Ibid

[3] Ibid

[4] Ibid., pp.8-9.

[5] Ibid

[6] L.A. Jones and C.N. Nelson, "The Control of Photographic Printing by Measured Characteristics of the Negative,"J. Opt. Am. 32, pp. 599-606 (1942).

[7] L.A. Jones and C.N. Nelson, "Control of Photographic Printing: Improvement in Terminology and Further Analysis of Results,"J. Opt. Soc. Am. 38, pp. 899-909 (1948).

[8] L.A. Jones and C.N. Nelson, "Control of Photographic Printing: Improvement in Terminology and Further Analysis of Results,"p.910.

[9] ANSI PH 2-46 Subcommittee, "Internal Subcommittee Memo," 2/80.

[10] L.A. Jones and C.N. Belson, "Control of Photographic Printing: Improvement in Terminology and Further Analysis of Results," p.912.

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[11] ANSI, "Sensitometry of Photographic Papers," pp. 8-9.

[12] L.A. Jones and C.N. Nelson, "Control of Photographic Printing: Improvement in Terminology and Further Analysis of Results," p.900

[13] American Society for Testing and Materials, Manual on Sensory Testing Methods, (Philadelphia: American Society for Testing and Materials, 1968), p.64.

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APPENDIX A

ANSI 1966 PH2.2 Standard for LER and Grade Numbers

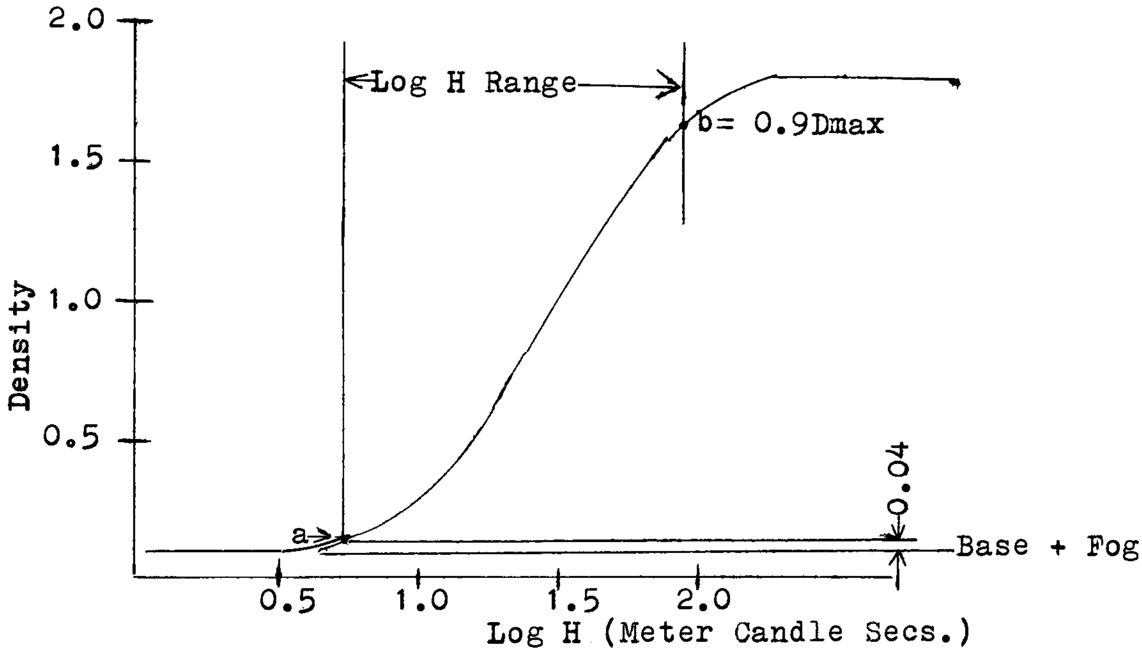

Figure 15.. Log Exposure Range of Paper From the 1966 ANSI PH2.2 Standard

Figure 15 shows how the log exposure range is defined by the 1966 ANSI formula. The LER formula equals Log H_b - Log H_a, where point b corresponds to 0.9 Dmax and point a corresponds to 0.04 + base + fog.

APPENDIX A (continued)

Table 14. Relation Between Log Exposure Range and "Contrast"

Contrast	Log Exposure Range
Very Soft	1.40 - 1.70
Soft	1.15 - 1.40
Medium	0.95 - 1.15
Hard	0.80 - 0.95
Very Hard	0.65 - 0.80
Extra Hard	0.50 - 0.65

Table 14 shows how the log exposure range of a paper is related to contrast which is related to the grade number of a paper. For example, a paper with a LER of 1.70 would be rated very soft, which would correspond to a low grade number designation.

APPENDIX B

Sensitometric Exposure Scale as Defined by Nelson and Jones

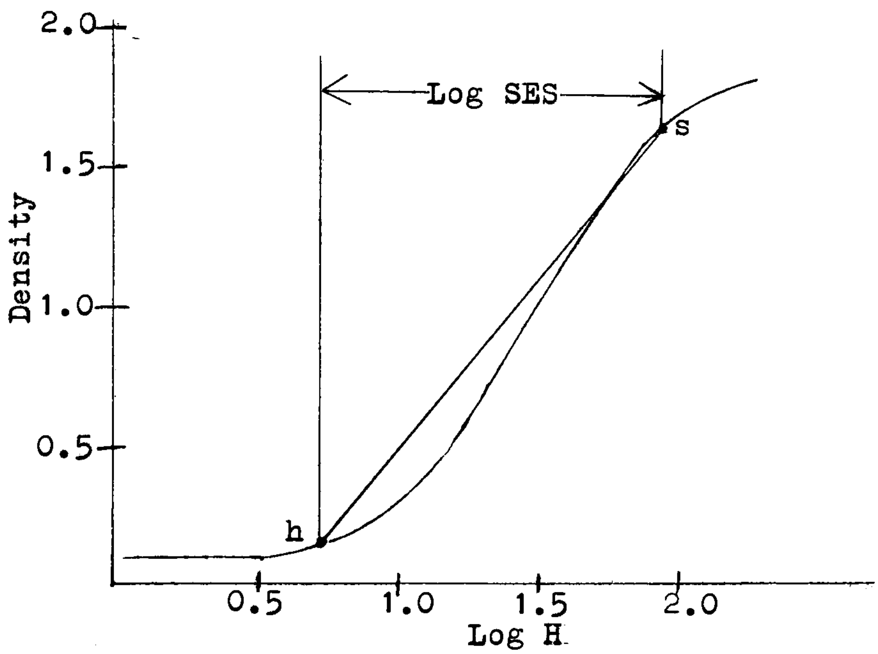

Figure 16. Sensitometric Exposure Scale (SES)

Figure 16 shows how the sensitometric exposure scale is defined by Nelson and Jones. The line that connects h and s is the average slope of the useful part of the paper curve and is known as $\bar{G}$.. Point h corresponds to a gradient value of 0.1 $\bar{G}$ on the toe, while point s corresponds to a gradient value of 1.0 $\bar{G}$ on the shoulder of the curve.

APPENDIX C

Sample Calculations for the Hypothesis Test for Variances and Means

Subject: Subject A

Step #1: Calculate sample variances for the Kodabrome matte and glossy surfaces.

Glossy Surface

Grade	LER	Freq.	(LER)(Freq)	$(LER)^2(Freq)$
1	1.17	7	8.19	9.58
2	1.04	15	15.60	16.22
3	0.84	5	4.2	3.53
Totals:		27	27.99	29.33

$$\text{Variance} = \frac{(27)(29.33) - (27.99)^2}{(27)(26)} = 0.012$$

Matte Surface

Grade	LER	Freq.	(LER)(Freq)	$(LER)^2(Freq)$
1	1.04	1	1.04	1.08
2	0.93	15	13.95	12.97
3	0.73	11	8.03	5.86
Totals:		27	23.02	19.9

$$\text{Variance} = \frac{(27)(19.9) - (23.02)^2}{(27)(26)} = 0.010$$

Please note that the LER values are based on the 1966 ANSI LER formula.

APPENDIX C (continued)

Step #2: Compare Variances Using the Hypothesis Test for Variance

Hypothesis: H_0: S^2(glossy) = S^2(matte)

H_1: S^2(glossy) $\neq$ S^2(matte)

The null hypothesis is that there is no significant difference in the variances of the matte and glossy surfaces. The alternative hypothesis is that a significant difference exists.

Test statistic: $F = \frac{0.012}{0.010} = 1.15$

Critical Value of the F Distribution: $F_{26,26,0.025} = 2.20$

Level of Significance: Alpha = 0.05

Conclusion: Since the F ratio (1.15) is less than the table value (2.20), we accept the null hypothesis that the variances are not significantly different.

Step 3: Calculate the mean LER for each surface

Mean LER (glossy) = $\frac{27.99}{27} = 1.04$

Mean LER (matte) = $\frac{23.02}{27} = 0.85$

APPENDIX C (continued)

Step #4: Pool the variances

$$s_p^2 = \frac{(26)(0.012) + (26)(0.010)}{52} = 0.0113 \quad S_p = 0.1063$$

Step #5: Compare the means of both surfaces using the hypothesis test for means.

Hypotheses: H_0: Mean LER (glossy) = Mean LER (matte)

H_1: Mean LER (glossy) > Mean LER (matte)

Test Statistic: $$t_{(52)} = \frac{1.04 - 0.85}{(0.1063)\sqrt{1/27 + 1/27}} = 6.48$$

Critical value of the Student's t Distribution:

$t_{52,0.05} = 1.68$

Level of Significance: Alpha = 0.05

Conclusion: Since the test statistic (6.48) is greater than the Student t value (1.68), we reject the null hypothesis, and conclude that the mean LER values are significantly different.

APPENDIX D

Paper Emulsion Numbers

I. Kodabrome II RC Paper

Surface	Grade	Emulsion Number
Matte	1	69714-11125LVP
Matte	1	75201-11116SLP
Matte	2	87201-73053TUR
Matte	3	82308-11095SOR
Matte	4	78401-71073RPR
Matte	5	73501-11201RLP
Glossy	1	84402-11193RDR
Glossy	2	84801-11031MDR
Glossy	3	84701-71017UDR
Glossy	4	81408-11046SRR
Glossy	5	81501-11209RRR

II. Galerie Paper

Surface	Grade	Emulsion Number
Glossy	1	90A-106
Glossy	2	94C-102
Glossy	3	89B309

APPENDIX E

Sample Prints of Subjects

Figure 17. Subject A

Figure 18. Subject B

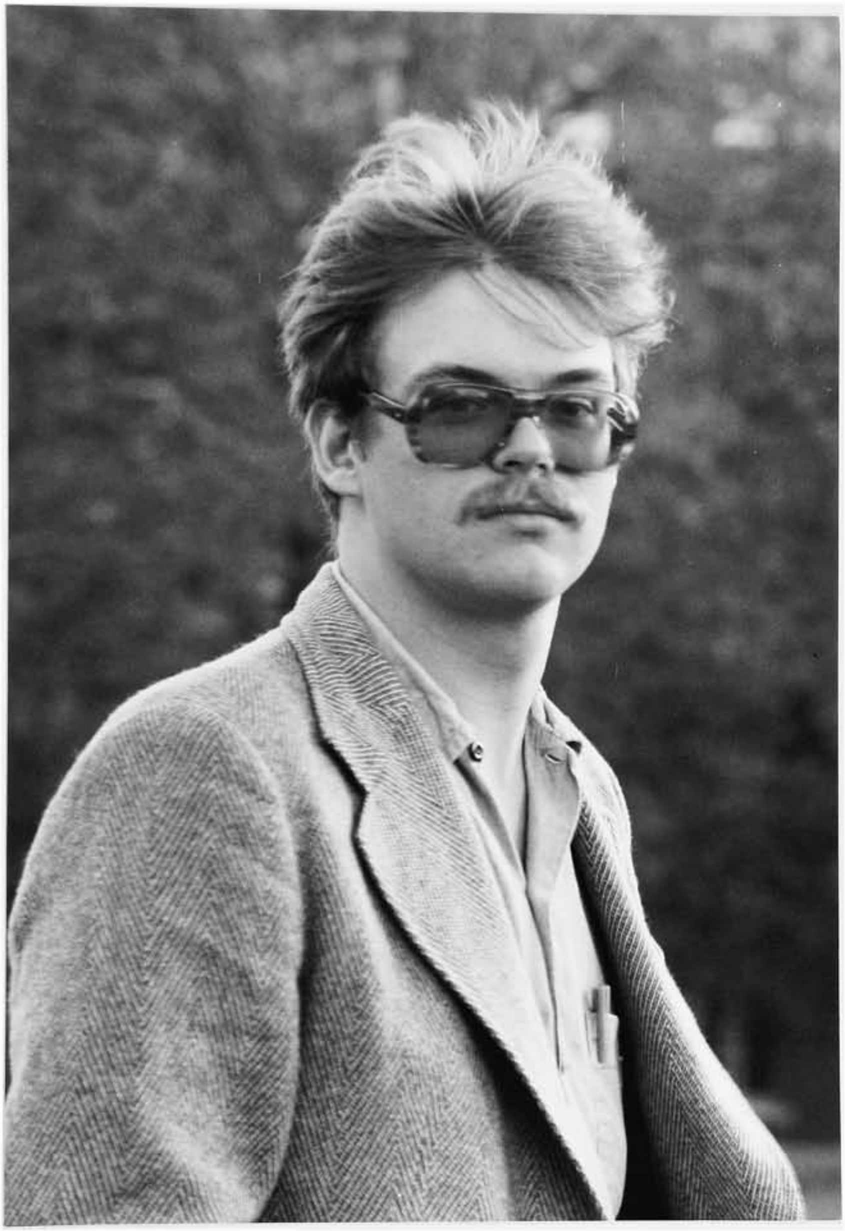

Figure 19. Subject C

Figure 20. Subject D

Figure 21. Subject E

Figure 22. Subject F

Figure 23. Subject G

Figure 24. Subject H

Figure 25. Subject I