Acceptability and Perceptibility Decisions Using the CMC Color Difference Formula

By RODERICK McDONALD, J. & P. Coats Ltd., Anchor Mills, Paisley, Scotland

QUALITY control of color by instrumental pass/fail matching has been one of the main objectives of color measurement over the past 25 years (*1*). The major difficulty lies in the interpretation of the reflectance data provided by the color matching instruments and relating these to the judgment of a visual observer. The size of the problem and the lack of success in relating color measurements to visual judgment can be assessed by the fact that in 1976 there were still some 13 color difference formulae in use in the United States and other parts of the world (*2*).

During the late 1960's an extensive series of investigations by McLaren and Jaeckel was undertaken in the United Kingdom in which all available formulae were evaluated against various sets of visual matching data. From this work it was concluded that the color difference formula from the Adams-Nickerson *Lab* Color Space (ANLAB space) (*3*) gave the closest agreement with visual judgment. The rather complex ANLAB space equations were subsequently simplified by the CIE in 1976 to give the nearly identical CIELAB space and color difference formula (*4*). The color difference is given in terms of the difference in *Lab* co-ordinates between target and sample:

$$\Delta E = (\Delta L^2 + \Delta a^2 + \Delta b^2)^{1/2}$$

CIELAB space and the earlier ANLAB space with their familiar *Lab* color co-ordinates are very widely used in the color using industries. However, when used to provide color differences for pass/fail quality control, they are not particularly successful. The problem is the visual nonuniformity of these spaces, which means that different numerical tolerances must be applied to target colors from different regions of color space.

When only a few colors are involved, it is possible to establish the required pass/fail matching tolerance in ΔL, Δa, Δb and ΔE specifically for each target color. However, this requires several samples grouped around the target and takes considerable time to set up. It is often impractical to derive individual tolerances for each color and it is therefore desirable to have a color difference formula which will produce a uniform single-number tolerance which can be applied to all colors of a given product.

Following work by McLaren in 1971 (*5*), an early investigation into ANLAB space in our laboratory showed that, for a given visual difference, the numerical difference between a pair of colors of high chroma is up to seven times greater than the numerical difference for a pair of neutral grays. This investigation produced a formula which tried to accommodate the nonuniformity by calculating a progressively larger ANLAB tolerance as the chroma of the target color increased (*6*). However, it was found that disagreements between dyers' judgments and the amended formula still occurred frequently. Other factors obviously were present and an extensive investigation was started in 1976 to try to determine these factors.

The initial investigation consisted in selecting 55 target colors systematically distributed throughout color space and then using computer recipe prediction to produce a series of dyeings clustered uniformly around each target. The dyeings were arranged in two shells, one visually close to the target and the second slightly further away, such that some dyeings would be commercially acceptable matches to target and others unacceptable.

The samples were presented to a panel of eight observers, together with a gray pair placed at the back of the matching cabinet to represent the standard of match required. The observers were asked to accept/reject each sample to the required tolerance. The panel repeated its examination some weeks later (*7*).

The panel results were converted into % Acceptability ratings; e.g., if a given sample was accepted 12 times out of 16 assessments, then it was given an Acceptability rating of 12/16 = 75%. Samples with high %A ratings should by definition lie closer to the target in color space than samples with lower %A ratings. Following this logic, it is possible to construct an ellipsoid around each target by various mathematical techniques such that the shell of the ellipsoid represents the 50% Acceptability boundary around the target, as shown in Fig. 1 (*8*).

In such an ellipsoid, the color difference is given by drawing a line from the target through the sample until it reaches the shell of the ellipsoid. The color difference

ABSTRACT

An extensive series of investigations in the United Kingdom has shown that the variations in CIELAB space can be described and overcome by the use of ellipsoid tolerance volumes in which the dimensions in the hue, chroma and lightness directions are varied according to the location in color space of the color standard. The CMC color difference formula defines this variation in numerical tolerance, allowing the use of a single-number pass/fail tolerance to be applied to all colors of a given product.

KEY TERMS

ANLAB Formula
BFD (*l*:*c*) Formula
CMC Formula
Color Measurement
JPC79 Formula

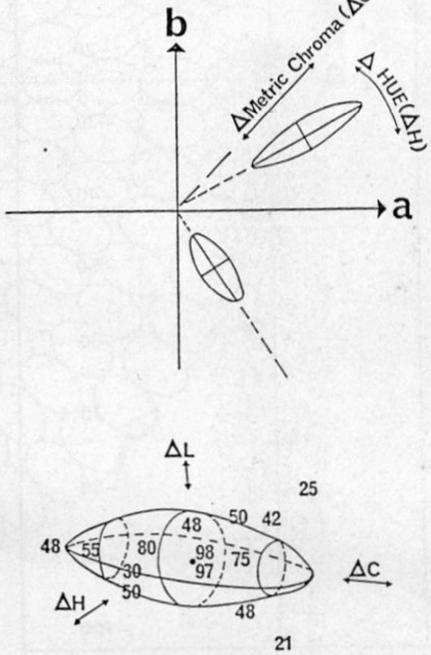

Fig. 1. Fitting of a tolerance ellipsoid.

is then given by the distance ratio (sample-target/shell-target) or mathematically:

$$E = [(\Delta L/L_t)^2 + (\Delta C/C_t)^2 + (\Delta H/H_t)^2]^{1/2}$$

where L_t, C_t and H_t are the dimensions of the semi-axes of the ellipsoid in the lightness, chroma and hue directions; ΔL, ΔC and ΔH are the differences in lightness, chroma and hue between dyeing and target.

Ellipsoids were fitted to all 55 target colors. When the ellipsoids were plotted in ANLAB space, it was found that each ellipsoid was oriented such that the longest dimension axis was along the chroma direction, with a much smaller axis along the hue direction. A relatively large axis also was present in the lightness direction. Contrary to the assumptions of the ANLAB formula, the tolerance volumes were not spherical. Moreover, the ellipsoids increased markedly in size as the chroma of the target color increased.

There also was evidence that the hue axis of the ellipsoids varied in size as the hue angle of the target colors varied. The hue dimension in the brown region was particularly small. This agreed with experience in our dyehouses that the ANLAB color differences were too slack for brown shades and too tight for greens and turquoise. A formula was derived to define these variations in ellipsoid dimensions and, when tested on our own data and on other published data, a significant improvement in agreement with visual judgment was obtained (*8*).

These indications of the pattern of the nonuniformity in space were confirmed by examination of 8454 pass/fail decisions made in one of our dyehouses over a period of two years. This gave the plots of differences in hue, chroma and lightness for the visually acceptable dyeings shown in Fig. 2 (*9*).

It can be seen that the chroma limits for acceptable dyeings are large and increase significantly as the chroma of the target increases. Hue limits also increase significantly with chroma but are much smaller limits than the chroma limits. The lightness limits were not found to increase with chroma but do increase significantly with increase in lightness of the target. Boundary limits were calculated to enclose 95% of the plotted points and equations were fitted to define the curved boundary limits which were obtained.

A further investigation showed that if the hue plots of Fig. 2 were split to cover small sectors of the hue circle, then the hue tolerance varied systematically as the hue angle of the target shade changed. This cyclical variation could be described by the ratio hue-tolerance/chroma-tolerance and an equation was derived to fit the cyclical pattern found, as shown in Fig. 3.

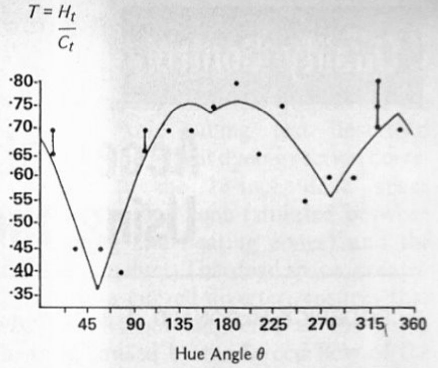

Fig. 3. Variation in H_t/C_t ratios.

JPC79 Formula

All the equations defining the variation in tolerance limits for chroma, lightness and hue were combined to give a color difference formula which gave significant improvement in agreement with visual observation over a wide range of published acceptability data. In each case the performance of the formula was better than that of the average visual observer when compared to the corporate decision of the matching panel and better than ANLAB or CIELAB.

The formula was rescaled for use in CIELAB space and was published as the JPC79 formula (*9*). The scaling was also such that a color difference of one unit calculated from the formula was equivalent to the fairly critical visual acceptability limit of the American Davidson and Friede observers who carried out one of the earliest and most frequently quoted matching experiments on wool carpet yarns (*13*).

The JPC79 formula is given below,

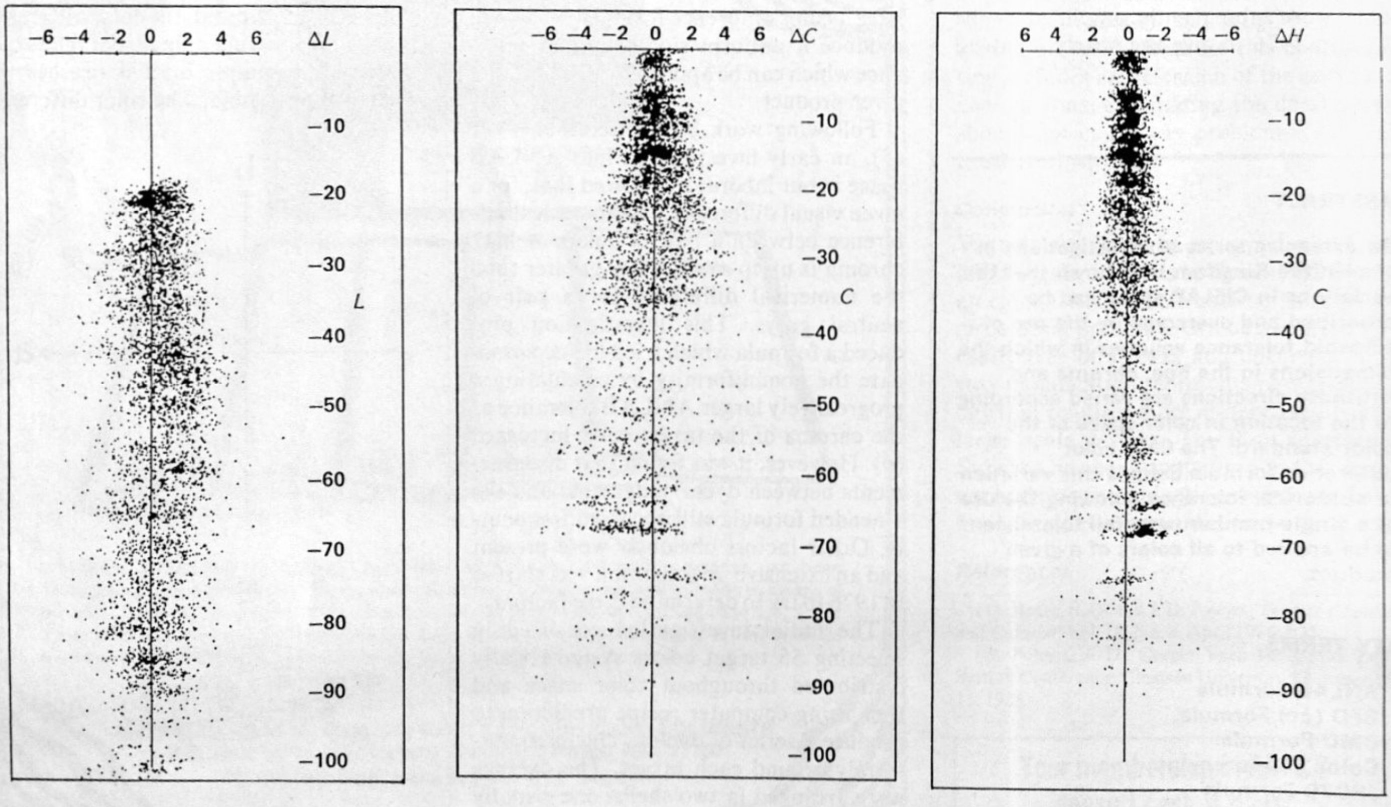

Fig. 2. Visually passed dyelots: lightness, chroma and hue differences.

showing the nonlinear equations describing the ellipsoid semi-axis dimensions L_t and C_T, and the variation of H_t as a fraction (T) of C_t which changes with hue angle (h).

$$L_t = 0.08195\,L/(1 + 0.01765\,L)$$
$$C_t = 0.0638\,C/(1 + 0.0131\,C) + 0.638$$
$$H_t = T.C_t$$

$T = 1$ if $C < 0.638$. Otherwise $T = 0.36 + \text{ABS}\ [0.4 \cos (h + 35)]$ unless h is between 164° and 345° when $T = 0.56 + \text{ABS}\ [0.2 \cos (h + 168)]$

$$\Delta E\ \text{JPC79} = [(\Delta L/L_t)^2 + (\Delta C/C_t)^2 + (\Delta H/H_t)^2]^{1/2}$$

ABS indicates the absolute—i.e., positive—value of the term within the brackets. L, C and h refer to the lightness, chroma and hue angle of the standard from a pair of samples, and all values are calculated from ANLAB(43.909) L, a, b values [or CIELAB L^*, a^* b^* values since ANLAB(43.909) is almost identical to CIELAB].

CMC Formula

The Colour Measurement Committee of the Society of Dyers and Colourists examined the JPC79 formula and several important modifications were made.

Firstly it was found that the lightness tolerance of the JPC79 formula became too tight for very dark samples with L co-ordinates less than $L = 16$ (cut pile carpets and transparent plastics). (This was because no samples with $L < 16$ had been available in the JCP79 investigation data.) The equation was modified to agree with data obtained from Bradford University which indicated that a constant lightness tolerance equal to that of $L = 16$ could be used for these very dark samples (*11*).

Secondly it was considered that there was an unsatisfactory discontinuity in the JPC79 formula where the elliptical chromaticity cross section of the tolerance ellipsoid was made to change abruptly to a circle for samples with chroma < 0.638; i.e., near the neutral gray origin of the CIELAB *a.b* diagram. A modification was introduced to smooth the change from elliptical cross section to circular cross section and back again as the target color moves through the CIELAB neutral origin. Some idea of the changing shape and size of the tolerance ellipsoids for different regions of color space is shown in Fig. 4.

A third very important modification was made. The JPC79 formula, derived for acceptability matching in the textile industry, had a comparatively large lightness tolerance. When the formula was applied to perceptibility matching data—e.g., in the assessment of fastness tests using a gray scale—it was found to give poor performance. The reason is that in perceptibility matching all attributes of color difference are of equal importance.

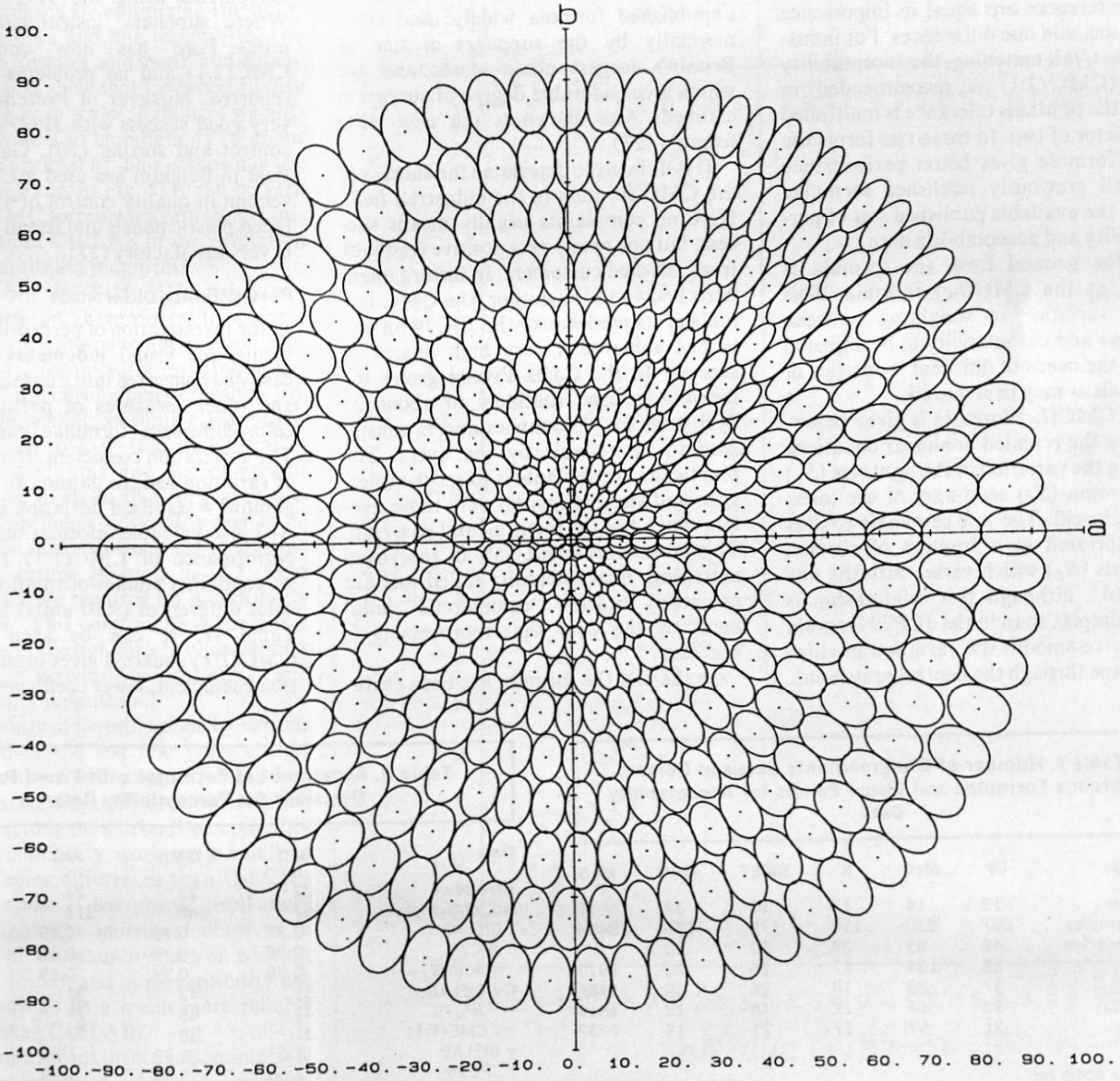

Fig. 4. CMC two-unit ellipsoids in CIELAB space.

In fastness testing a difference in hue between two patterns is equated to a difference in lightness in the ISO gray scale. Initial investigation showed that halving the lightness tolerance restored the formula performance, and subsequent investigations at Bradford University confirmed that this was the optimum correction over the available sets of perceptibility data.

The JPC79 lightness equation was therefore halved to produce a perceptibility weighting and a new formula incorporating all modifications was published by SDC's Colour Measurement Committee as the CMC(*l*:*c*) formula for use with CIELAB color space (*10*,*11*,*12*). The perceptibility form of the equation is known as the CMC(1:1) equation in which lightness differences are equal in importance to chroma and hue differences. For industrial pass/fail matching, the acceptability form (CMC/2:1) is recommended in which the lightness tolerance is multiplied by a factor of two. In these two forms the CMC formula gives better performance than all previously published formulae within the available published sets of perceptibility and acceptability data.

In the general form the formula is known as the CMC(*l*:*c*) formula. This allows variation in weighting between lightness and chromaticity to be adjusted to suit the needs of different industries or materials as may be required.

The CMC(*l*:*c*) formula is given below, showing the rescaled nonlinear equations defining the variation in the lightness (S_L) and chroma (S_C) semi-axes of the tolerance ellipsoid. The hue semi-axis (S_H) is still expressed as a fraction of chroma semi-axis (S_C) which varies with the hue angle (h), although this relationship is more complex than in the JCP79 formula in order to smooth the variation in ellipsoid shape through the neutral gray point.

$$S_L = 0.040975\ L^*/(1 + 0.01765\ L^*)$$

unless $L^* < 16$ when $S_L = 0.511$.

$$S_C = -.0638\, C^*/(1 + 0.0131\, C^*) + 0.638$$

$$S_H = S_C(T.F + 1 - F)$$

$$F = \{(C^*)^4/[(C^*)^4 + 1900]\}^{1/2}$$

$$T = 0.36 + ABS\ [0.4\ \cos\ (h + 35)]$$

unless h is between 164° and 345° when $T = 0.56 + ABS\,[0.2 \cos (h + 168)]$

$$\Delta E\ \mathrm{CMC}\ (l{:}c) = [(\Delta L^*/lS_L)^2 + (\Delta C^*/cS_c)^2 + (\Delta H^*/S_H)^2]^{1/2}$$

L^*, C^* and h refer to the standard from a pair of samples, these values and ΔL^*, ΔC^* and ΔH^* being calculated from the CIELAB formula.

Performance

Performance in acceptability decisions is very important for industrial quality control. Table I shows that in the main published sets of acceptability matching data, the CMC(2:1) formula performs considerably better than CIELAB.

The table also shows the performance of the M&S83A formula which is an unpublished formula widely used commercially by the suppliers of one of Britain's largest chain stores and for which a considerable degree of success is claimed. Also shown is the new BFD formula (*27*).

It is difficult to determine the success of the CMC formula in the industrial field. Here no complaints usually means success, but one rarely gets positive feedback from satisfied customers. In the organizations known to the author, the CMC formula or its predecessor the JPC79 formula has achieved a very high degree of success. In the Coats-Viyella group the formula is used routinely in about 25 dyehouses in 20 countries and is considered to be reliable by the dyers. The practice in these plants is to set the tolerance and visually inspect only those dyelots which fail the instrumental pass/fail. This eliminates about 95% of the visual matching. Instrumentally failed lots are examined to allow "commercial" judgment by the dyer that reprocessing is necessary.

In the UK the formula has been evaluated and adopted by leading chain store retailers for quality control purposes, and by the Ministry of Defence. The CMC formula has been evaluated by the British Standards Institution and will be published as a British Standard for Measurement of Colour Difference.

Since the CMC formula is so similar to JPC79, the performance of the CMC formula in industrial control is similar to JPC79 and substitution of CMC(2:1) for JPC79 will not alter the tolerance settings previously established. This means that earlier studies on the performance of JPC79 compared to CIELAB can also be used to indicate the reliability of the CMC formula. Osman of Ford Motor Co. (UK) reported that the JPC79 formula has been used by Ford for pass/fail matching of automotive fabrics and that quality control standards for the company's suppliers were based on this formula (*19*). He reported that in 300 batches 28% wrong instrumental decisions were made using visual control charts and only 3% disagreements using the JPC79 formula. Where suppliers' instrumentation permits, Ford has now converted to CMC(2:1) and no problems have been reported. Niederer of Pretema reported very good success with JPC79 in quality control and sorting (*20*). Gaunt of Du Pont in Belgium has used a CMC(1.3:1) version in quality control of smooth surfaced plastic panels and found the formula very satisfactory (*21*).

Perceptibility Differences

In the investigation of perceptibility judgments, the visual judgments can more easily be converted into a continuous scale and other measures of performance of color difference formulae can be used. The correlation coefficient, the coefficient of variation and the gamma function (log gamma = standard deviation of log $\Delta E/\Delta V$) give valuable information (*22*). The performance of CMC(1:1) formula in perceptibility studies of small to medium color differences (<10 units) is shown in Table II. It can be seen that the CMC(1:1) equation gives higher correlation coefficient, lower coefficient of varia-

Table I. Number of Disagreements Between Color Difference Formulae and Visual Panels for Acceptability Data

Data	DF	McD	K	KMET	ISCC	McD
Reference	13	14	15	16	17	18
No. of Samples	287	630	110	179	179	8454
Single Observer	49	85	28	32	23	*
CIELAB	55	134	17	24	22	1919
M&S83A	37	80	18	26	19	1486
BFD(1.5:1)	33	64	17	18	19	1316
CMC(2:1)	31	57	17	21	19	1232

---

*Only one observer.

Table II. Agreement of Formulae with Visual Panel Decisions for Perceptibility Data

Data	BFD	MMB	MC	BFD/MC
Reference	22	23	24	24
No. of Samples	567	548	317	884
r CIELAB	0.33	0.73	0.49	0.38
JPC79	0.38	0.75	0.56	0.44
CMC(1:1)	0.59	0.77	0.63	0.65
CV CIELAB	51	43	37	51
JPC79	41	43	27	36
CMC(1:1)	31	39	27	30
γ CIELAB	1.57	1.72	1.50	1.57
JPC79	1.50	1.69	1.39	1.50
CMC(1:1)	1.38	1.67	1.38	1.39

tion and gamma value nearer 1.0 than the JPC79 or CIELAB formulae. The data set MC is extracted from work by M. Cheung (*24*) at Bradford, who prepared color samples at the five color centers recommended for study by the CIE. At each center, from 59 to 82 pairs of samples were assessed by a panel of observers—over 13,000 observations being made.

The final column in Table II shows the performance when the BFD and MC data were combined by Cheung after scaling experiments to bring the two sets of data onto a common visual scale. Cheung tested some 14 color difference formulae on these data and the CMC(1:1) was ranked best by all the criteria in Table II.

Adebayo (*25*) at Bradford has checked the optimum weighting of lightness to chroma and hue in the CMC formula on both textile samples and on matt and glossy paints. Using 20 observers and perceptibility judgments based on ratio comparisons and on gray scale comparisons at 17 color centers, he found that the agreement with visual judgment can be significantly increased by optimizing the lightness to chroma and hue weightings. His studies on textiles and matt and glossy paint surfaces show that for perceptibility work using gray scales, a relative weighting of lightness to chromaticity of about 1.4:1 gave optimal fit. This is shown in the scatter diagrams in Fig. 5. It can be seen that the CMC formula is again signficantly better than CIELAB in its correlation with perceptibility judgments.

As shown in Table III, Adebayo's experiments on these different surfaces show that the chroma to hue relationships in the CMC formula are essentially correct—i.e., the chromaticity ellipsoids are correct (the scaling constant, *c*, is approximately equal to 1.0)—but that ratios of lightness to chroma and hue of greater than 1:1 are likely to give optimal results from perceptibility work. However in no case did he find that lightness to chroma and hue ratios as high as 2:1 were needed, as were required for acceptability judgments. This confirms that there is a difference in the lightness to chromaticity weightings between perceptibility and acceptability judgments.

The results of investigations by various workers over the last few years clearly show that the CMC color difference formula gives substantially better correlation with visual judgment in both acceptability and perceptibility work with small to medium color differences than the CIELAB formula. It has proved itself more reliable than the individual observer in every set of acceptability data on which it has been tested, and in perceptibility has been shown to be a much more reliable formula than CIELAB.

The most recent investigation into providing an improved color difference formula is that of Luo and Rigg (*26*,*27*). In

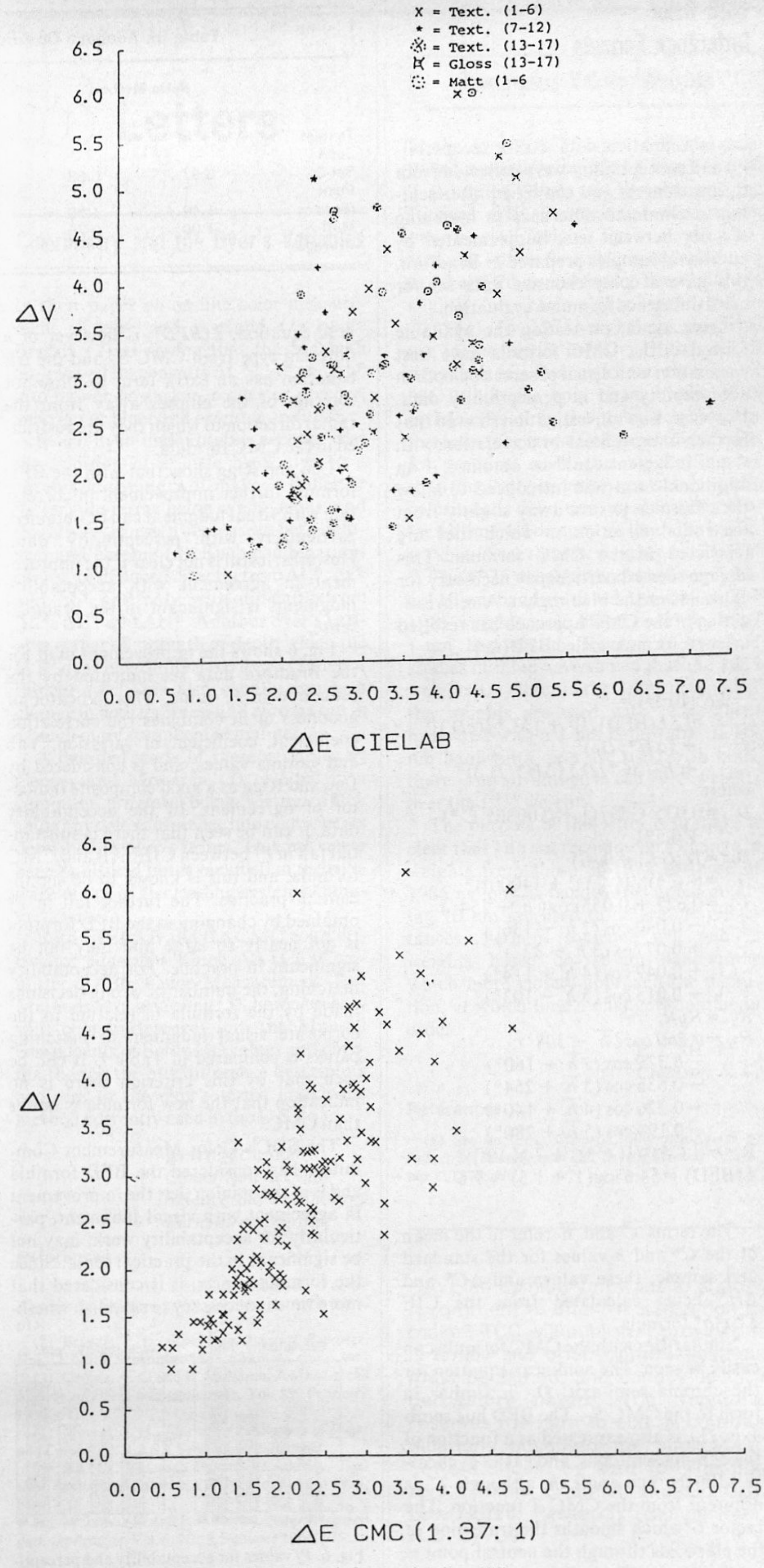

Fig. 5. Adebayo combined textile, matt and glossy paint data (*25*).

Table III. Adebayo Optimum *l:c* Ratios for CMC formula

	Ratio-Method		Gray-Scale		Average	
	l	c	*l*	*c*	*l*	*c*
Textiles						
Set 1			1.47	1.11	1.47	1.11
Set 2	0.97	0.83	1.39	1.00	1.18	0.91
Paint						
Gloss	1.49	1.00	1.25	1.11	1.37	1.05
Matt	1.00	0.75	1.25	1.00	1.13	0.88
Average			1.36	1.00		

this investigation, data sets for acceptability and perceptibility were collected from various sources and combined after scaling to eliminate difference in matching severity between sets. Supplemented by additional samples prepared at Bradford, this gave a comprehensive data set for color difference formulae evaluation.

Once again, on testing the available formulae, the CMC formula gave best correlation with visual observation both in acceptability and in perceptibility data. However, Luo's investigation showed that further improvement in correlation with visual judgment could be obtained if an additional term was introduced to allow the ellipsoids to turn away slightly from the radial direction to which they are restricted in the CMC formula. This change seemed particularly necessary for ellipsoids in the blue region. A reinvestigation of the CMC approach has resulted in a new formula called BFD(*l:c*)

$$\Delta E\ (\mathrm{BFD}) = \{[\Delta L(\mathrm{BFD})/l]^2 + [\Delta C^*/(cD_c)]^2 + (\Delta H^*/D_H)^2 + R_T(\Delta C^*/D_c)(\Delta H^*/D_H)\}^{1/2}$$

where:

$$D_c = 0.035\,\overline{\mathrm{C}}^*)/(1 + 0.00365\,\overline{\mathrm{C}}^*) + 0.521$$

$$D_H = D_c(GT' + 1\text{-}G)$$

$$G = \{(\overline{C}^*)^4/[(\overline{C}^*)^4 + 14000]\}^{1/2}$$

$$\mathrm{T}' = 0.627 + 0.055\cos(\overline{h} - 254^\circ) - 0.040\cos(2\overline{h} - 136^\circ) + 0.07\cos(3\overline{h} - 32^\circ) + 0.049\cos(4\overline{h} + 114^\circ) - 0.015\cos(5\overline{h} - 103^\circ)$$

$$R_T = R_H R_c$$

$$R_H = 0.260\cos(\overline{h} - 308^\circ) - 0.379\cos(2\overline{h} - 160^\circ) - 0.636\cos(3\overline{h} + 254^\circ) - 0.226\cos(4\overline{h} + 140^\circ) - 0.194\cos(5\overline{h} + 280^\circ)$$

$$\mathrm{R_c} = \{(\overline{C}^*)^6/[(\overline{C}^*)^6 + 7 \times 10^7]\}^{1/2}$$

$$L(\mathrm{BFD}) = 54.6\log(Y + 1.5) - 9.6$$

The terms $\overline{C}$ and $\overline{h}$ refer to the mean of the C^* and h values for the standard and sample, these values and ΔC^* and ΔH^* being calculated from the CIE $L^*a^*b^*$ formula.

Similarities with the CMC formula can easily be seen. The nonlinear equation for the chroma semi-axis, D_C, is similar in form to the CMC S_C. The BFD hue semi-axis, D_H, is also expressed as a function of the chroma semi-axis, and varies cyclically with the hue angle, h, although T' is different from the CMC T function. The factor G which smooths the transition of the ellipsoids through the neutral point is similar to the CMC F factor. The lightness equation, $L(BFD)$, is however of a different type from CMC S_L and the ΔE equation has an extra term to allow for rotation of the ellipses away from the radial direction to which they are restricted in the CMC formula.

Luo and Rigg show that with the BFD formula further improvement in correlation with visual judgment can be obtained, particularly with perceptibility data. However, it still is not clear if the improvement in agreement with acceptability judgments is significant in the practical sense.

Fig. 6 shows the improvement in fit for the Bradford data set indicated by the reduction in *Pf* value. This indicator of goodness of fit combines the correlation coefficient, coefficient of variation, Vab and gamma values, and is considered by Luo and Rigg as a good composite indicator of agreement. In the acceptability data, it can be seen that there is substantial fall in *Pf* between CIELAB and CMC formula, and this is known to be significant in practice. The further fall in *Pf* obtained by changing to the BFD formula is not nearly so large and may not be significant in practice. For acceptability matching, the number of wrong decisions made by the formula in relation to the corporate visual judgment of matching panels is compared in Table I. It can be seen that by this criterion there is no indication that the new formula is better than CMC.

The SDC's Color Measurement Committee has considered the BFD formula and is of the opinion that the improvement in agreement with visual judgment, particularly for acceptability work, may not be significant in the practical sense. Since the formula is new, it is considered that more time is necessary to establish whether the improvements are enough to merit any change from CMC. In the meantime, the important objective is to move away from CIELAB, and for this reason the committee is in agreement with the British Standards Institution's decision to adopt the well established CMC formula as the recommended method for measurement of small color differences.

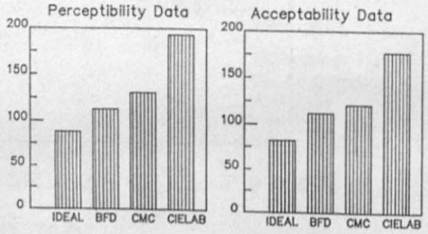

Fig. 6. *Pf* values for acceptability and perceptibility data.

Another advance in color specification has been the development of a color space by Luo and Rigg (*28*) which incorporates the improvements in visual uniformity obtained from the CMC formula. This should prove very useful for the design of color collections and other problems where mapping and examination of the distribution of colors in a uniform color space is advantageous.

At the time of publication of the CMC formula, the available data sets on large color differences indicated that the CMC formula might not be so suitable for the assessment of large color differences (*11*). More recent work at Bradford with new data sets has shown that the CMC formula gives good correlation with visual judgment even for large color differences of the order of 13 CIELAB units (*29*), and that the anomalous performance previously found appears to be due to errors in the data sets tested.

Conclusions

In general the CMC formula has proved to be a substantial improvement over CIELAB for pass/fail matching and its increasing use throughout the color using industries in the UK and Europe is assisting in the implementation and development of practical methods of instrumental quality control of color. ∞

References

(1) McDonald, R., *Journal of the Oil & Colour Chemists Association*, Vol. 65, 1982, p43 (review: 126 references).

(2) McLaren, K., *Journal of the Society of Dyers and Colourists*, Vol. 96, 1976, p317.

(3) McLaren, K., *Journal of the Society of Dyers and Colourists*, Vol. 86, 1970, p354.

(4) CIE Colorimetry Committee, *Journal of the Optical Society of America*, Vol. 64, 1974, p896.

(5) McLaren, K., *Proceedings of the AIC Conference*, Driebergen, Holland, 1971, p296.

(6) McDonald, R., *Journal of the Society of Dyers and Colourists*, Vol. 90, 1974, p189.

(7) McDonald, R., *Journal of the Society of Dyers and Colourists*, Vol. 96, 1980, p372.

(8) McDonald, R., *Journal of the Society of Dyers and Colourists*, Vol. 96, 1980, p418.

(9) McDonald, R., *Journal of the Society of Dyers and Colourists*, Vol. 96, 1980, p486.

(10) Clarke, F. J. J., R. McDonald and B. Rigg, *Textile Chemist and Colorist*, Vol. 16, No. 8, August 1984, p46.

(11) Clarke, F. J. J., R. McDonald and B. Rigg, *Journal of the Society of Dyers and Colourists*, Vol. 100, 1984, p128.

(12) Clarke, F. J. J., R. McDonald and B. Rigg, *Journal of the Society of Dyers and Colourists*, Vol. 100, 1984, p281.

(13) Davidson, H. R. and E. Friede, *Journal of the Optical Society of America*, Vol. 43, 1953, p581.

(14) McDonald, R., *Journal of the Society of Dyers and Colourists*, Vol. 96, 1980, p372.

(15) Kuehni, R. G., *Journal of Color and Appearance*, Vol. 1, 1971, p30.

(16) Metropolitan Section, AATCC, *Textile Chemist and Colorist*, Vol. 3, No. 11, 1971, p55.

(17) Kuehni, R. G. and R. T. Marcus, *Color Research and Application*, Vol. 4, 1979, p83.

(18) McDonald, R., *Journal of the Society of Dyers and Colourists*, Vol. 97, 1981, p517.

(19) Osman, P., *Proceedings of Finishing Group Conference, The Textile Institute*, Bolton, England, 1985.

(20) Private communication.

(21) Private communication.

(22) Alder, C. et al., *Journal of the Society of Dyers and Colourists*, Vol. 98, 1982, p14.

(23) Morley, D. I., R. Munn and F. W. Billmeyer, *Journal of the Society of Dyers and Colourists*, Vol. 91, 1975, p229.

(24) Cheung, M., PhD thesis, University of Bradford, 1984.

(25) Adebayo, O., PhD thesis, University of Bradford, 1985.

(26) Luo, M. R. and B. Rigg, *Journal of the Society of Dyers and Colourists*, Vol. 103, 1987, p86.

(27) Luo, M. R. and B. Rigg, *Journal of the Society of Dyers and Colourists*, Vol. 103, 1987, p126.

(28) Luo, M. R. and B. Rigg, *Journal of the Society of Dyers and Colourists*, Vol. 102, 1986, p164.

(29) Adae-Badu, S., PhD thesis, University of Bradford, 1986.

Entries Announced for 1988 Intersectional Competition

Three entries have been filed in AATCC's 1988 Intersectional Technical Paper Competition to be conducted September 29 at Nashville, Tenn. They are:

- Rhode Island Section: Method of Determining Potential Problems in Dyeing and Printing of Rayon. Speaker: Karen E. Kyllo, University of Rhode Island.
- South Central Section: Chemical Analysis of Stain Blocking Finishes for Nylon Carpet Fiber. Speaker: John L. Crouse, University of Tennessee.
- Palmetto Section: A New Method of Evaluating the Performance of Color Measuring Instruments. Speaker: J. Richard Aspland, Clemson University.

The competition will be a highlight of the association's International Conference & Exhibition to be held September 28 through October 1 at the Opryland Hotel.

The contest has been a feature of AATCC's annual conferences since 1940.

Letters

Colorimetry and the Dyer's Variables

In their paper on on-line color measurement, Keesee and Aspland (*1*) quote Braddy (*2*) as saying that the Macbeth on-line system converts ΔL*, Δa* and Δb* into lighter or darker, redder or greener, yellower or bluer and *brighter or duller*.

Every dyer undoubtably accepts that the addition of a little black dye to a chromatic dyeing will make it duller or flatter, the terms being synonymous, and this always causes a decrease in both lightness and chroma (*3*). Such combinations cannot be deduced directly from ΔL*, Δa* and Δb* and only with difficulty from ΔL*, ΔC* and ΔH*. Another dyer's variable is that of strength or depth which the U.K. dyer invariably describes as fuller or thinner (*4*). This also usually causes a change in both lightness and chroma but in a much more complicated manner.

A detailed study of these variables by Cooper and McLaren (*3*) resulted in a computer program being written which splits any color difference into components described in dyer's terms. This has never been published but is included in the software of one of the leading systems manufacturers.

Both CIELAB and the CMC color difference equations which AATCC Committee RA36, Color Measurement Test Methods, is considering (*5*), however, only split color differences into the Munsell components of lightness (value) and chroma though the hue difference descriptors conform to the dyer's terms unlike the method currently used in the U.S. (*6*).

KEITH MCLAREN
Consultant in Color
Science and Technology
Berkshire, England

References

(1) Keesee, S. H. and J. R. Aspland, *Textile Chemist and Colorist*, Vol. 20, No. 4, April 1988, p15.

(2) Braddy, P. D., *American Dyestuff Reporter*, Vol. 72, No. 9, September 1983, p24.

(3) Cooper, A. C. and K. McLaren, *Journal of the Society of Dyers and Colourists*, Vol. 89, February 1973, p41.

(4) Morton, T. H., *Journal of the Society of Dyers and Colourists*, Vol. 92, September 1976, p342.

(5) AATCC Research Committee Activity, *Textile Chemist and Colorist*, Vol. 20, No. 4, April 1988, p34.

(6) McLaren, K. and P. F. Taylor, *Color Research and Application*, Vol. 6, No. 2, Summer 1981, p75.

Tristimulus Values/Weights

In the August 1985 issue of TCC I published an article entitled Calculation of Tristimulus Values and Weights with the Revised CIE Recommendations which gave a set of weights for calculating tristimulus values for reflectances measured at 10 and 20 nm intervals. These differed slightly from the weights I published in 1975 (*1*). The 1975 weights are in general use in the textile industry. Either set of weights is satisfactory for intralaboratory use. While the only claim in the 1985 article was that the new weights conformed to the latest CIE recommendation for practical work, the implication was that the 1985 weights were closer to the colorimetric definition, were therefor better for interlaboratory use, and the industry should use the new weights.

The 1975 weights were based on practical 10-nm bandwidth reflectances and the 1985 weights were based on impractical 1-nm bandwidths. Recent unpublished studies of mine have shown that the 1985 weights are closer to the definitions only if the weights are used with reflectances measured with a 1-nm bandwidth. If 10-nm bandwidth data are used with both, there is no advantage in the 1985 weights over the 1975 weights.

The purpose of this letter is to make it clear that I do not recommend a change in weights from those of 1975 to those of 1985 as long as bandwidths approximating 10 nm are used to determine reflectances. Perhaps someone will publish weights based on 10-nm bandwidths which more closely approach the definition, at which time a change would be in order.

E. I. STEARNS
Clemson, S. C.

References

(1) Stearns, E. I., *Clemson University Review of Industrial Management and Textile Science*, Vol. 14, No. 1, 1975, p79.

HAVE an opinion you want to share? A comment to offer? A suggestion to make? TCC will publish it provided it is timely and brief. Communications must be signed, and cannot be of a derogatory nature. The magazine reserves the right to edit all communications accepted for publication. Letters should be sent to: The Editors, Textile Chemist and Colorist, Box 12215, Research Triangle Park, N.C. 27709.