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Investigation to establish acceptability tolerance limits in various regions of the cielab color space

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INVESTIGATION TO ESTABLISH ACCEPTABILITY TOLERANCE LIMITS IN VARIOUS REGIONS OF THE CIELAB COLOR SPACE

By

Barry Yuhas

1980

This research report is respectfully submitted to the Department of Chemical Engineering of Lehigh University in partial fulfillment of the requirement for the degree of Master of Science.

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Approved and accepted as a research report in partial fulfillment of the requirements for the degree of Master of Science,

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Date

Eugene M. Allen
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Accepted

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Date

Contents

General Introduction

In recent years it has been of great concern to the United States Army to find another way of accepting shipments of textiles, other than the visual method previously used. This visual method has led to problems due to disagreements between inspectors for the Army and the textile manufacturers.

The objective of this investigation was to develop a new method of finding acceptance limits by use of a numerical method involving instrumental measurements on submitted samples. The part of this investigation presented here includes the instrumental measurements on submitted samples, picking of sample pairs for blue and the visual test used on the inspectors. The results of the visual test will be used to find the acceptance limits.

I. Determination of CIELAB Coordinates

A. Introduction and Equipment

The CIELAB color space was used in this investigation. This color space is a Cartesian coordinate system, consisting of three mutually perpendicular axes. One axis is the lightness (L^*) axis and extends from black (minus) to white (plus). The two remaining axes are the yellow-blue axis (b^* axis) and the red-green axis (a^* axis) which are perpendicular to the lightness axis (L^* axis) and perpendicular to each other.

Measurements on all submitted samples, 200 to 300 samples for each color studied, were obtained on a Diano-Hardy II spectrophotometer. These measurements were the reflectances of each submitted sample between 400 and 700 nanometers, taken in 20 nanometer intervals. These reflectance values were obtained with use of a 10 degree-diffuse geometry. A tungsten lamp was used to obtain the reflectances. These reflectances were used to calculate the L^*, a^* and b^* values for each sample. These values were calculated by use of an ACS 2000 color computer with programs on storage discs. The L^*, a^* and b^* values were obtained for illuminant D75, 1931 Standard Observer.

After the CIELAB values for each sample had been obtained a data file was created, which contained the L^*, a^* and b^* values along with the corresponding sample number. A separate file was created for each color studied. Appendix A gives a typical page from a data file listing.

B. Procedure

The first step was to calibrate the equipment using a white standard, Barium Sulfate ($Ba\ SO_4$). After correct reflectances were obtained from a standard and sample, both of Barium Sulfate, the next step was to obtain the reflectance factor for the color standard of interest. The next step was to use the color standard as the standard in the beam marked for standards (reference beam) and test each submitted sample in the beam marked for samples (sample beam). Two sets of reflectances were obtained for each sample and their average was used in the calculations. The programs stored on the discs were used to calculate the tristimulus values, chromaticity coordinates, color differences and CIELAB coordinates for each sample. This procedure was repeated for each color studied.

III. Use of Sample Pairs for Finding Tolerances

A. Introduction

The standard and limit samples, of the color studied, should form a three-dimensional figure in the CIELAB color space. This figure will be set up such that all the points in the interior represent an acceptance and all that lie outside represent a rejection. This figure is an ellipsoid with its axis oriented in the lightness, hue and chroma directions. The acceptability tolerances that correspond to this ellipsoid shall be determined from the pass or fail responses, of inspectors, to various sample pairs which differ in only lightness, hue and chroma.

It can be recognized that six tolerances will be found for each color studied, one tolerance in each of the plus and minus directions of the three axes. To find each tolerance a series of four sample pairs were used.

B. Visual Test Method

In each of the six directions studied, four color differences in increasing amounts were studied. Thus 24 color differences were used for each color. Each color difference is represented by a sample pair in which one sample is designated as the standard and the other is designated as the sample to be judged against the standard. These color differences were set up such that the largest difference would be deemed unacceptable and the smallest difference would be deemed acceptable as a match. The desired tolerance limit will lie somewhere in the range of the four differences.

Each of the color differences, sample pairs, will be shown to an inspector ten times in random order. This was done so that the inspector did not realize that the same difference is shown repeatedly. Each time a sample pair was shown, the inspector was asked if he or she would accept or reject the sample against the standard. Thus 240 judgements were made by each inspector for every color studied. A special sample holder, lazy susan, was used during the judging so that the inspector could not recognize which sample pair was presented for judgment.

C. Procedure

1. Finding Sample Pairs

To find the sample pairs needed for use in the visual test a set of several hundred sample submissions was used for each color. These samples lie closely all around the standard and should make it possible to find the needed sample pairs amoungst the set of samples.

It would be very difficult to find a single standard to be used in all the sample pairs. It is easier to use a series of standards in the pairs with which corresponding samples can be used to represent the required color difference.

The following procedure was used to determine the sample pairs:

The data file was rearranged such that the listing was in increasing numerical order of sample identification. This rearrangement was performed by the computer program presented in Appendix B supplied by Dr. Eugene Allen. The next step was to enter the rearranged data file into a program supplied by Dr. Eugene Allen see Appendix C), to find all the possible sample pairs obtainable from the entire et of sample submissions.

The program in Appendix C considers each sample as a standard for which a subset of samples are found. These samples all lie on one of the six lines, previously mentioned, extending outward from that standard. The program prints out, for each sample submission considered individually as a standard, the subset along with the corresponding color difference between each sample in the subset and the standard. From the output it was easy to find pairs of samples in which the sample differs from the standard in each of the six directions, with four color differences in each direction. It must be remembered that the standard varies with each pair and that each pair represents a specific color difference in either hue, chroma, or lightness. This procedure was carried out by myself for one of the colors studied, blue, and Dr. Allen performed the sample selection on all the other colors studied. Table I shows the sample pair selection for blue. A full description of how the program, in Appendix C, works can be found in the first reference.

2. Using Sample Pairs

The number of sample pairs actually used for each shade was less than 24, needed to represent the six directions with four color differences in each direction. This is due to the fact that in many cases the same pair was used for a minus difference and also for a plus difference. To further explain this refer to page 19 of the first reference.

A computer program, supplied by Dr. Eugene Allen, was used to randomize the order of sample pair presentation for each shade. The program randomized the presentation of 24 sample pairs, with each pair being presented ten times; thus the listing was composed of 240 total presentations. After the listing was obtained the visual test was performed on the shade and the results were recorded. The randomizing program used is given in Appendix D.

This procedure was used on six inspectors, three from civil service (Bill, Moe and Carol) and three from textile manufacturers (Jim, Charlie and Robie).

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Table I

Sample Pair Selection Results For Blue

	Delta E	Standard	Sample
Plus Lightness	0.50	681	984
	1.00	714	644
	1.50	5000	5327
	2.01	1000	5310
Minus Lightness	0.50	984	681
	1.00	644	714
	1.50	5327	5000
	2.01	5310	1000
Plus Chroma	0.36	1001	8444
	0.69	7294	7426
	1.07	7291	8443
	1.42	7052	7000
Minus Chroma	0.36	8444	1001
	0.69	7426	7294
	1.07	8443	7291
	1.42	7000	7052
Plus Hue	0.18	709	7023
	0.38	847	979
	0.57	866	650
	0.75	006	837
Minus Hue	0.18	7023	709
	0.38	979	847
	0.57	650	866
	0.75	837	006

These six inspected all three shades while a seventh inspector (Linda), recently entered into civil service and previously from textile manufacturing, only inspected the pairs from the blue shade.

For this visual test procedure, illuminant D75 was used by all inspectors except Jim and Robie. Jim and Robie used a cool white fluorescent illuminant due to the fact that a D75 illuminant was unavailable. During this procedure a neutral gray background was used by all inspectors, except for inspector Robie. Inspector Robie used a very light tan background due to the unavailability of neutral gray. All inspectors made judgements looking at the face of the material and overlaped the sample over the standard.

D. Results

The results of the visual test were recorded and tabulated. These results can be seen in Tables II, III, and IV. In these tables the leftmost column shows the total CIELAB color difference (Delta E) given for each pair. In the columns to the right the percentage of acceptance judgements are shown for each inspector.

It can be seen that in most cases the expected outcome, the percentage of pass judgements decreasing with increasing color difference, occured. Occassionally the opposite of the expected outcome occured. Despite this the results of the tests agreed with what was expected.

IV. Use of the Visual Test Results

From the data in Tables II, III, and IV the color difference corresponding to a 50% acceptance rate must be calculated. This is done by use of a logistic function, see reference two. The 50% acceptance rates were found for each color by using a computer program written by Dr. Eugene Allen. This was then considered the accepted tolerances. This final tolerance evaluation was done by Dr. Allen.

Table II

Visual Results For Olive Green

	Delta E	% Pass (Bill)	% Pass (Moe)	% Pass (Carol)	% Pass (Jim)	% Pass (Charlie)	% Pass (Robie)
Plus Lightness	0.60	100	90	100	100	100	100
	1.17	70	100	100	100	90	100
	1.82	30	10	70	0	30	40
	2.29	50	40	90	0	0	90
Minus Lightness	0.60	100	100	100	100	100	100
	1.17	100	100	100	100	90	100
	1.82	100	10	100	0	20	60
	2.29	90	40	50	10	0	90
Plus Chroma	0.40	100	100	100	100	100	100
	0.80	40	50	70	90	90	100
	1.13	20	80	90	50	40	100
	1.52	20	40	70	50	30	30
Minus Chroma	0.40	100	100	100	100	100	100
	0.80	100	50	80	40	60	100
	1.13	100	70	80	100	20	70
	1.52	100	20	40	20	10	10
Plus Hue	0.40	100	70	100	80	100	100
	0.77	70	0	40	0	0	70
	1.17	10	0	0	0	0	10
	1.32	0	0	0	0	0	0
Minus Hue	0.40	40	90	90	100	100	100
	0.77	20	0	0	0	0	10
	1.17	0	0	0	0	0	0
	1.45	0	0	0	0	0	0

Table III

Visual Results for Tan

	Delta E	% Pass (Bill)	% Pass (Moe)	% Pass (Carol)	% Pass (Jim)	% Pass (Charlie)	% Pass (Robie)
Plus Lightness	0.66	60	100	100	100	100	100
	1.32	30	50	20	20	100	100
	1.95	20	0	10	0	100	100
	2.65	0	0	0	0	40	30
Minus Lightness	0.66	100	100	100	100	100	100
	1.32	50	20	30	0	90	100
	1.95	30	70	10	0	100	100
	2.65	10	0	0	0	40	90
Plus Chroma	0.50	80	100	80	100	100	100
	0.92	80	40	80	0	90	100
	1.33	10	0	20	100	100	80
	1.92	10	0	10	0	100	100
Minus Chroma	0.50	90	100	100	100	100	100
	0.92	20	20	30	0	100	100
	1.33	0	10	0	70	100	100
	1.92	0	0	0	0	50	90
Plus Hue	0.25	40	70	60	100	100	100
	0.47	40	60	30	90	90	100
	0.69	0	0	0	0	20	100
	1.01	0	0	0	0	0	100
Minus Hue	0.25	50	70	60	100	100	10
	0.48	10	0	70	100	90	100
	0.69	0	0	10	10	10	20
	1.01	0	0	0	0	0	100

Table IV

Visual Results For Dark Blue

	Delta A	% Pass (Bill)	% Pass (Moe)	% Pass (Carol)	% Pass (Jim)	% Pass (Charlie)	% Pass (Robie)	% Pass (Linda)
Plus Lightness	0.50	50	100	60	100	100	100	90
	1.00	30	100	10	10	100	100	90
	1.50	0	10	0	10	0	100	20
	2.01	0	0	0	0	0	10	10
Minus Lightness	0.50	90	100	70	100	90	100	100
	1.00	70	80	10	10	90	100	100
	1.50	10	20	0	0	0	100	60
	2.01	0	0	0	0	0	0	10
Plus Chroma	0.36	70	90	80	10	100	100	80
	0.69	20	80	80	100	100	100	100
	1.07	0	0	10	0	0	100	10
	1.42	20	70	40	0	60	100	40
Minus Chroma	0.36	80	100	40	50	100	100	100
	0.69	30	90	80	100	100	100	90
	1.07	10	100	10	10	0	100	0
	1.42	30	80	10	0	50	100	100
Plus Hue	0.18	70	100	100	90	100	100	100
	0.38	80	100	90	100	100	100	100
	0.57	60	100	80	100	100	100	90
	0.75	50	90	0	0	0	100	100
Minus Hue	0.18	70	100	80	100	100	90	100
	0.38	50	90	90	100	100	100	90
	0.57	100	100	100	100	100	100	100
	0.75	60	10	0	10	10	80	30

IV. Conclusions

The methods of selecting samples for inspection and presenting samples to inspectors seem to be dependable and worthy of future use. Some of the unexpected results can be attributed to the use of a different illuminant, other than D75, and the use of a non-gray background by inspector Robie.

It is suggested that the same procedure be used for sample selection in the future. It is strongly suggested that inspectors be required to use a neutral gray background and the same illuminant, D75, as that from which the CIELAB coordinates were calculated.

VI. References

1. Dr. E. M. Allen and Barry Yuhas, "Performing Laboratory Investigations to Define Acceptability Tolerance Ranges in Various Regions of Color Space", Technical Report to United States Army, Agreement #DAAK60-78-C-0084.
2. J. Berkson, "Application of the Logistic Function to Bio-Assay", Am. Stat. Assn. J. 39, pp. 357-305 (1944).

Appendix A

Typical Page of a Data File

100	0000	22.90	0.40	-11.49
110	0002	22.18	-0.06	-10.79
120	0003	23.09	0.05	-11.48
130	0004	22.53	0.23	-10.89
140	0005	23.56	-0.03	-11.16
150	0006	22.70	-0.25	-11.25
160	0007	22.34	-0.16	-10.92
170	0001	20.93	0.16	-10.81
180	0009	22.85	0.13	-11.12
190	7613	22.17	-0.60	-11.67
200	7614	22.36	-0.76	-11.64
210	7618	22.43	-0.71	-11.54
220	7607	22.51	-0.76	-11.61
230	7442	21.71	-0.64	-11.48
240	7462	21.56	-0.45	-11.18
250	4408	23.09	-0.08	-10.97
260	7428	21.75	-0.22	-11.25
270	7426	21.75	-0.30	-11.19
280	5310	23.67	-0.23	-11.02
290	5327	23.43	-0.27	-10.91
300	8365	23.07	-0.13	-10.90
310	7409	21.56	-0.40	-11.30
320	7408	21.46	-0.39	-11.35
330	7432	21.84	-0.53	-10.63
340	7410	21.65	-0.21	-11.19
350	2000	21.24	-0.61	-11.51
360	3000	21.81	-0.50	-10.58
370	4000	21.34	-0.62	-11.52
380	5000	21.93	-0.32	-10.92
390	6000	22.06	-0.59	-11.70
400	7000	22.15	-0.46	-10.43
410	8000	22.03	-0.35	-10.87
420	9000	21.66	-0.51	-11.69
430	1000	21.66	-0.21	-11.01
440	4297	23.37	-0.35	-11.02
450	1001	21.64	-0.64	-11.39
460	1100	22.31	-0.76	-11.39
470	7189	21.88	-0.47	-10.84
480	7277	21.50	-0.50	-11.68
490	7198	21.91	-0.41	-11.90
500	7197	22.06	-0.81	-11.44
510	7206	21.69	-0.38	-11.58
520	7279	21.58	-0.54	-11.66
530	7281	21.76	-0.41	-11.57
540	7207	21.95	-0.45	-11.48
550	7203	22.04	-0.35	-11.63
560	7262	21.72	-0.42	-11.71
570	7250	21.50	-0.41	-11.74
580	7252	21.99	-0.27	-11.52
590	7253	22.05	-0.61	-11.60
600	7255	21.85	-0.40	-11.68
610	7257	21.71	-0.38	-11.62
620	7200	21.74	-0.33	-11.94
630	7259	21.59	-0.39	-11.71
640	7283	22.06	-0.61	-11.63
650	7190	21.70	-0.50	-11.55
660	7275	21.75	-0.63	-11.66
670	7191	21.46	-0.56	-11.78
680	7195	21.50	-0.47	-11.80
690	7208	21.90	-0.61	-11.56
700	7400	21.86	-0.66	-11.79
710	7377	21.79	-0.66	-11.72
720	7391	21.70	-0.62	-11.93
730	7393	21.64	-0.49	-11.83

Appendix B

Program to Rearrange the Data File

(supplied by Dr. Eugene M. Allen)

```
      PROGRAM REARRAN (INPUT, OUTPUT, TAPE1, TAPE3)
      DIMENSION I(200), A(200), B(200)
      REAL L(200)
      LOGICAL OK
      REWIND 3
      J = 1
  100 READ (3, 1001) I1, I2, L(J), A(J), B(J)
 1001 FORMAT(I5, 1X, I3, F11.0, F15.0, F10.0)
      IF (I1 . EQ . 999) GO TO 120
      I(J) = 1000 * I1 + I2
      J = J + 1
      GO TO 100
  120 NCOLORS = J - 1
      NMIN1 = NCOLORS - 1
      ITER = 0
  130 OK = .TRUE.
      ITER = ITER + 1
      PRINT 1004, ITER
 1004 FORMAT(1H≤,I4)
      DO 160 J = 1, NMIN1
      IF (I(J) . LE . I(J + 1)) GO TO 160
      OK = .FALSE.
      ITEMP = I(J)
      I(J) = I(J + 1)
      I(J + 1) = ITEMP
      TEMP = L(J)
      L(J) = L(J + 1)
      L(J + 1) = TEMP
      TEMP = A(J)
      A(J) = A(J + 1)
      A(J + 1) = TEMP
      TEMP = B(J)
      B(J) = B(J + 1)
      B(J + 1) = TEMP
  160 CONTINUE
      IF (.NOT . OK) GO TO 130
      DO 180 J = 1, NCOLORS
      I1 = I(J) / 1000
      I2 = I(J) - 1000 * I1
      WRITE (1, 1002) I1, I2, L(J), A(J), B(J)
 1002 FORMAT(I5, 1H-, I3, F11.2, 2F10.2)
  180 CONTINUE
      STOP
      END
```

Appendix C

Program to Find Sample Pairs

(supplied by Dr. Eugene M. Allen)

```
      PROGRAM SIXWAYS (INPUT, OUTPUT, TAPE1, TAPE7)
C
C           IN A GROUP OF COLOR POINTS IN CIELAB SPACE, DETERMINES
C           ALL COLORS THAT ARE ON ISO(HUE-LIGHTNESS),
C           ISO(HUE-CHROMA) AND ISO(CHROMA-LIGHTNESS)
C           LINES RADIATING FROM EACH POINT IN TURN.
C
      DIMENSION A(400), B(400), NUMBER(400), NUMB(40, 3, 2),
     +DE(40, 3, 2), NP(3, 2)
C
      REAL L(400)
C
C           READ FILE OF COLOR POINTS.
C
      J = 1
      REWIND 1
      REWIND 7
  100 READ (1, 1001) NUMBER(J), L(J), A(J), B(J)
      IF (NUMBER(J) . EQ . 7H9999999) GO TO 120
      J = J + 1
      GO TO 100
  120 NCOLORS = J - 1
C
C           SET UP DO LOOP BASED ON EACH POINT.
C
      DO 300 J = 1, NCOLORS
      PRINT 1014, J
      WRITE (7, 1002) NUMBER(J)
C
C           SET UP DO LOOP BASED ON THE THREE ISO LINES IN
C           COLOR SPACE.
C
      DO 220 IVIA = 1, 3
      M1 = 0
      M2 = 0
C
C           SET UP DO LOOP BASED ON TESTING EACH POINT TO SEE
C           IF IT IS ON THE ISO LINE.
C
      DO 200 K = 1, NCOLORS
      IF (J . EQ . K) GO TO 200
      GO TO (130, 135, 140), IVIA
C
C           FORMULAS FOR DISTANCE BETWEEN COLOR POINT AND ISO LINE.
C
  130 DIST = SQRT((L(J) - L(K)) ** 2 + (A(J) * B(K) - A(K) * B(J))
     + ** 2 / (A(J) ** 2 + B(J) ** 2))
      GO TO 150
  135 DIST = SQRT((L(J) - L(K)) ** 2 + (A(J) ** 2 + B(J) ** 2
     + - A(K) * A(J) - B(K) * B(J)) ** 2 / (A(J) ** 2 + B(J) ** 2))
      GO TO 150
  140 DIST = SQRT((A(J) - A(K)) ** 2 + (B(J) - B(K)) ** 2)
C
C           IF DISTANCE IS TOO GREAT, ELIMINATE THE POINT.
C
  150 IF (DIST . GT . 0.1) GO TO 200
C
C           DETERMINE ON WHICH SIDE OF THE ISO LINE THE POINT LIES.
C           CALCULATE THE COLOR DIFFERENCE BETWEEN THE POINT
C           AND THE REFERENCE COLOR.
C
      GO TO (160, 165, 170), IVIA
 1011 FORMAT
```

```
      IF (BI . GT . B(J)) GO TO 180
      GO TO 190
  165 AI = A(J) + B(J) * (A(K) * B(J) - A(J) * B(K)) / (A(J) ** 2
     + + B(J) ** 2)
      IF (AI . GT . A(J)) GO TO 190
      GO TO 180
  170 IF (L(K) . GT . L(J)) GO TO 180
      GO TO 190
  180 M1 = M1 + 1
      NUMB(M1, IVIA, 1) = NUMBER(K)
      DE(M1, IVIA, 1) = SQRT((L(J) - L(K)) ** 2 + (A(J) - A(K))
     + ** 2 + (B(J) - B(K)) ** 2)
      GO TO 200
  190 M2 = M2 + 1
      NUMB(M2, IVIA, 2) = NUMBER(K)
      DE(M2, IVIA, 2) = SQRT((L(J) - L(K)) ** 2 + (A(J) - A(K))
     + ** 2 + (B(J) - B(K)) ** 2)
  200 CONTINUE
      NP(IVIA, 1) = M1
      NP(IVIA, 2) = M2
  220 CONTINUE
C
C         PRINT OUT RESULTS FOR EACH STANDARD POINT.
C
      NMAX = MAX0(NP(1, 1), NP(1, 2), NP(2, 1), NP(2, 2), NP(3, 1),
     + NP(3, 2))
      IF (NMAX . EQ . 0) GO TO 270
      WRITE (7, 1011)
      DO 250 K = 1, NMAX
      WRITE (7, 1004)
      DO 250 M1 = 1, 3
      DO 250 M2 = 1, 2
      IF (K . GT . NP(M1, M2)) GO TO 250
      IF (M1 . EQ . 1 . AND . M2 . EQ . 1) WRITE (7, 1005)
     + NUMB(K, M1, M2), DE(K, M1, M2)
      IF (M1 . EQ . 1 . AND . M2 . EQ . 2) WRITE (7, 1006)
     + NUMB(K, M1, M2), DE(K, M1, M2)
      IF (M1 . EQ . 2 . AND . M2 . EQ . 1) WRITE (7, 1007)
     + NUMB(K, M1, M2), DE(K, M1, M2)
      IF (M1 . EQ . 2 . AND . M2 . EQ . 2) WRITE (7, 1008)
     + NUMB(K, M1, M2), DE(K, M1 ,M2)
      IF (M1 . EQ . 3 . AND . M2 . EQ . 1) WRITE (7, 1009)
     + NUMB(K, M1 ,M2), DE(K, M1 ,M2)
      IF (M1 . EQ . 3 . AND . M2 . EQ . 2) WRITE (7, 1010)
     + NUMB(K, M1 ,M2), DE(K, M1, M2)
  250 CONTINUE
      GO TO 300
  270 WRITE (7, 1012)
  300 CONTINUE
      STOP
C
C         FORMAT STATEMENTS
C
 1001 FORMAT(2X,A7,F12.2,2F10.2)
 1002 FORMAT(////* SAMPLE NUMBER *, A7)
 1003 FORMAT(I5)
 1004 FORMAT(* *)
 1005 FORMAT(1H+,    A7,F6.2)
 1006 FORMAT(1H+,17X,A7,F6.2)
 1007 FORMAT(1H+,34X,A7,F6.2)
 1008 FORMAT(1H+,51X,A7,F6.2)
 1009 FORMAT(1H+,68X,A7,F6.2)
 1010 FORMAT(1H+,85X,A7,F6.2)
 1011 FORMAT(* PLUS CHROMA*, 5X, *MINUS CHROMA*, 7X,
```

```
     .+*MINUS LIGHT*)
 1012 FORMAT(* NO POINTS FOUND IN ANY DIRECTION*)
 1014 FORMAT(1H≤,I5)
C
      END
```

Appendix D

Program to Randomize the Order of Sample Pairs

(supplied by Dr. Eugene M. Allen)

```
      PROGRAM FUNFER (INPUT, OUTPUT, TAPE1)
C
C        PREPARES RANDIMIZED LIST OF COMPARISONS FOR THE INSPECTOR
C
      DIMENSION NAME (2, 24), ITAL(24)
C
      LOGICAL DONE
C
      DATA NAME/
     +1001,8444,8444,1001,7030,7430,7430,7030,
     +7291,8443,8443,7291,7052,7000,7000,7052,
     +0709,7023,7023,0709,0847,0979,0979,0847,
     +0866,0650,0650,0866,0006,0837,0837,0006,
     +0681,0984,0984,0681,0714,0644,0644,0714,
     +5000,5327,5327,5000,1000,5310,5310,1000/
C
      DO 100 J = 1, 24
  100 ITAL(J) = 0
  150 K = IFIX(RANF(0.0) * 24. + 1.)
      IF (ITAL(K) . GE . 10) GO TO 150
      WRITE (1, 1001) (NAME(J, K), J = 1, 2)
      ITAL(K) = ITAL(K) + 1
      DONE = .TRUE.
      DO 200 J = 1, 24
      IF (ITAL(J) . LT . 10) DONE = .FALSE.
  200 CONTINUE
      IF (DONE) STOP
      GO TO 150
 1001 FORMAT(//1X, I4, I9)
      END
```

****** 17.25.57. MANNYLW 000081 LINES PRINTED /// END OF LIST /// LQ 22

****** 17.25.57. MANNYLW 000081 LINES PRINTED /// END OF LIST /// LQ 22

Appendix D

Program to Randomize the Order of Sample Pairs

(supplied by Dr. Eugene M. Allen)

```
      PROGRAM FUNFER (INPUT, OUTPUT, TAPE1)
C
C           PREPARES RANDIMIZED LIST OF COMPARISONS FOR THE INSPECTOR
C
      DIMENSION NAME (2, 24), ITAL(24)
C
      LOGICAL DONE
C
      DATA NAME/
     +1001,8444,8444,1001,7030,7430,7430,7030,
     +7291,8443,8443,7291,7052,7000,7000,7052,
     +0709,7023,7023,0709,0847,0979,0979,0847,
     +0866,0650,0650,0866,0006,0837,0837,0006,
     +0681,0984,0984,0681,0714,0644,0644,0714,
     +5000,5327,5327,5000,1000,5310,5310,1000/
C
      DO 100 J = 1, 24
  100 ITAL(J) = 0
  150 K = IFIX(RANF(0.0) * 24. + 1.)
      IF (ITAL(K) . GE . 10) GO TO 150
      WRITE (1, 1001) (NAME(J, K), J = 1, 2)
      ITAL(K) = ITAL(K) + 1
      DONE = .TRUE.
      DO 200 J = 1, 24
      IF (ITAL(J) . LT . 10) DONE = .FALSE.
  200 CONTINUE
      IF (DONE) STOP
      GO TO 150
 1001 FORMAT(//1X, I4, I9)
      END
```

****** 17.25.57.   MANNYLW 000081 LINES PRINTED /// END OF LIST ///   LO 22

****** 17.25.57.   MANNYLW 000081 LINES PRINTED /// END OF LIST ///   LO 22