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II

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Manfred Richter

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Oscar Estévez, Amsterdam (The Netherlands):

The Stiles and Burch 2^o Color-Matching Functions: A Better 'Standard' Observer

The CIE '1931 Standard Observer' color-matching functions are not satisfactory due to problems with the Photometric V(λ). The Stiles and Burch 2^o data appear to agree well in WDW chromaticity coordinates with the original data of Guild and Wright, but are to be preferred since they are directly measured color-matching functions.

Les fonctions spectrales trichromatiques de l'observateur-standard CIE 1931 ne sont pas satisfaisantes au regard de la fonction V(λ) de la photométrie. Les dates trouvés par Stiles et Burch pour l'observateur 2^o semblent bien d'être d'accord avec les coordonnées originales de Guild et Wright dans le système WDW, mais ils sont à préférer parce qu'ils représentent des fonctions spectrales qui sont mesurées directement.

Die Spektralwertfunktionen des Normalbetrachters CIE 1931 sind nicht befriedigend im Hinblick auf die V(λ)-Funktion der Photometrie. Die Daten, die Stiles und Burch für den 2^o-Betrachter gefunden haben, scheinen gut mit den Original-Daten von Guild und Wright in WDW-Farbart-Koordinaten übereinzustimmen, sind aber zu bevorzugen, weil sie direkt gemessene Spektralwertfunktionen sind.

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For research on fundamental aspects of color vision, it is of considerable importance to have at one's disposal a set of color-matching functions (c.m.f.) that is representative of the trichromatic color vision of normal observers. While the CIE '1931 Standard Observer' has served this purpose ever since its adoption, it has become increasingly clear that it fails to correctly represent normal trichromatic data, especially, but not exclusively, at the blue-green part of the visual spectrum.

The basic difficulty with the CIE Standard Observer arises from its artificial nature: the CIE c.m.f. were synthesized from Wright's (1) and Guild's (2) Colorimetric data and the CIE (1924) V_λ function of Photometry.

Because of inadequacies in the CIE-V_λ function, Judd (3) proposed a modified form of luminosity and a revised set of c.m.f. that he derived following the general pattern of the CIE-Standard. While the 'Standard' proposed by Judd was a clear improvement and has been ever since preferred by visual scientists, it is still based on the assumption that Photometric and Colorimetric data can be combined to recover the c.m.f.

In the middle of the fifties W.S. Stiles, with the collaboration of J.M. Burch, measured directly the 2^{o} color-matching functions of ten subjects at the National Physical Laboratory (4). In this study they observed that a V_λ synthesized from their average c.m.f. (the converse of the CIE procedure) did not fit the Judd V_λ function. (Is does not fit either the CIE-V_λ!). While the differences are small, they appear to be real, as they also show up in the same form and in the same part of the spectrum in the data collected by H. Sperling (5): he measured the c.m.f. and Photometric functions of six subjects to test whether the latter were a linear combination of the former.

The problem, which appears to lie on the V_λ function, is not caused by the CIE-V_λ being a mixture of data from different studies, since the average luminosity data (flicker method) of the 125 subjects of Coblentz and Emerson (6) can not be fitted either by a linear combination of the Stiles and Burch 2^{o} c.m.f. (Fig. 1).

The conclusion that can be drawn is that the spectral sensitivity represented by Photometric data, whatever the method used to collect it, is not a linear combination of color-matching functions. By implication, one must conclude that the c.m.f. of the CIE-Standard Observer are not a correct representation of an 'average' normal trichromatic observer. While the differences would appear to be small, and in many applications of either Colorimetry of Photometry the error introduced can be neglected, they can become of large importance in those studies that consider particularly data from the blue-green region.

Stiles and Burch (4) compared their 2^{o} data to the CIE-Standard Observer in WDW chromaticity coordinates and concluded that significant differences were present. I have recently re-analysed their data (7), but compared it not to the CIE-Standard, which is based on an average of Wright's and Guild's results; rather, I compared it directly first with Wright's data and then with Guild's (in the WDW basis of Wright). The results of this analysis (Fig. 2) show that these differences are comparable to the differences between Guild's and Wright's data (which were combined to form the CIE-Standard). Therefore the data of Guild, Wright and Stiles and Burch represent the same normal average trichromatic observer; the data of Stiles and Burch, however, are the only complete set of measured color-matching functions for a 2° field and are to be preferred in those studies concerning fundamental questions of human color vision.

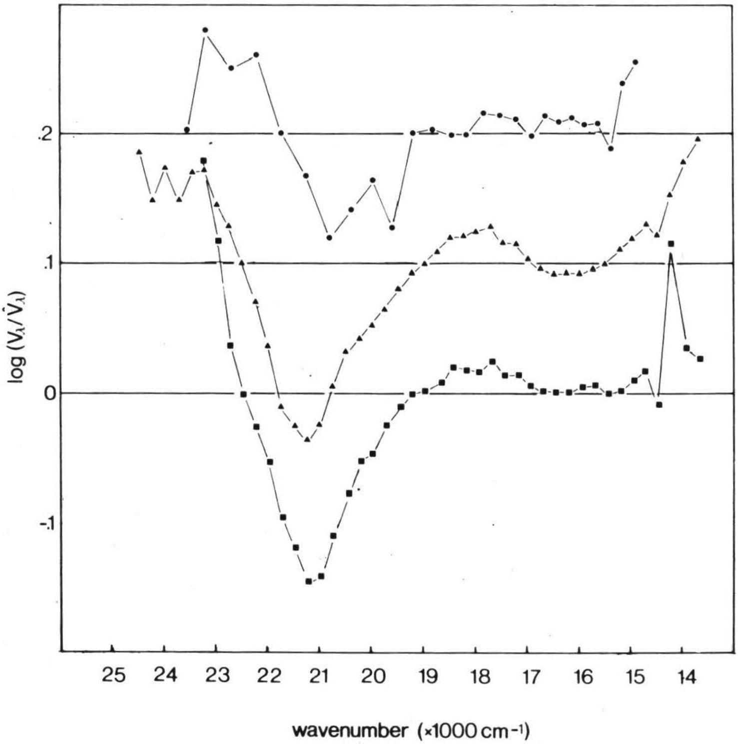

Fig. 1. Logarithm of the ratios of Photometric functions ($V\lambda$) to linear combinations of color-matching functions ($\hat{V}_\lambda$). The coefficients corresponding to the r_λ, g_λ, and b_λ functions are the luminances of the respective primaries estimated by the Photmetric method or by the tabulated function $V\lambda$. The upper comparison (circles) is that of Sperling (5), using the average of six subjects' own color-matching functions and flicker Photometric measures. The middle and lower plots compare the data of Stiles and Burch (4) 2° color-matching functions to the V_λ functions proposed by Judd (3) (triangles) and the flicker data of Coblentz and Emerson (6) (squares). (Note that the two upper functions, circles and triangles, are displaced by 0.2 and 0.1 respectively).

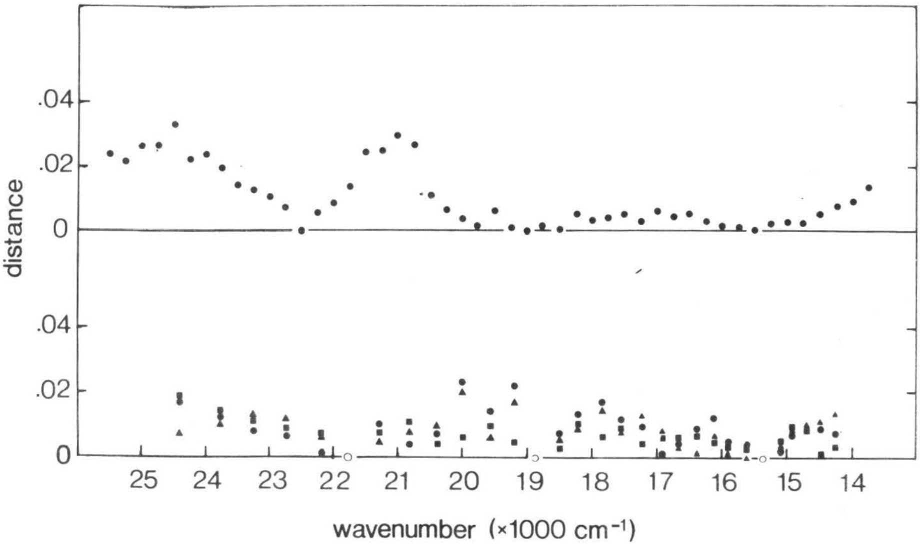

Fig. 2. Chromaticity distances between corresponding points of the 1931 CIE spectrum locus and the spectrum locus of the 2° data of Stiles and Burch, both transformed by them to a WDW basis using their spectral primaries. In the lower panel the distances are computed from the data of Stiles and Burch and Wright (triangles), Stiles and Burch and Guild (squares), and Guild and Wright (circles). For the lower panel the computations were carried out after transforming the data of Guild and that of Stiles and Burch to the WDW basis used by Wright.

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Copies of Estévez's thesis can be obtained from the author upon request.

Fred W. Billmeyer jr., Eugene Fox and Ellen M. Gerrity, Troy (New York):

Redetermination of CIE Standard Sources B and C

It is not possible for modern workers to reproduce CIE standard sources B and C, because of incomplete instructions, unavailability of original chemicals, improved purity of modern chemicals, and lack of the original (absorbing) glass cell. Modern attempts to produce sources B and C do not have the same spectral power distributions as standard illuminants B and C. Modern sources and corresponding illuminants closely approximating B and C will be presented.

Il n'est pas possible de reproduire aujourd'hui les illuminants-standards B et C parce que les instructions sont incomplètes, on ne peut pas gagner les substances originaires, parce que la pureté des substances modernes est améliorée, et on ne peut pas trouver des cuvettes originaires. C'est pourquoi les expériences de produire les illuminants B et C montrent que ces illuminants n'ont pas la même distribution spectrale de rayonnement comme les standards. Ici on présente des sources modernes qui se rapprochent des standards B et C.

Es ist heute nicht möglich, die Normlichtarten B und C zu reproduzieren, weil die Herstellungsanweisungen unvollständig, die Original-Chemikalien nicht mehr erhältlich, die modernen Chemikalien von verbesserter Reinheit sind, und weil die Original-Kuvetten nicht mehr hergestellt werden. Neuere Versuche, die Lichtarten B und C herzustellen, haben gezeigt, daß damit nicht die gleiche spektrale Strahlungsverteilung erzielt wird, wie sie für die Normlichtarten B und C festgelegt ist. Moderne Lichtquellen, die die ursprünglichen Normlichtarten annähern, werden vorgestellt.

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In 1931 the CIE adopted [1] standard sources and illuminants B and C, representing direct sunlight and average daylight, respectively, based on a study of Davis and Gibson [2]. Illuminant C, in particular, formed the basis of substantially all colorimetric calculations involving daylight-quality illumination until the adoption of the D-series illuminants by the CIE in 1964. It is still widely used today, and is likely to remain so despite the stated intention of the CIE [3] that "at some future date, that is yet to be decided, illuminants B and C will be dropped from the list of recommended standard illuminants." Stenius [4] has pointed to the widespread use of illuminant C in the paper industry as a compelling reason for retaining it as a CIE-recommended standard illuminant.

Davis and Gibson developed a series of two-component liquid filters which, when combined with incandescent sources, changed the color temperature of the source by a known amount. They prepared and studied extensively "standard" solutions of the various components, at concentrations differing by up to 50% from those selected for sources B (converts 2848 K to 4800 K) and C (converts 2848 K to 6500 K). The properties of the latter were inferred by calculations using Beer's law; it is not clear that the solutions for sources B and C were prepared at the time. Spectrophotometric data were obtained by the use of visual, thermoelectric, photoelectric, and photographic methods, with an accuracy commensurate with the times.

In 1950 and 1951 Davis, Gibson and Haupt [5] reported further studies. The filters leading to sources B and C were made up, and spectrophotometric measurements were made (Beckman DU) at the ends of the visible range and at a few additional check points. Discrepancies of up to 1% from the 1931 data were noted. The new data were incorporated into the CIE recommendation.

No later studies are known to us. It appeared that a redetermination of both sources and illuminants B and C was needed. In 1979 plans were made for the filter solutions to be prepared at Rensselaer and measured using the U. S. National Bureau of Standards reference spectrophotometer [6,7] and the spectral power distributions of illuminants B and C to be calculated by Stenius. This paper describes progress to date.

The following observations complicate the proposed task:

1. The current CIE recommendation provides incomplete information on how to prepare standard sources B and C. Important information on the stability of the solutions and the purity of the chemicals is omitted.

2. The 1931 and 1950-1951 measurements were made using a glass cell, since lost [8], with appreciable spectral absorption which is incorporated into the currently recommended illuminants, but omitted in the directions for preparing the sources.

3. The purity of the chemicals used has improved over the years, leading to reduction in absorptions from impurities in the early preparations.

4. Some of the chemicals specified in the current recommendations are no longer available, and equivalent substitutes must be used instead.

Our present opinion is that it is not feasible to reproduce standard sources B and C as recommended in 1931 or in 1971 precisely. Nor is it feasible to produce sources corresponding exactly to standard illuminants B and C as currently recommended. In considering alternatives, we feel two requirements are important: that any new source and illuminant should be in close correspondence, and that the chromaticities of current illuminants B and C should be preserved.

We hope to be able to recommend new sources and illuminants meeting these requirements, minimally different from 1931 standard sources and illuminants B and C, and defined with state-of-art precision and accuracy.

Acknowledgments. We thank A. S. Stenius for helpful discussions and look forward to his participation in later phases of this work. This is Contribution No. 104 from The Rensselaer Color Measurement Laboratory and a project of the Council for Optical Radiation Measurements. Financial support of the Ford Motor Company, the 3M Company, and the Sherwin-Williams Company is gratefully acknowledged.

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This paper will be published in full in COLOR research and application.

J3

Noboru Ohta, Minami-Ashigara (Japan):

A Simplified Method for Formulating Pseudo-object Colors and Its Application to Colorimetric Problems

A method for formulating the spectral reflection curves of "pseudo-object colors" is proposed here which is based on a simplified assumption derived from actual objects.

Ici on propose une méthode pour formuler les courbes spectrales de réflexion de „couleurs de pseudo-objets"; cette méthode est basée sur une hypothèse simplifiée dérivée d'objets réels.

Hier wird ein Verfahren zur Berechnung der spektralen Remissionskurven von „Pseudo-Körperfarben" vorgeschlagen; es beruht auf einer vereinfachenden Annahme, die von wirklichen Körperfarben abgeleitet ist.

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In colorimetry, it is sometimes necessary to study the behavior of a number of unknown spectral reflectance functions $\rho(\lambda)$ under a given condition. If no limitation is imposed to the shape of $\rho(\lambda)$, unrealistic functions such as very jagged one may be introduced in the calculation.[1] The results thus obtained may therefore be far from that for actual object colors.

Due to its practical importance, many sophisticated methods have been proposed in an attempt to numerically formulate the $\rho(\lambda)$ of actual object colors.[2-6] The purpose of the present study is to propose a method for formulating the $\rho(\lambda)$ of "pseudo-object colors" based on a simplified assumption derived from actual object colors.

Here we merely treat characteristics of $\rho(\lambda)$ at discrete points as ρ_i. It may be quite reasonable to assume that the value of ρ_i is not independent of that of ρ_{i-1} and ρ_{i+1} but is closely dependent on both of them. One of the simplest ways for formulating the dependency may be to use the value δ_i defined by

$$\left| (\rho_{i-1} + \rho_{i+1}) / 2 - \rho_i \right| = \delta_i \tag{1}$$

where i runs from i=2 to i=n-1. An upper limit Δ such that $\delta_i \leqq \Delta$ for i=2 to i=n-1 may be found for actual object colors. The smaller the upper limit Δ, the closer the value of ρ_i dependent on that of ρ_{i-1} and ρ_{i+1}.

We have evaluated the upper limit Δ for two data sets of actual object colors. One data set is random mixtures of typical cyan, magenta, and yellow dyes used in modern subtractive color photography. The three dyes are mixed completely at random within a peak density 3.0. Another data set is the Macbeth Color Rendition Chart whose spectral reflectance functions are already published elsewhere.[7] We found that the upper limit Δ for actual object colors may well be lower than 0.03 for a 10 nm wavelength interval, considering the results for two data sets used here.

We can immediately apply the results obtained here to interesting problems in colorimetry. For example, an optimal color may be defined as the color that gives the highest luminous reflectance for a given chromaticity. A spectral reflectance function of the optimal color is very unrealistic with one or two block-type reflectances in the visible range.[8] A mathematical procedure is well established for calculating the color gamuts obtainable by optimal colors, and some practical examples are published elsewhere.[9] The present author has proposed an alternative method for calculating the optimal color gamuts.[1] The new method makes full use of a linear programming technique, and Eq. (1) can be easily incorporated into the calculation as an additional constraint.

Figure 1 shows the results of calculation in the CIE 1960 (u,v) diagram for luminous reflectances Y_S=10,50,and 90. The solid lines in Fig. 1 show the optimal color gamuts obtainable by the pseudo-object colors. The dotted lines

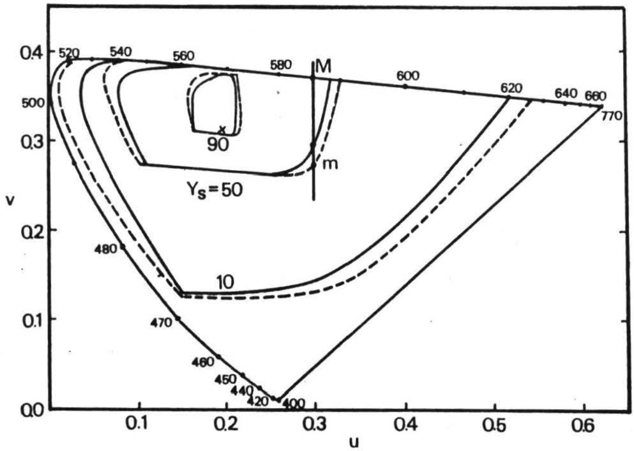

Fig. 1 Optimal color gamuts obtainable by pseudo-object colors (solid lines). Dotted lines are those by optimal colors.

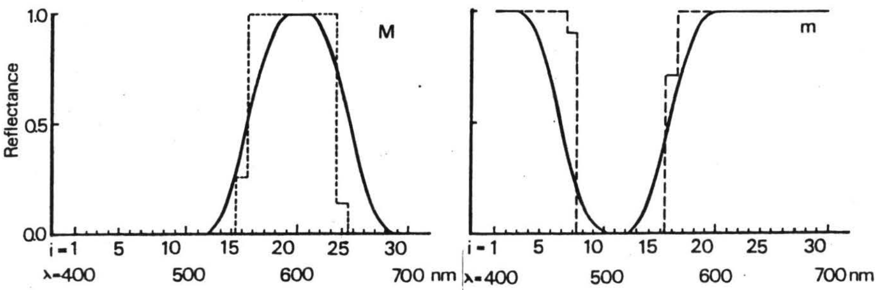

Fig. 2 Spectral reflectance functions to give points M and m in Fig. 1.

are those by the optimal colors and are shown for the purpose of comparison. It is noteworthy that two loci are only slightly different one another.

Figure 2 shows the spectral reflectance functions ρ_i to give the point M and m on the two loci of $Y_S=50$ in Fig. 1. We note the spectral reflectance functions shown in Fig. 2 by solid lines are not unrealistic but rather quite plausible. It is of interest that the optimal color gamuts are not very exaggerated but only by 10% or so at most in comparison with the pseudo-optimal color gamuts. It is also of interest to point out that the results obtained for the pseudo-optimal colors are similar to those actually obtained by a combination of liquid crystals.[10,11]

In the above calculation, we used the CIE standard illuminant D_{65} and the color matching functions of CIE 1931 standard colorimetric observer. The summations of tristimulus values are carried out within the visible range 400-700 nm by a 10 nm wavelength interval. The value of Δ is set to 0.03.

Another example when applied to chromaticity-mismatch limits of metamers[1] will also be described in detail.

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Yoshinobu Nayatani, Kotaro Takahama and Hiroaki Sobagaki, Osaka (Japan):

Color-Matching Function and Observer Metamerism

The color-matching functions given by Wyszecki and Stiles (1967) were analyzed for studying the effect of observer metamerism. The conclusions are summarized as follows. (1) The 20 color-matching functions are well reconstituted by using three deviation functions. (2) The first deviation functions constitute the new 1st standard deviate observer (SDO), which show a very high correlation between the observer metamerism indices by the new 1st SDO and those averaged for the 20 individual observers. (3) One test observer given by the new 1st SDO is effective and sufficient in assessing the effect of metamerism for observer differences.

Les fonctions colorimétriques individuelles publiées par Wyszecki et Stiles (1967) ont été analysées pour les recherches sur l'effet du métamérisme des observateurs. On a trouvé que (1) ces vingt fonctions spectrales peuvent être reconstruites à l'aide de trois fonctions de déviation; (2) les premières fonctions de déviation définissent un nouvel „Observateur-Standard Divergent" qui présente une haute corrélation entre les indices de métamérisme des observateurs et la moyenne des vingt observateurs individuels (3).
Ce nouvel „Observateur-Standard Divergent" suffira pour l'évaluation des différences des effets de métamérisme des observateurs.

Die von Wyszecki und Stiles (1967) angegebenen individuellen Spektralwert-Funktionen wurden für die Untersuchung über die Auswirkung der Beobachter-Metamerie analysiert. Dabei ergab sich: 1. Die 20 Spektralwert-Funktionen lassen sich gut mit Hilfe von drei Fehler-Funktionen darstellen; 2. Die ersten Fehler-Funktionen können zur Definition eines neuen „Abweichungs-Normalbeobachters" (SDO) verwendet werden, der eine hohe Korrelation zwischen den Beobachter-Metamerie-Indizes und dem Mittelwert der 20 individuellen Beobachter zeigt; 3. Dieser neue „Abweichungs-Normalbeobachter" genügt daher für die Bewertung der zu erwartenden Beobachter-Differenzen.

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The metamerism subcommittee of CIE has studied to specify an index of metamerism for observer differences. These observer differences are supposed to be caused by the differences in their color-matching functions.

The 10 degree color-matching functions $\bar{r}(\lambda)$, $\bar{g}(\lambda)$, $\bar{b}(\lambda)$ of 20 individual observers have been published[1]. By use of these color-matching functions, the average of 20 indices of metamerism may be calculated for any sample pair, which is metameric with respect to the reference color-matching functions and an illumination used. This averaged index is expected to be a meaningful measure of observer metamerism. The calculation, however, is too laborious to use in practice.

Allen[2] proposed an index for change from the CIE 1964 standard observer to a standard deviate observer(SDO), which he derived from the variances and the covariances of the above 20 color-matching functions. He replaced the 20 actual observers to one SDO. His observer-metamerism index was derived between the CIE 1964 standard observer and one test observer(SDO). Later, Strocka[3] studied how many observers were to be chosen to have a good correlation between the averaged metamerism index of the 20 observers and that of the selected observers. He recommended to use two suitably selected color-matching functions as the test observers.

The purpose of the present paper is derive new SDO's based on the same 20 observers by using an analysis different from Allen[2], and to decide how many test observers are needed, whether one or two.

Decomposition of color-matching functions.

The color-matching functions $\bar{r}_p(\lambda)$, $\bar{g}_p(\lambda)$, $\bar{b}_p(\lambda)$ of the 20 observers are transformed to $\bar{x}_p(\lambda)$, $\bar{y}_p(\lambda)$, $\bar{z}_p(\lambda)$ by the equations in page 427 of Ref.[1]. The subscript p corresponds to each observer, and runs from 1 to 20. The functions $\Delta\bar{x}_p(\lambda)$, $\Delta\bar{y}_p(\lambda)$, $\Delta\bar{z}_p(\lambda)$ are derived which are the deviations of the p'th color-matching functions from those averaged for the 20 observers. These deviations are represented by a 20 × 93 matrix

$$[m_{p\lambda}] = \begin{bmatrix} \Delta\bar{x}_1(400),\ldots,\Delta\bar{x}_1(700),\ \Delta\bar{y}_1(400),\ldots,\Delta\bar{y}_1(700),\ \Delta\bar{z}_1(400),\ldots,\Delta\bar{z}_1(700) \\ \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \\ \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \\ \Delta\bar{x}_{20}(400),\ldots,\Delta\bar{x}_{20}(700),\Delta\bar{y}_{20}(400),\ldots,\Delta\bar{y}_{20}(700),\Delta\bar{z}_{20}(400),\ldots,\Delta\bar{z}_{20}(700) \end{bmatrix}.$$

The subscript λ runs from 1 to 93, and λ in parentheses corresponds to wavelength(nm). This matrix is analyzed by the method of singular-value decomposition[4], and decomposed as

$$m_{p\lambda} = \sum_{i=1}^{20} \sqrt{\mu_i}\,\xi_{ip}\eta_{i\lambda}\ , \qquad (1)$$

where the values μ_i (i=1,2,..,20) are eigen values of a 20 × 20 matrix $[a_{pq}]$ with the elements $a_{pq}=\sum_\lambda m_{p\lambda}m_{q\lambda}$. All the eigen values are positive and arranged in the order as $\mu_1 \geqq \mu_2 \geqq \cdots \geqq \mu_{20}$. The value ξ_{ip} is the p'th element of a 20 dimensional vector $\vec{\xi}_i=(\xi_{i1},\xi_{i2},\ldots,\xi_{i20})$. The vectors $\vec{\xi}_i$ (i=1,2,...,20) are eigen vectors of the matrix $[a_{pq}]$ and mutually constitute an orthonormal system. The value $\eta_{i\lambda}$ is given by

$$\eta_{i\lambda} = (1/\sqrt{\mu_i})\cdot\sum_p m_{p\lambda}\xi_{ip}\ , \quad (\lambda=1,2,\ldots,93).$$

The eigen value μ_i represents a contribution of the i'th component in Eq.(1) to the total variance of the 20 color-matching functions, and $\mu_i/\sum_i \mu_i$ is called a contribution factor of the i'th component. The computed results of the contribution factors are 56.4% for the 1st component, 17.8% for the 2nd, 10.5% for the 3rd, and 5.4% for the 4th. As the contribution factors are small for the 4th and the succeeding components, the variation between the 20 color-matching functions is well represented by using the first three components. Equation (1) is reduced to

$$m_{p\lambda} \simeq \sqrt{\mu_1}\,\xi_{1p}\eta_{1\lambda} + \sqrt{\mu_2}\,\xi_{2p}\eta_{2\lambda} + \sqrt{\mu_3}\,\xi_{3p}\eta_{3\lambda} \; .$$

Fig.1(a) shows the deviation functions of the 1st component $\eta_{1\lambda}$ multiplied by $\sqrt{\mu_1/19}$, where $\eta_{1,1}$ to $\eta_{1,31}$ correspond to $\Delta\bar{x}_{(1)}(\lambda)$, $\eta_{1,32}$ to $\eta_{1,62}$ to $\Delta\bar{y}_{(1)}(\lambda)$, and $\eta_{1,63}$ to $\eta_{1,93}$ to $\Delta\bar{z}_{(1)}(\lambda)$, and $\Delta\bar{x}_{(1)}(\lambda)$, $\Delta\bar{y}_{(1)}(\lambda)$, and $\Delta\bar{z}_{(1)}(\lambda)$ are separately shown in Fig.1(a). We call these the deviation functions of the new 1st SDO. Figure 1(b) shows the deviation functions of

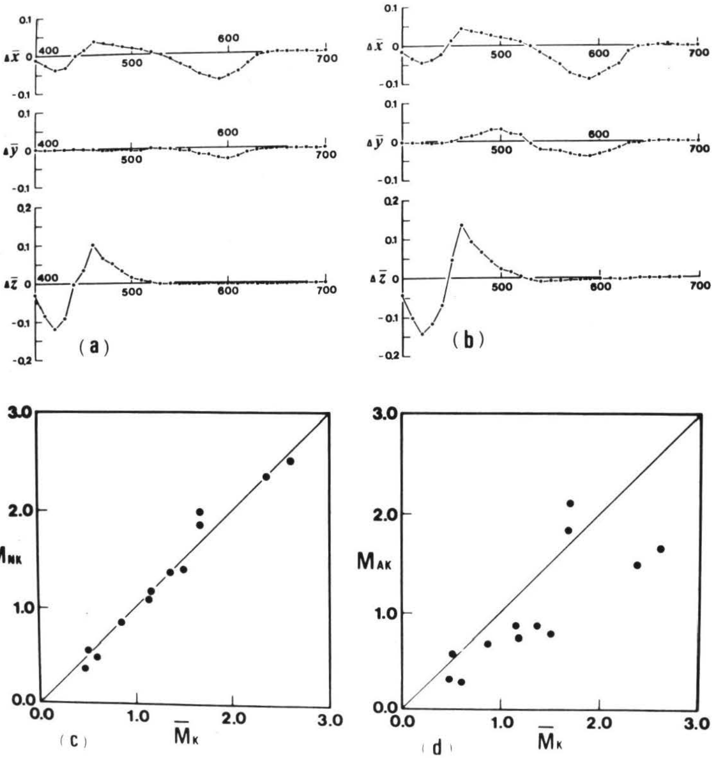

Fig.1 (a) The deviation functions of the new 1st SDO. (b) The deviation functions derived by Allen. (c) Correlation between the mean metamerism indices(20 observers) and the indices of the new 1st SDO. (d) Correlation between the mean metamerism indices and the indices of Allen's SDO.

the Allen's SDO. Though two sets of functions in Figs.1(a) and 1(b) are very similar, these SDO's are quite different from each other in predicting the effect of observer metamerism.

By the similar procedure, we can derive two other deviation functions of SDO's corresponding to $\sqrt{\mu_2/19}\,\eta_{2\lambda}$ and $\sqrt{\mu_3/19}\,\eta_{3\lambda}$.

Observer metamerism

The analysis was done on the basis of the calculation of metamerism indices with 12 metameric sample pairs[5], each of which consisted of a nonselective gray and one of the 12 metameric grays[6]. Their metamerism is stronger than other actual metameric pairs, and this may stress the difference between the new 1st and the Allen's SDO in estimating the indices of the observer metamerism.

For every one of the 12 metameric sample pairs(subscript k), indices of metamerism M_{pk} were calculated by changing the reference observer to each of the 20 individual observers(subscript p) under D_{65}. The residual color differences in the metameric sample pairs under the reference conditions were eliminated by the multiplicative correction[7] including the succeeding computations. The mean index of the 20 observers

$$\bar{M}_k = (1/20)\cdot\sum_p M_{pk}$$

was taken as a reference of observer metamerism of the k'th sample pair.

Then, metamerism index for each sample pair k was derived by changing the reference observer to the new 1st SDO by the present authors or to the Allen's one. The former is shown by M_{NK} and the latter by M_{AK}. The correlation between $\bar{M}_K$ and M_{NK} is shown in Fig.1(c), and the correlation coefficient is high(r=0.9848). On the other hand, the correlation between $\bar{M}_K$ and M_{AK} is shown in Fig.1(d), and the correlation coefficient is not so satisfactory(r=0.7989) as suggested by Strocka[3].

By using the 68 metameric sample pairs[8] as Strocka used, the same correlation coefficient was calculated and was 0.9848 for the new 1st SDO.

The additional use of two other new SDO's did not improve the correlation.

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Anders Hård, Göteborg (Schweden):

Psychophysical Co-relation Between Psychometrics of NCS and Physical CIE-measurements

After having established the basic concept of the NCS (the Natural Color System) psychometric colour space, colour samples have been produced to illustrate uniform spacing of the system. By instrumental measurement of the samples it has been possible to formulate physical correlates in the CIE-system to the psychometrics of NCS. A data-program has been worked out, and X Y Z-data for 16,000 NCS-colour notations will be published.

Après l'établissement de l'espace psychométrique pour le Système Naturel des Couleurs (NCS), des échantillons sont produits pour démontrer la distribution équidistante dans le système. A l'aide de la mesure des échantillons on savait formuler les relations colorimétriques du système CIE. On a élaboré un programme de l'ordinateur pour calculer les valeurs trichromatiques CIE pour 16000 notations NCS.

Nachdem ein Grundkonzept für den psychometrischen Farbenraum des Natural Color Systems (NCS) aufgestellt war, wurden Farbproben hergestellt, um die Gleichabständigkeit des Systems zu zeigen. Durch Farbmessung der Farbmuster konnten die farbmetrischen Beziehungen des NCS-Systems zum Normvalenzsystem formuliert werden. Ein Computer-Programm ist dafür ausgearbeitet worden, um 16000 NCS-Farbbezeichnungen berechnen zu können.

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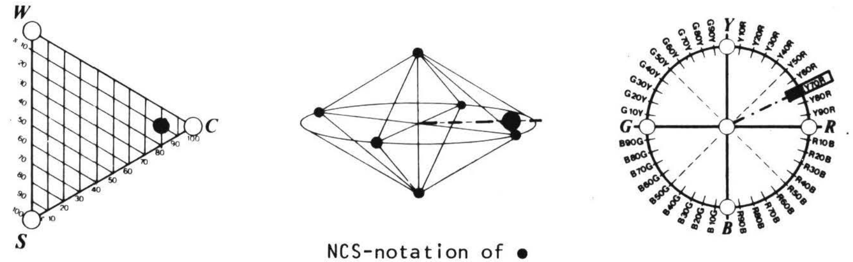
The NCS (Natural Color System) represents, in its general sence, a psychometric structure of how colours are related based on phenomenological analyses. In this context colour means nothing but appearance, most probably conforming with the word's original meaning. Thus, the NCS is an abstraction that can be graphically shown as "the NCS colour space with its two projections, the NCS colour Triangle and the NCS colour Circle".



NCS-notation of ●
1080-Y70R

Fig 1 Graphical representation of a colour in NCS colour space and notation

Another way to symbolise the characteristics of a colour perception is the combined letter-digital combination accepted as a Swedish standard for colour notations. It is deduced from the fact that any colour can be related to the six elementary colours white, black, yellow, red, blue and green by its apparent degree of resemblance to them. The graded (0-100) resemblance to white is called the elementary attribute whiteness (w), to black blackness (s from swarthy), to red redness (r) etc.

just as
However, we need rulers to make the meter-system practically useful, we need colour samples to illustrate the NCS colour measures. In the NCS colour atlas, the samples are not the NCS-system but represent their notations under a restricted set of observing conditions.

From this one can relate the psychometrics of the NCS to the physiometrics of the CIE-system under a restricted set of conditions for measuring samples in physical terms. Thus, it has been possible to establish a psycho-physical correlation between NCS and CIE for just one combination of observing and stimulus-measuring conditions.

Experimentally this followed a certain schedule:

a) The spacing of the four hue-scales was carried out on some different nuance levels (a certain nuance is represented in the NCS Triangle by a point). Thus, we found colour samples representing appearance constants of different hues. This was also checked by simultaneous inter comparison between such samples (fig 2a).

b) For achromatic colours spacing experiments between white and black ended up in the equation (1) for relationship between appearant blackness (s) and luminous reflectance factor Y_ℓ

$$s = 100 - 156 \cdot Y_\ell (Y_\ell + 56) \qquad \text{(whiteness is 100 - s).} \qquad (1)$$

c) For each hue, spacing experiments took place for the scales between the maximum chromatic colour C, to white W and to black S respectively. The result was used to produce samples in every hue ϕ to represent every 10th step in blackness/whiteness of constant chromaticness c (chromatic amount) (fig 2a,b), every 10th step in whiteness/chromaticness of constant blackness s (fig 2a,c), and every 10th step in blackness/chromaticness of constant whiteness w (fig 2a,d).

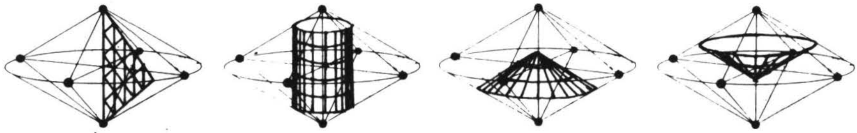


Fig 2a - d How samples were cross-examined in NCS-experiments

The uniformity and constancy in every scale and attribute was visually cross-checked in every possible combination of attributes (fig 2a-d) by 5-10 critical observers. Every sample was adjusted until accepted as being a natural part of each serie. These 900 samples represented what is called the PROTOTYPE of the NCS Colour Atlas.

These colour samples illustrate or concretise a 100-psychometrics of the NCS colour space (which is closed according to its own definition, but maybe there exists an outer space) and thus forming a NCS Colour Solid.

The samples were measured in a Zeiss DMC25 for standard light C (as D65 recommendation was not realizable). Polar CIE-coordinates were adopted for the psycho-physical comparison as described in fig 3.

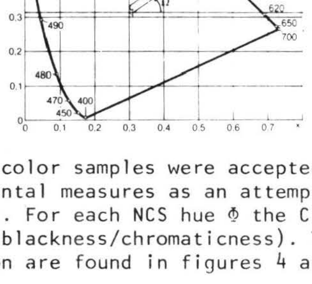


Fig 3 Polar coordinates in CIE diagram

Y_ℓ = luminous reflectance factor

D = chromaticity distance

Ω = chromaticity angle

Now the color samples were accepted as the experimental result and the instrumental measures as an attempt to find an acceptable physical correlation. For each NCS hue Φ the CIE values were denoted for every 10th nuance (blackness/chromaticness). The final conclusions of this interpretation are found in figures 4 and 5.

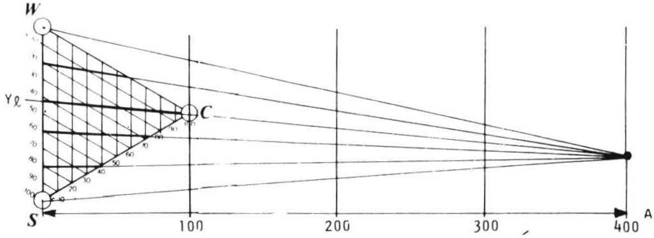
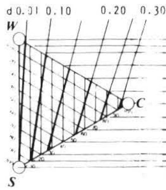


Fig 4 Correlation with Y_ℓ

Lines representing constant Y_ℓ are straight and convert to a point outside the NCS triangle, and the distance to the converging point and the Y_ℓ-line through C varies over hue.



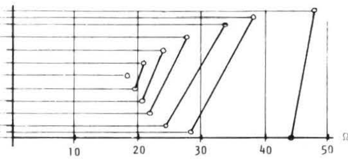


Fig 5a Correlation with D

Constant D-values are straight between random values for chromaticness c on the C/W- and C/S-scales

Fig 5b Correlation with Ω

Constant Ω-values vary linearly with blackness s for constant chromaticness c between random values on the C/W- and C/S-scales.

By specifying, for every 5th hue

- the Y_ℓ for C and the A-distance
- the c-values for D-values 0.010, 0.020, 0.040, 0.060 etc on the C/W- and the C/S-scales and
- the Ω-values on the C/W- and the C/W-scales for c-values of 5, 10, 20 etc

- the NOMINAL CIE (X Y Z)-data for every 5th colour sample in the colour solid representing the NCS colour space could be calculated.

These figures will be available as specification tables for 16,000 NCS colours. Also are available corresponding tables for the NCS colours represented in the NCS colour atlas, also adopted as Swedish standard SS 01 91 02. So has also been developed an INVERSE program converting CIE-(X Y Z) readings to NCS coordinates. Used on the PROTOTYPE - colour atlas the deviation of predictions from that program to experimental result is less than 3 NCS units as an average, compared with confidence interval of 5 for the psychometric experimentation.

The paper is sent to COLOR, RESEARCH AND APPLICATION, USA, for publication in full.

William A. Thornton, Co-authors: E. Chen, E.W. Morton, D. Rachko all of Westinghouse Lamp Divisions, Bloomfield (N.J.):

A Brightness-Meter Which Copies Human Vision

A meter measuring perceived brightness, rather than luminance, is needed. The footcandle-meter and the human observer usually disagree when comparing brightness of illuminations of different spectral power distribution. Unlike the footcandle-meter, the human visual system is non-additive and multiple-input. A brightness-meter having these characteristics is shown to correlate much better to human vision.

On a besoin d'un instrument qui indique la luminosité perçue au lieu de la luminance. L'observateur humain souvent n'accepte pas l'indication de l'illuminomètre si les luminosités d'illuminances de différentes compositions spectrales sont à comparer. Au contraire à l'illuminomètre l'oeil humain n'évalue pas additivement, et il a plusieurs entrées. Ici on présente un mètre à luminosité qui a ces propriétés et dont l'indication correspond mieux à la vision humaine.

Man braucht ein Meßgerät, das die wahrgenommene Helligkeit und nicht die Leuchtdichte anzeigt. Der Beleuchtungsmesser und der menschliche Beobachter stimmen meistens nicht in ihrem Urteil überein, wenn die Helligkeiten von Beleuchtungen mit verschiedener spektraler Zusammensetzung verglichen werden sollen. Anders als der Beleuchtungsmesser arbeitet das menschliche Sehsystem nicht additiv und hat mehrfache Eingänge. Hier wird ein Helligkeitsmesser vorgestellt, der diese Eigenschaften hat, und daher entspricht seine Anzeige dem menschlichen Auge viel besser.

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The need for a meter to quantify brightness is very great. Problems related to the use of the footcandle meter for this purpose are summarized. A design for a brightness meter, which much more nearly correlates to what the normal observer sees, is described. The meter functions according to the expression

$$\beta = fc + B - Y + |G - R|$$

where β is perceived brightness, fc represents the measured footcandle level, and B,Y,G,R are blue-content, yellow-content, green-content and red-content of the illumination, defined by four specific spectral responses. Being necessarily a "four-eyed" meter, it reintroduces the question of the dimensionality of human vision. Also raised is the question, "If image-formation and color-contrast contribute to the sensation of brightness, how can a meter without this capability correlate so well with humanly perceived brightness?" We do not have a unit for amount of light with the guarantee of seeing better the more there is. Early this century some experiments with flickering lights were interpreted to mean that the normal human visual system responds to light of different wavelengths according to what we now call the $\bar{y}$ curve. The need for a detector to substitute for the human visual system was already very great. These experimental results were seized upon, and the $\bar{y}$ curve was immediately put to use as if it were indeed representative of human vision under ordinary conditions. Eventually it came to be regarded by most as the essential spectral response of human vision. It also became the basis of the lumen and footcandle, and hence of the design of artificial illumination. A detector with this response is said to measure luminance. To this day, the footcandle (fc)-meter is considered by most to be arbiter of "how much light." To quote MacAdam, "It recognized and standardized the only available, precise, and unambiguous approximation to the solution of an urgent technical problem."[1] The trouble is that the fc-meter usually disagrees with a human observer on comparison of two amounts of light, when the spectral power distributions of the two lights differ. Wright comments: "The embarrassing situation can arise that a fluorescent lamp A of one colour may look brighter than a lamp B of slightly different colour, although the lumen output of B as measured photometrically is greater than that of A."[2] That is, the lamps would be ranked one way by their measured luminance, and the other way by their perceived brightness. Another trouble with a fc-meter is that it is additive. But, to quote MacAdam again, "It is easy to show that the law of additivity, which necessarily applies to luminance because of its definition, does not apply to brightness."[3] MacAdam describes an example in which white light, from which some red component is removed, becomes bluish-green and "very obviously brighter than the (original) white."[3] The fc-meter would disagree with the observer in this experiment also, since the removal of red-fc component from the white light can only reduce the fc content of that light. Yet its brightness increases. A third trouble with the fc-meter: Two commercial lamps may emit light of the same color, and yet the two spectral power distributions may be markedly different. Let two identical furnished rooms be illuminated, one by each type of lamp, and the fc level be equalized. One room may be considerably brighter than the other.

Thus the discrepancies between measured luminance on the one hand, as measured by the fc-meter, and visually perceived brightness on the other, all arise because of differences in the spectral power distributions of the two illuminants to be measured and compared. The objective of this paper is to progress toward a meter that measures perceived brightness, which corresponds to what an observer sees, rather than luminance, which often does not correspond to what an observer sees.

What precision can be expected of a human observer's assessment of perceived brightness? MacAdam[5] points out that errors in direct visual comparison are not generally very large (1-5 percent), and Breneman's results[6] suggest that errors may be about 2-3 percent in the region of chromaticity of commercial light sources. Can the operation of a practical brightness meter be based simply upon additivity? Judd points out[4] that Helmholtz by about 1870 had noticed the failure of additivity, and Judd sums up the present situation by stating that no additive definition of light can possibly meet the requirement that equal amounts of light, measured additively, always appear equally bright to an average observer. So the fc-meter cannot possibly be dependable. If red and green lights are mixed (to form a yellowish light), the perceived brightness of G + R will be considerably less than the sum of the brightnesses of G and of R.[4] A brightness meter, if it is to respond to an illuminant as does the normal human observer, cannot simply add the brightnesses of the spectral parts, or slices, by generating independent output signals each of which is characteristic of some slice. Effects such as this can be described conveniently by reference to brightness-per-footcandle of lights of different colors. Wright's comment[2] can be stated this way by saying that a cool white fc is somewhat brighter than a warm white fc. Chapanis and Halsey[7] determined the brightness-per-footcandle (β/fc) for lights of many colors. The general shape of the contours of perceived β/fc, as exemplified in Fig.1, suggest that yellowish lights are dimmest, per footcandle, both along the blue-to-yellow axis of the color diagram and along the green-to-red axis. The β/fc is relatively high for green light and for red light. When, however, power at green wavelengths are both present in a light, the color of the light is shifted toward the yellow and β/fc decreases. The β/fc contours also suggest that the greater the blue-content and the smaller the yellow-content, the brighter the light. Thus perceived brightness may vary as $B-Y+|G-R|$. We put back the "footcandle" term, and assume that perceived brightness $\beta = fc+B-Y+|G-R|$. Notice that if we assume wrongly that the fc-meter measures brightness, we are saying that $\beta = fc$. The "fc" response can be synthesized by a linear combination of B,G,Y, and R, and so only four detectors are necessary in such a brightness meter. For present purposes, we use the four spectral responses of Fig.2.

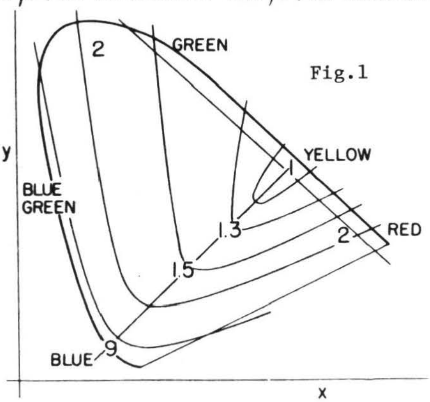

Fig.1

Experiment: In this work, two small identical contiguous furnished rooms were used. One room was illuminated by fluorescent lamps of one type, and the other room by fluorescent lamps of another type. The observer was asked to dim the brightest room until the averaged perceived brightnesses were equal. The fc levels -- one of them always in the neighborhood of 100 fc -- were then measured. Table I lists the results. For example, for equal perceived brightness, the human observers required 78 fc of standard daylight fluorescent to 100 fc of standard warm white fluorescent. The ten pairs of illuminants include standard lamps, prime-color lamps (in which output is concentrated near 450, 540, 610 nm), an anti-prime-color lamp (in which output is concentrated in the yellow and blue-green), and saturated yellow, blue, red and green lights. Pairs 5-7 are the same in source-color. The four stimulus values B,G,Y,R are computed for each of the ten illuminants, from its SPD. The coefficients of expression (1) are chosen for best fit to column (1) of Table I, with the results

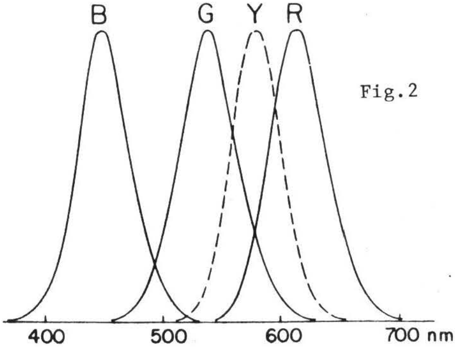

Fig.2

$$\beta = 0.38B + 1.62G + 0.55R - 0.32Y + |0.42G - 0.42R| \qquad (1)$$

shown in column (2). It is important to bear in mind that the usage of traditional photometry, colorimetry, and the footcandle meter is that brightness-per-footcandle β/fc is a constant, depending neither on the color of light nor on its spectral power distribution. We show in this paper that β/fc is not constant, but (1) shows rather systematic variation with color of the illuminant, as so many have shown before, and (2) shows systematic variation with spectral power distribution, even when color of the illuminant is constant. This is to be expected of a detector -- the human observer -- with multiple inputs and signal-processing which is not simply linear.

	TABLE I	(1) Human Observers	(2) Brightness Meter	fc Meter
1	Std. WW vs std. day	0.78	0.74	1
2	Std. WW vs prime-color CW	0.77	0.73	1
3	Std. WW vs std. CW	0.92	0.90	1
4	Std. CW vs std. day	0.87	0.82	1
5	Antiprime CW vs std. CW	0.78	0.74	1
6	Std. CW vs prime-color CW	0.80	0.81	1
7	Std. WW vs prime-color WW	0.75	0.73	1
	Yellow	(1.00)	(1.00)	1
8	Green vs yellow	2.0	1.9	1
9	Red vs yellow	2.0	1.8	1
10	Blue vs yellow	9.0	10.3	1

References: (1) D.L.MacAdam, JOSA, 44, 9, 724 (1954). (2) W.D.Wright, The Measurement of Colour, 4th Ed. (1969) Van Nostrand, p.66. (3) D.L.MacAdam, JOSA, 40, 9, 591 (1950). (4) D.B.Judd, Illum.Engin., 53, 2, 61 (1958). (5) D.L.MacAdam, ref.4, in "discussion". (6) E.L.Breneman, JOSA, 48, 4, 228 (1958). (7) A.Chapanis and R.M.Halsey, JOSA, 45, 1, 1 (1955).

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Robert W.G. Hunt, Assistant Director of Research, Kodak Ltd., Harrow (Engl.):

A Theory of Hue Appearance

Constant hue loci in chromaticity diagrams are predicted well by constant ratios of differences in square-roots of cone responses. Unique red, green, yellow and blue correspond to four simple values of these ratios.

Les lignes de tonalité constante dans un diagramme chromatique sont bien représentées par des quotients constants des différences des racines carrées des réponses des cônes. Les couleurs uniques rouge, vert, jaune et bleu correspondent à quatre valeurs simples de ces quotients.

Die Linien empfindungsgemäß konstanten Bunttons in der Farbtafel lassen sich gut darstellen als konstante Verhältnisse der Differenzen der Quadratwurzeln der Grundfarbwerte. Urrot, Urgrün, Urgelb und Urblau entsprechen vier einfachen Werten dieser Verhältnisse

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The purpose of this paper is to seek a relationship between colour appearance data for hue, and a typical set of cone spectral sensitivity functions. No unique set of cone functions has been established, but Estevez, arguing that the best set of experimentally determined 2^{o} colour matching functions are those of Stiles and Burch[1] has used these functions to determine a set of cone spectral sensitivities that adequately account for colour deficiency data[2]. These cone functions have been normalized for Standard Illuminant C (S_C). A simple linear transformation of this R,G,B system yielding a chromaticity diagram that is very similar in shape to the u',v' diagram, is obtained by plotting $\frac{2}{3}b'$ against $r'-g'$, where r', g', b' are chromaticity co-ordinates corresponding to responses $R'=1.05R$, $G'=1.35G$, $B'=0.6B$.

In the figure, the outer full line is the spectral locus and S_C is situated at $r'-g'=-0.1$ and $\frac{2}{3}b'=0.133$. The outer broken line is the u',v' spectral locus when S_C is located at the same point, and when the straight, long-wavelength, portions of the two spectral loci are parallel. It is clear that the two chromaticity diagrams are very similar.

Constant Hue Loci

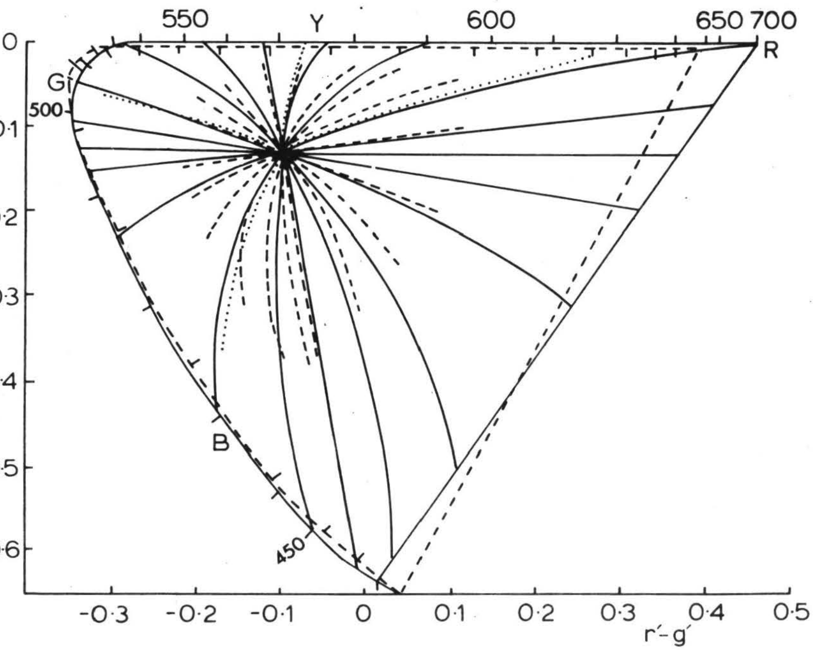
It is well known that constant hue loci in chromaticity diagrams are curved. One of the most thorough investigations of these loci for surface colours was that by Wilson and Brocklebank[3] and their results, after transformation to the u',v' diagram, are shown in the figure by the broken lines radiating from the S_C point. The constant hue loci of the Swedish NCS and Munsell systems and those determined by MacAdam are broadly similar.

The full lines in the figure are lines of constant ratios of $(R'^{1/2}-G'^{1/2})$ to $(G'^{1/2}-B'^{1/2})$. These lines have three directions in which they are straight, corresponding to dominant wavelengths of about 567, 498, and 493 nm. These directions correspond closely to those in which the Wilson and Brocklebank broken lines are also straight, and the curvatures of the full lines in the other directions coincide closely with the curvatures of the Wilson and Brocklebank lines. That such a simple criterion based on the RGB responses correctly predicts such a complicated pattern of line curvatures is a gratifying result.

Wilson and Brocklebank also found that after-image loci followed the same pattern as constant hue loci and this suggests that the square-root functions may represent physiological responses at a post cone-absorption stage.

Unique Hue Loci

Also shown in the figure, by the dotted lines, are loci for the unique red, green, yellow, and blue, hues of the NCS system[4]. The curvature of these lines is, again, closely similar to those of the full lines. (For the unique blue line, the curvature is more similar to that of the full line than for the Wilson and Brocklebank line.) The full line labelled, R, which lies close to the NCS red locus, is the line for which $R^{1/2}-G^{1/2}=G^{1/2}-B^{1/2}$: this can be rewritten as $G^{1/2}=\frac{1}{3}(R^{1/2}+G^{1/2}+B^{1/2})$; for the illuminant ($S_C$), $R=G=B$, so that, again, $G^{1/2}=\frac{1}{3}(R^{1/2}+G^{1/2}+B^{1/2})$. Thus the criterion for unique red is the strikingly simple one that $G^{1/2}/(R^{1/2}+G^{1/2}+B^{1/2})$ has the same value as for the illuminant. The full line labelled G, which lies close to the NCS green locus, is the line for which $R^{1/2}-G^{1/2}=-\frac{1}{2}(G^{1/2}-B^{1/2})$: this can be rewritten as $G^{1/2}-R^{1/2}=R^{1/2}-B^{1/2}$ or as $R^{1/2}=\frac{1}{3}(R^{1/2}+G^{1/2}+B^{1/2})$. Thus the criterion for unique green is, again, a simple one, namely that $R^{1/2}/(R^{1/2}+G^{1/2}+B^{1/2})$ has the same value as for the illuminant. The unique red and green loci do not together form a smooth locus, but have a discontinuity at the illuminant point; this is a consequence of the criteria being different for unique red and unique green.



It is clear from the figure that the loci for NCS unique yellow and unique blue (the remaining two dotted lines) also have a discontinuity at the illuminant point, so that, again, different criteria must be involved. The full line labelled Y, which lies close to the NCS yellow locus, is the line for which $R^{1/2}-G^{1/2}=(1/11)(G^{1/2}-B^{1/2})$: this can be rewritten as $R^{1/2}=(12/11)G^{1/2}-(1/11)B^{1/2}$. The full line labelled, B, which lies close to the NCS blue locus is the line for which $R^{1/2}-G^{1/2}=\frac{1}{4}(G^{1/2}-B^{1/2})$: this can be rewritten as $R^{1/2}=(5/4)G^{1/2}-\frac{1}{4}B^{1/2}$. If these relationships arise because, prior to comparison with the $R^{1/2}$ response, the $G^{1/2}$ response is partially inhibited by the $B^{1/2}$ response[5], then the discontinuity at the illuminant point indicates that the extent of the inhibition is different for yellowish and bluish colours.

Wilson and Brocklebank found that pairs of complementary after-image loci did not exhibit discontinuities at the illuminant point, and this suggests that the criteria for the unique hues is established at a stage in the visual pathway subsequent to that at which after-images arise.

Conclusions

Constant hue loci in chromaticity diagrams are predicted well by constant ratios of differences in square roots of cone responses, $(R^{1/2}-G^{1/2})/(G^{1/2}-B^{1/2})$. Unique red and green correspond to $G^{1/2}/(R^{1/2}+G^{1/2}+B^{1/2})$ and $R^{1/2}/(R^{1/2}+G^{1/2}+B^{1/2})$, respectively, being the same as for the illuminant. Unique yellow and unique blue correspond to $R^{1/2}=(12/11)G^{1/2}-(1/11)B^{1/2}$ and $R^{1/2}=(5/4)G^{1/2}-\frac{1}{4}B^{1/2}$, respectively.

References:

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Scaling Saturation by Matching to Achromatic Samples

A comparison is presented among the results obtained by judging saturation under three different matching tasks: matching quantity of colour to numbers (numerical estimation), matching quantity of colour to quantity of white and black (intramodal matching), and matching differences in the quantity of colour to differences in the quantity of grey (interval intramodal matching). The availability of these tests leads to new possibilities in the measurement of surface colours.

On a fait des comparaisons entre les résultats d'une estimation de saturation par trois problèmes de comparaison: coordination de quantités de couleur aux nombres (estimation numérique), coordination de quantités de couleur aux quantités de blanc et noir („estimation intramodale"), et différences de coordination de quantités aux différences de quantité de gris („estimation intervalle-intramodale"). De l'utilité de tels tests des possibilités nouvelles pour le mesurage des couleurs d'objet résultent.

Es wurden Vergleiche angestellt zwischen den Ergebnissen einer Sättigungs-Abschätzung bei drei verschiedenen Abmusterungsaufgaben: Zuordnung von Farbmenge zu Zahlen (zahlenmäßige Schätzung), Zuordnung von Farbmenge zu Menge an Weiß und Schwarz („Intramodal-Vergleich") und Zuordnungsunterschiede von Farbmengen zu Mengen-Unterschieden in Grau („Interval-Intramodal-Vergleich"). Die Brauchbarkeit dieser Tests ergeben neue Möglichkeiten zur Messung von Körperfarben.

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The method of matching one chromatic sample to another is one of the techniques most widely used in colour measurement When the stimuli are pigmented surfaces, experimental tasks call for a technique that takes into account the difficulties involved in the preparation of the samples. For this reason, in the last few years we have used the method of numerical estimation in which the magnitude of the stimuli (luminance or saturation) are matched to a number magnitude.

The present work represents an attempt to measure pigmented surfaces by matching them to grays samples applying two non numerical procedures: intramodal matching(I) and interval intramodal matching (II).

I - Matching chromatic samples to blackness and whitness

Twenty six experiments were performed, two under the method of numerical estimation,and the others under the intramodal matching procedure. In the two first experiments, ten Os. scaled a set of grey samples by assigning numbers to the blackness first and then to the whitness of each sample . Results are shown in fig. la. In the experiments that followed were presented at the Os. four set of different hues - blue, green, yellow and red - at three levels of reflectance They matched the amount of colour (saturation) to the amount of white (W) and to the amount of black (B) of the samples. Figure 1 b-c shows as an example, the power functions obtained for a red set. The data for the other three hues adjusted equally well to power functions and the respective exponents are shown in Table I. The same Table show also the exponents obtained in a previous work (1) for the same samples used here judged under the method of numerical estimation. These exponents (NE) can be used to predict the exponents for intermodality matching procedure by applying a standard calculation (2). The difference (in decilogs) between the predicted and obtained exponents is also indicated in Table I. The average difference was somewhat lower for matching to white (0.465) than for matching to black (0.494) It is observed that, in general, the slope of the power functions obtained by numerical matching is equal to or steeper than the functions obtained by non numerical matching.

II - Matching pair of chromatic samples to pair of gray

Seventeen experiments were performed in order to scale differences of grays and differences in colorimetric purity.

At the first place ten Os estimated a set of nine pairs of grays samples by the method of numerical estimation. Each pair exhibited an average differences in luminance of 20% reflectance. Results are presented in Fig. 2a. Nex, the same procedure was used to scale, pair by pair, pigmented surfaces at 20 % of reflectance. Figure 2b shows the results. Finally the contrasted pair of greys samples were compared with the contrasted pair of colors samples and the results are shown in Fig. 2c. The values between brackets in the figure show the difference in decilogs between the exponents obtained under both procedures: numerical estimation (Fig2b) and interval intramodal matching (Fig 2c). The average decilog difference, between the obtained and the predicted exponents (0.12), was substantially lower than the one obtained when the quantity of colour was matched to black and white. A relevant outcame here is the fact that it is possible to use gray samples as an stick to measure surface colors. In addition to the possible perceptive implications of the present results it becomes evident that since the judgments are referred directly to a gray common scale, the collected data can be easily standardised, in spite of the differences in hue, saturation and luminance.

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	BLUE(460nm)			GREEN (510nm)			YELLOW (580nm)			RED (620nm)		
a-	12%	40%	65%	12%	40%	65%	12%	40%	65%	12%	40%	65%
b-	1.35	1.42	0.85	1.60	1.80	1.00	1.73	3.73	2.90	1.69	1.35	1.00
c-	1.27	1.50	1.15	1.85	1.55	0.84	1.94	3.93	2.65	1.50	1.35	1.03
d-	0.26	0.24	1.30	0.63	0.65	0.75	0.49	0.23	0.39	0.52	0.00	0.13
e-	1.00	0.81	0.60	1.20	1.20	0.47	1.08	3.30	1.60	1.17	1.15	0.69
f-	0.92	0.97	0.45	1.10	1.23	0.68	1.18	2.55	1.98	1.15	0.92	0.68
g-	0.36	0.78	1.24	0.38	0.48	1.60	0.38	1.12	0.92	0.07	0.97	0.06

Table I- The letters correspond to: a-Reflectance; b-Exponent (ME); c-Matching (W); d-Difference; e-Matching (B); f-Predicted slope g-Difference.

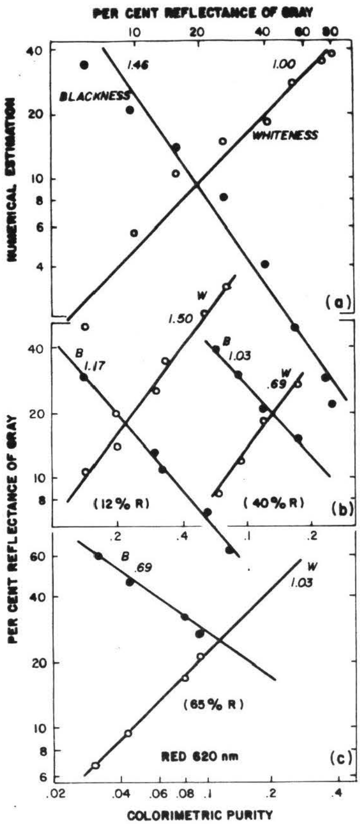

Figure 1

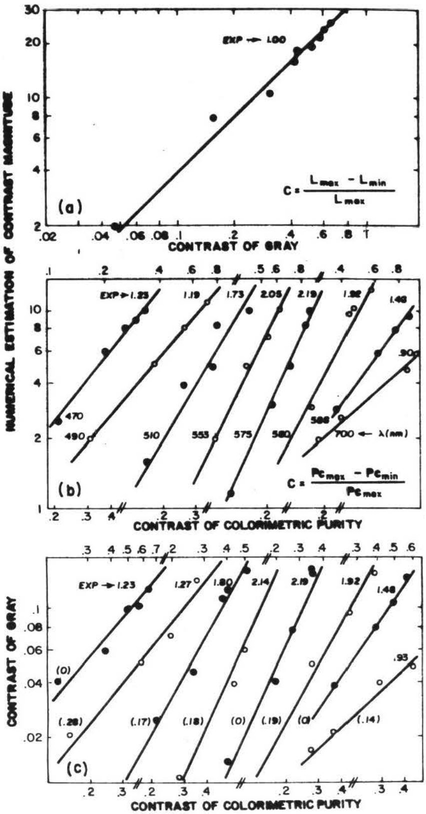

Figure 2

Wolfgang Roddewig, Berlin:

Buntheitsschätzung von Infeldfarben unterschiedlicher Farbart und gleicher Leuchtdichte im Umfeld der Farbart D65

Using two different experimental designs, the chroma of colours with equal luminance was estimated in a test field surrounded by an adaptation field of standard illuminant D65. The results are calculated for different colour spaces and are discussed with regard to the claim of an "ideal" colour space.

On a estimé le chroma de couleurs au moyen de deux expériences différentes. Les couleurs ont la même luminance et l'oeil d'observateur est adapté à illuminant normalisé D65. Les calculs sont présentés dans des espaces de couleurs différents et sont discutés à l'égard d'exigence d'un espace de couleurs „idéal".

In einem Umfeld der Lichtart D65 wurde die Buntheit von Infeldfarben gleicher Leuchtdichte relativ und absolut mittels zweier verschiedener Experimente skaliert. Die Ergebnisse sind in verschiedenen Farbenräumen dargestellt und werden hinsichtlich der Anforderungen an einen „idealen" Farbenraum diskutiert.

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1. Einleitung

Schon lange ist bekannt, daß die Normfarbtafel vielen Erfordernissen der modernen Farbmetrik nicht genügt, so daß die CIE es für nötig befunden hatte, neue Farbenräume zu definieren /1/. Dabei war das Hauptkriterium, eine empfindungsgemäße Gleichabständigkeit zu erreichen, d.h. visuell subjektiv gleichempfundene Farbunterschiede sollen in einem "idealen" Farbenraum als adäquate geometrische Abstände erscheinen. Es hat sich jedoch gezeigt, daß die meisten vorgeschlagenen Farbenräume nur annähernd diesem "idealen" Farbenraum entsprechen und daß weitergehende Modifizierungen nötig sind. So hat die CIE zusätzlich zu ihrem Farbenraum CIEUVW 1964 im Jahre 1976 zwei weitere Farbenräume empfohlen, und zwar den Farbenraum CIELUV 1976, der eine Modifikation des Farbenraums CIEUVW 1964 ist, und den Farbenraum CIELAB, der eine große Verbreitung in der industriellen Anwendung gefunden hat. Diese Zweigleisigkeit erscheint unbefriedigend und führt zu einer Uneinheitlichkeit zwischen den verschiedenen Bereichen, in denen die Farbmetrik angewendet wird. Daraus ergibt sich die Forderung, anhand von Farbexperimenten neue Daten zu gewinnen, mit denen eine Vereinheitlichung möglich ist. Dieser neue Farbenraum sollte für verschiedene Lichtarten definiert sein, was durch Farbumstimmungs- und Farbabstandsexperimente nachgewiesen werden muß. Einen Schritt in diese Richtung hat RICHTER /2/ mit der Definition des Farbenraums LABHNU 1977 getan.
Die hier vorliegenden Ergebnisse sollen einen Beitrag dazu liefern, aufgrund von experimentellen Daten die Stärken und Schwächen der verschiedenen Farbenräume zu diskutieren, um einen Weg zum "idealen" Farbsystem zu finden.

2. Beschreibung der Experimente und ihre Darstellung

In einem Umfeld (10°, 500 cd/m^2, Lichtart D65) wurde ein Infeld (2°, 100 cd/m^2) durch einen Projektor mit einem vorgesetzten, motorisch steuerbaren Filterhalter erzeugt. In dem Filterhalter befanden sich Filter gleichen Transmissionsgrads, so daß eine Vielzahl von Farben gleicher Leuchtdichte, aber verschiedenen Bunttons und Buntheit erzeugt werden konnten.
Mit dieser Versuchsapparatur sind Buntheitsschätzungen durchgeführt worden. Zuerst wurde für acht verschiedene Linttöne eine relative Buntheitsskalierung zwischen Unbunt und der für diesen Buntton maximal einstellbaren Buntheit durchgeführt. Jeder angebotene Buntton sollte empfindungsgemäß gleichabständig in 5 Stufen unterteilt werden. Als zweites wurde eine absolute Skalierung durchgeführt. Zu einer vorgegebenen Farbe gleicher Leuchtdichte wie das Infeld wurde bei allen mit der Apparatur einstellbaren möglichen Bunttönen die gleiche Buntheit eingestellt.

Die Ergebnisse sind in den Farbtafeln bzw. Farbarttafeln verschiedener Farbenräume dargestellt. Dies sind:

1. der CIE-Farbenraum 1931 mit den Koordinaten (x,y)
2. der Farbenraum CIEUVW 1964 mit den Koordinaten (u,v)
3. der Farbenraum CIELUV 1976 mit den Koordinaten (u',v')
4. der valenzmetrische Gegenfarbenraum mit den Koordinaten (a,b)
5. der Farbenraum CIELAB 1976 mit den Koordinaten (a',b')
6. der Farbenraum LABHNU 1977 mit den Koordinaten (A',B')

3. Diskussion der Ergebnisse

Die Ergebnisse sollen anhand der Daten einer ausgewählten Versuchsperson dargestellt und diskutiert werden.
Im "idealen" Farbenraum sollen Farben gleicher Buntheit auf Kreisen um den Unbuntpunkt liegen und die Abstände der Buntheitsstufen gleich groß sein. Die unterschiedlichen Farbabstände der Buntheitsstufen sind in der Normfarbtafel offensichtlich (Bild 1). Ebensowenig liegen Farben gleicher Buntheit auf Kreisen. In der Farbtafel des Farbenraums CIEUVW 1964 sind deutlich Ellipsen statt Kreise zu sehen. Außerdem sind die Abstände der Buntheitsstufen in der Gelb-Rot-Richtung (YR-Richtung) zu klein gegenüber der Rot-Grün-Richtung (RG-Richtung). In den Farbtafeln der Farbenräume CIELUV und im valenzmetrischen Gegenfarbenraum ergeben sich angenähert Kreise, jedoch sind die Abstände der Buntheitsstufen in RG-Richtung für Rot zu weit ausgedehnt.

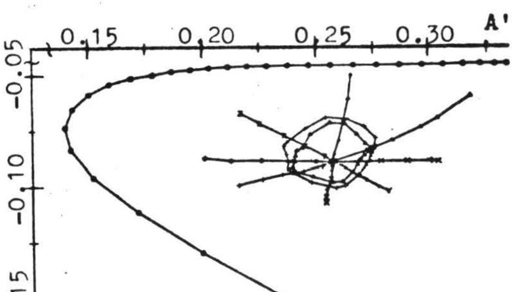

Bild2: Farbarttafel des Farbenraums LABHNU

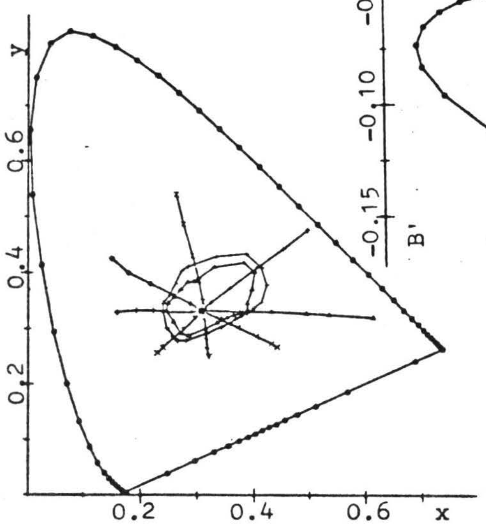

Bild 1: Normfarbtafel

Zu den Farbenräumen CIELAB und LABHNU gehören Farbarttafeln statt Farbtafeln. Farbarttafeln sind nichtlineare Transformationen von Farbtafeln. Üblicherweise werden in der Farbmetrik Kubikwurzeltafeln verwendet. Die Auswirkung der Kubikwurzeltafel ist, daß für die RG-Richtung Grün gestreckt und Rot gestaucht wird und für die YB-Richtung Gelb gestreckt und Blau gestaucht wird. In den Farbarttafeln (a',b') und (A',B') der Farbenräume CIELAB und LABHNU sind Farben gleicher Buntheit angenähert Kreise. In (a',b') ist jedoch Gelb in YB-Richtung zu stark ausgedehnt. Im Farbenraum LABHNU (Bild 2) ist Gelb deshalb gestaucht worden durch die Einführung des Summanden 1/6, der eine Vergleichmäßigung in YB-Richtung bewirkt.
Zusammenfassend kann also gesagt werden, daß sich in dem untersuchten Farbbereich für den valenzmetrischen Gegenfarbenraum und für die Farbenräume CIELUV, CIELAB und LABHNU für Farben gleicher Buntheit angenähert Kreise ergeben. Ferner ergibt sich für den valenzmetrischen Gegenfarbenraum und für den Farbenraum CIELUV die Tendenz, daß in RG-Richtung Rot zu stark ausgedehnt ist.
Die Ergebnisse können auf die Gleichabständigkeit von Körperfarben angewandt werden, da die demonstrierten Farben einen Hellbezugswert von Y=20 besaßen und fast den gesamten durch Körperfarben realisierbaren Farbbereich umgrenzten.

4. Weiterer Ausblick

Mit dem vorgestellten Versuchsaufbau ist eine Vielzahl von farbmetrischen Experimenten möglich, da einzelne Parameter auf einfache Weise bei sonst konstanten Versuchsbedingungen geändert werden können. Besonders interessant erscheinen in diesem Zusammenhang Experimente zur Buntheitsskalierung mit Umfeldern verschiedener Farbart, wie z.B. D65 und A.

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Farbe + Design Nr. 11 (1979), S. 3-12

Der vollständige Text wird in "Farbe + Design" veröffentlicht werden.

Michael H. Brill and Gerhardt West, Alexandria (VA) / Bergisch-Gladbach:

Spectral Conditions for Color Constancy via Von Kries Adaptation

Spectral constraints are presented that are sufficient for Von Kries chromatic adaptation to insure the illuminant-invariance of object colors inferred from adapted tristimulus values (color constancy). Functions of Von-Kries-adapted tristimulus values are also presented that display illuminant invariance for a larger class of illuminant and reflectance spectra. Such a hierarchy of invariants may be useful in developing interdependent lighting and pigment standards in partially controlled viewing environments.

On regarde les nécessités spectrales qui suffisent pour l'adaptation chromatique selon von Kries pour assurer l'invariance des couleurs-objets de l'illuminant qui se dérive des couleurs trichromatiques (constance des couleurs). Aussi on présente des fonctions des valeurs trichromatiques, adaptés selon von Kries qui montrent une invariance de l'illuminant pour un certain groupe d'illuminants et de spectres de réflexion. Un tel groupe d'invariants peut être utile pour développer des combinaisons de sources lumineuses et pigments comme standards pour un contrôle partielle des conditions d'observations.

Spektrale Bedingungen werden aufgezeigt, die für die Farbumstimmung nach von Kries ausreichen, um die Unabhängigkeit der Körperfarben von der Beleuchtung sicherzustellen und die aus angepaßten Farbwerten abgeleitet wurden (Farben-Konstanz). Außerdem werden Funktionen der nach von Kries umgerechneten Normfarbwerten aufgestellt, die für eine größere Gruppe von Lichtarten und Reflexionsspektren eine von der Lichtart unabhängige Bewertung liefern. Eine solche Gruppe von Invarianten kann für die Entwicklung gegenseitig abhängiger Beleuchtungs- und Pigmentstandards bei teilweise kontrollierten Beobachtungsbedingungen nützlich sein.

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A visual system can attain color constancy only for restricted spectral classes of illuminant spectral power distributions (SPDs) and reflectances.[1] Because color constancy is attributed to chromatic adaptation--particularly via the Von Kries coefficient rule[2]--we ask what physically reasonable spectral constraints insure that Von Kries adaptation restores object colors in human tristimulus space to illuminant-invariant positions in the space.

In the simplest formulation of Von Kries adaptation, changes in illuminant SPD $I(x)$ are compensated by scaling each tristimulus function $q_j(x)$--in the photopigment spectral-sensitivity basis--so a matte white reflectance maps to the tristimulus vector (1,1,1). (Here, x is a monotonic function of wavelength and j=1,2,3.) For a matte spectral reflectance $r(x)$ compared to a matte white reference $w(x)$ under a light $I(x)$, the Von-Kries-adapted tristimulus vector $\underline{\Phi}$ has components $\phi_j(r,w,I)=\langle Irq_j\rangle/\langle Iwq_j\rangle$ (where $\langle Irq_j\rangle \equiv \int I(x)r(x)q_j(x)dx$, etc.) If r=w, then $\underline{\Phi} = (1,1,1)$ and is independent of $I(x)$. We now present spectral conditions under which $\underline{\Phi}$ is illuminant-invariant even when $r \neq w$, and then extend our previous work[3] to derive related invariants.

For all visible wavelengths x, let $I(x)$ be a linear combination of N basis functions $s_k(x)$ with coefficients a_k:

$$I(x) = \sum_{k=1}^{N} a_k s_k(x) \tag{1}$$

where the a_k characterizing a particular $I(x)$ are constrained so $I(x) \geqslant 0$ for all x. The basis functions (universal to all illuminants in the class) are derivable by a principal-components analysis on the SPDs of natural illuminants.[4]

Let $w(x) = 1$ for all visible x, and express $r(x)$ as an expansion in a complete set of basis functions $r_n(x)$:

$$r(x) = \sum_{n=0}^{\infty} \rho_n r_n(x) \tag{2}$$

Choose the basis functions so that $r_0(x) = 1$, and

$$\langle u_\ell r_n\rangle = \delta_{n\ell} \tag{3}$$

where $u_\ell(x) = q_j(x)s_k(x)$ and $\ell = (j-1)N + k$. $(0 < \ell \leq 3N,\ 0 < n < \infty)$

So far, we have not constrained $r(x)$, but represented it as an expansion in a complete set of functions. Now, we constrain the coefficients ρ_n $(1 \leq n \leq 3N)$ such that, for some numbers ρ'_j (j=1,2,3),

$$\rho_\ell = \rho'_j \langle u_\ell \rangle \tag{4}$$

The numbers ρ_0, ρ'_1, ρ'_2, ρ'_3, and ρ_n ($n \geq 3N$) are the signature of the reflectance $r(x)$, constrained only by $0 \leq r(x) \leq 1$ for all x. As with the illuminant basis functions, $r_n(x)$ are universal to the "illuminant-invariant" spectral class. From Eqs. (1)-(4), one can show that

$$\phi_j(r,w,I) = \rho_0 + \rho'_j \tag{5}$$

This expression is independent of the illuminant parameters a_k, and hence is manifestly illuminant-invariant. Also, note that the eye is blind to $r_n(x)$ ($n > 3N$) for any allowed illuminant.

To find a set of reflectance-basis functions $\{r_n\}$ satisfying Eq. (3), choose any complete set of independent functions $\{P_m(x)\}$. Take as the first 3N reflectance-basis functions linear combinations of the first 3N of the functions $P_m(x)$, such that

$$\sum_{m=1}^{3N} b_{nm} \langle P_m u_\ell \rangle = \delta_{n\ell} \tag{6}$$

where (b_{nm}) is the 3Nx3N transformation matrix from $\{P_m\}_1^{3N}$ to $\{r_n\}_1^{3N}$. Clearly (b_{nm}) is the inverse of the matrix $(\langle P_m u_\ell \rangle)$, and can be computed by standard methods if $(\langle P_m u_\ell \rangle)$ is not singular. (This nonsingularity is a necessary constraint on $\{P_m\}_1^{3N}$, and in turn requires the set $\{u_\ell\}_1^{3N}$ to be linearly independent.) Then, for $1 \leq n \leq 3N$,

$$r_n(x) = \sum_{m=1}^{3N} b_{nm} P_m(x) \tag{7}$$

Once these basis functions are found, more r_n --the orthogonal complement of $\{u_\ell\}_1^{3N}$--can be found by the Gram-Schmidt method, but may be unnecessary if the first 3N functions $\{P_m\}_1^{3N}$ are chosen as the first 3N principal-component reflectance spectra about $r_0(x)$ for a large ensemble of natural pigments. (In fact, Cohen[5] showed that 433 Munsell pigments are adequately represented by only three principal components--about zero rather than about the mean spectrum as is usually done.) Choosing $\{P_m\}_1^{3N}$ outside the principal-component subspace reduces (desirably) the significance of the constraints (4), but also reduces (undesirably) the values of ρ'_j which alone convey object color information. Choosing P_m for optimum matching of real spectra to the conditions (1)-(4) remains an interesting research question.

Whereas the above spectral constraints involve basis-function expansions for I and r, the degrees of freedom of I and r may not be inherently additive (e.g., for black-body SPDs). As a first step toward understanding illuminant-invariance with non-additive spectral degrees of freedom, we found invariant functions of $\phi_j(r,w,I)$ subject to the following assumptions: $q_j(x)$ are equal-spread Gaussians $\exp[-(x-x_j)^2]$ (where x_j are constants)--a tolerably good approximation used for heuristic purposes previously[6]; $I(x) = b\exp(cx)$ (with variable parameters $b>0$, c); $r(x) = B\exp[-(x-x_0)^2/\sigma^2]$ (with variable parameters $B\geq 0$, x_0, σ).

Two independent invariants can be constructed from a single vector (i.e., from one unknown reflectance and w):

$$S = (x_2 - x_3)R_1 + (x_3 - x_1)R_2 + (x_1 - x_2)R_3$$

where $R_j \equiv \ln\phi_j$; and

$$T = (R_2 - R_1)^2 - SG(R_2 + R_1)$$

where the constant G is given by

$$G = \frac{2(x_2 - x_1)^2}{(x_2 - x_3)x_1^2 + (x_3 - x_1)x_2^2 + (x_1 - x_2)x_3^2}$$

An invariant discovered earlier[7] involves three vectors $\underline{\phi}_k$ (from three unknown reflectances and w):

$$U = \det(\ln\phi_{kj})$$

where ϕ_{kj} is the j-th component of $\underline{\phi}_k$.

Since S, T, and U are functions of Von-Kries-adapted tristimulus values, they also are illuminant-invariant under the series-expansion assumptions for which $\underline{\phi}$ is invariant. It should be noted that all the invariances in this paper obtain even when the reflectance w is not a known reflectance. The object-color-recognition utility of invariants in the absence of a "ground truth" reference is an interesting topic for further study.

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Munehira Akita and Yoshimichi Ejima, Kyoto (Japan):

Unique Hue Spectral Loci Influenced by the Range of Stimulus Series Employed for Measurements

A direct test of the invariance of unique hue in each of yellow, green, and blue was performed by determining the spectral locus when stimulus conditions (i.e., exposure time, size, and level of retinal illuminance) were changed. The invariance was found. The change of the loci for unique hues discovered previously when the range of the stimulus series employed for measurements was varied, are therefore considered as owing not to the effect of adaptation, but to the effect of context in the range of stimulus.

On a examiné directement l'invariance des tonalités uniques de jaune, vert et bleu en determinant la courbe spectrale dans le diagramme des chromaticités. Par changement des conditions de stimulus (temps d'exposition, extension du champs visuel et niveau d'illuminance rétinale) l'invariance a été constatée. C'est pourquoi on ne doit pas attribuer le changement des points des tonalités uniques que l'on avait découvert dans les expériences précédentes quand on avait changé l'étendu des séries de stimulus dans des mesurages à l'adaptation chromatique mais à la relation dans l'étendue des stimulus.

Eine direkte Prüfung der Invarianz der Urfarben Gelb, Grün und Blau ist durch Bestimmung des Spektral-Farbenzuges durchgeführt worden, wobei die Reizbedingungen (Belichtungszeit, Größe des Gesichtsfeldes und retinale Beleuchtungsstärke) verändert wurden. Die Invarianz wurde bestätigt. Daher müssen die Änderungen der Farbörter der Urfarben, die früher bei Änderung des Reizumfanges bei den Messungen entdeckt worden sind, nicht als Auswirkung der Umstimmung betrachtet werden, sondern als Wirkung des Zusammenhanges im Bereich der Reize.

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Introduction

The concept of unique hue is important to explore underlying mechanisms of color perception in terms of the opponent-color theory. A balancing point of the red-green system, for example, is considered the spectral locus that evokes unique yellow which appears neither reddish nor greenish. The change of the locus for unique yellow, therefore, corresponds to the change of the equilibrium state of the red-green hue coding systems. In a previous AIC meeting in Troy, New York, 1977 we reported recovery of hue responses after chromatic adaptation measured by observing the rate of return of unique hue spectral loci to their neutrally adapted loci [1]. Recently we found that the loci of unique hues shifted as a function of the change of stimulus range employed for measurements of unique hue while the loci remained relatively unchange against changing sizes of the stimulus field which varied from 10' to 30^{o} in visual angle and that the luminance levels varied from 35 td to 700 td [2]. The contribution of chromatic adaptation to the shift was not clear because of the lack of precise control over temporal conditions in presenting a colored stimulus.

The aim of the present study is to determine the effect of chromatic adaptation under the strict control of the temporal conditions at presentation of the stimulus.

Methods

A circular stimulus was presented in the Maxwellian view through a 2 mm-dia artificial pupil. The size of the stimulus was controlled by a small hole in the stop made with the vacum evaporation technique.A Baush and Lomb diffraction grating monochromator with a halogen ribbon filament source provided the colored illumination for the center field. A half-band width of monochromatic lights was adjusted to 6 nm for various wavelength lights employed in the study. An equal brightness spectrum was accomplished by adjusting the voltage supplied to the lamp directly with the aid of a microcomputer with stored programmed data in advance.

Two observers participated. MA, male, in his fifties, and YE, male, in his thirties. They were all within the limits of normal trichromatic color vision according to tests with the Nagel anomaloscope, the Ishihara pseudoisochromatic plates, and the Farnsworth-Munsell 100 hue test.

The observer was seated for 1 min in a dimly illuminated (about 20 lx on the top of the table in front of him) black painted observation cubicle. He was instructed to report via push buttons whether a field appeared as a unique hue or not.

Eleven stimuli spaced 2 nm apart were presented 6 times in random order for each stimuli with the microcomputer. The neutral stimulus range in which the middle wavelength in the range is equal to the spectral locus of a given unique hue was provided for each observer.

Time intervals between stimulus presentation were kept for 6 seconds through the whole sessions of the experiment. When a session was over, the computer printed out the following results: (1) the average of spectral locus for "yes" (unique-hue) responses in the last 55 trials (the first 11 trials were considered necessary for light adaptation to the illuminating field and excluded from data) with an estimated SD, (2) a frequency curve of yes-responses, and (3) the average response times for each of the stimuli with an estimated SD.

A direct test of the invariance of unique hue in each of yellow, green, and blue was performed by determining the spectral locus when stimulus conditions which were considered as being responsible to define the state of chromatic adaptation were changed. That was, exposure time to a test stimuli was set to either 50, 100, 500, 1000, or 2000 msec at a given 3° test field in 48-td level; a stimulus size set to either 10', 30', 1°, 3°, or 10° in both 50 and 2000 msec exposure time at 48 td; and a retinal illuminance set to either 200, 48, 9.6, and 1.9 td in both 50 and 2000 msec exposure time at a given size, 3°.

Results and Discussion

The results are shown in Table 1. Obviously there are not significant amounts of wavelength shift found in unique yellow, green, and blue loci under all three experimental conditions: exposure time, size, and level of retinal illuminance, except in 5 cases among 134 cases. No systematic trends were found in the 5 cases, however.

Table 1. The unique-hue loci in the spectrum (Mean±SD) for yellow green, and blue of two observers, M A and Y E.

			M A			Y E		
Size	msec	td	Yellow	Green	Blue	Yellow	Green	Blue
10'	50	48	581±4.0*	500±5.2	469±5.6	571±5.3	503±5.2	470±4.0
30'	50	48	577±2.0	497±2.5*	464±4.8	570±4.4	502±5.3	469±4.4
1°	50	48	574±2.5*	502±3.0	469±3.9	569±2.6	502±4.2	471±3.8
3°	50	48	577±2.3	504±5.7	470±4.2	570±2.9	503±3.7	470±2.5
10°	50	48	577±1.9	501±3.9	466±3.1	572±2.4	501±3.3	470±2.3
10'	2000	48	577±1.9	504±2.5	464±3.6	570±2.1	499±3.9	467±3.0*
30'	2000	48	579±1.9	503±1.4	468±3.7	570±2.0	501±2.7	471±2.5
1°	2000	48	574±1.5	502±1.4	468±1.9	571±1.9	502±1.6	473±2.5
3°	2000	48	577±1.3	502±1.8	464±4.2	569±1.6	502±3.4	473±1.7
10°	2000	48	578±1.4	501±1.7	469±3.7	569±1.7	502±2.2	473±2.2
3°	50	48	578±2.4	501±3.5	466±3.1	569±2.7	503±3.7	470±2.5
3°	100	48	578±2.1	501±3.0	465±3.4	570±2.8	501±2.3	471±2.2
3°	500	48	577±1.9	503±1.9	466±3.9	570±1.9	501±2.8	472±2.4
3°	1000	48	579±1.9	502±2.7	465±3.8	570±1.5	500±2.0	473±2.2
3°	2000	48	578±1.9	502±2.2	464±3.9	569±1.6	502±1.6	473±1.7
3°	50	220	578±2.2	502±1.4		570±2.6	501±2.0	
3°	50	48	580±2.0	500±1.5	463±3.8	569±2.7	503±3.7	470±2.5
3°	50	9.6	578±1.5	503±2.5	468±1.3	569±2.9	503±4.2	471±2.6
3°	50	1.9	576±2.0	507±2.0*	467±4.3	569±4.0	504±3.6	469±3.0
3°	2000	220	577±0.9	502±1.4		569±2.0	504±2.2	
3°	2000	48	578±1.6	501±1.3	464±4.2	569±1.6	502±3.4	473±1.7
3°	2000	9.6	578±1.8	501±2.3	467±2.6	569±1.6	502±3.6	473±2.0
3°	2000	1.9	578±1.3	505±2.4	465±1.9	570±2.0	500±2.8	472±1.9
Grand average + SD			577.6 ±2.45	501.9 ±3.34	466.3 ±4.24	569.7 ±2.77	501.7 ±3.57	471.1 ±3.14

A two-tailed t-test was made for comparison. * $p<0.01$

In general the invariance of unique hue was observed against variously changing states of local adaptation accomplished by different conditions in the presentation of the colored test stimuli.

This result suggested that the state of adaptation was not related to the shift of unique-hue loci observed in the previous study, that is, the shift of unique hues, toward either longer or shorter wavelengths, depending on whether the stimulus series consisted of longer or shorter wavelengths as shown in Figure 1.

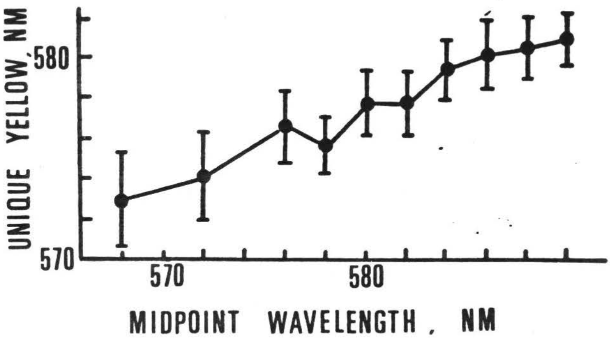

Figure 1. Wavelength settings for unique yellow as a function of the midpoint wavelength of a test stimulus range. Observer M.A., 3^{0} size and 300 td retinal illuminance.

Thus the shift would be due to a context effect in the range of stimulus series which affects an observer's criterion about the uniqueness. The mean value of the wavelengths of unique hue would be near the center of the series, because in the neutral range of stimulus series in which an approximately equal amount of both longer and shorter wavelengths than the wavelength of a would-be unique hue are given. Assuming that a holo effect of predominant wavelengths in the series is operating, the mean would probably be slightly away from center toward the end of predominant wavelengths. Since the predominant wavelengths are presented more frequently the satiation for these hues increases and an observer would become less attentive to them, but would be more attentive to a hue different from those hues. Because of this tendency, one would predict a slightly reddish yellow hue, for instance, to appear either less reddish or unique yellow when embeded in a long wavelength predominant series than when in a context of a short wavelength predominant series. This is exactly what we predicted would happen in the previous study.

We conclude that the unique hue determination is not only related to a simple sensory adaptation process but to a more complex process involving such factors as judgmental and/or cognitive function when taken in the whole stimulus condition as a frame of reference.

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Horst Scheibner, Elmar Wolf, Düsseldorf:

Direkte Zerlegungen, isomorphe und homomorphe Abbildungen in der linearen Farbentheorie

Suitable additive decompositions of the vectorial colour space may be used to describe various facts of colour vision. Spectral tri-stimulus and di-stimulus functions can be calculated from isomorphic and homomorphic mappings of the colour space. Missing colours, alychnes and joint spaces of missing colours play a part as kernels of mappings.

On peut appliquer des décompositives additives appropriées de l'espace des vecteurs des couleurs à la description de faits réels de la vision colorée. On peut calculer des fonctions spectrales tri-stimulus et di-stimulus sortant des images isomorphes et homomorphes de l'espace des couleurs. Les couleurs manquées, l'alychne et les espaces associantes des couleurs manquées jouent un rôle comme noyaux de dépeinture.

Geeignete additive Zerlegungen des vektoriellen Farbenraumes können benutzt werden, um farbphysiologische Sachverhalten darzustellen. Aus isomorphen und homomorphen Abbildungen des Farbenraumes können spezielle Spektralwertfunktionen berechnet werden. Fehlfarben, Alychnen und Verbindungsräume von Fehlfarben spielen dabei als Abbildungskerne eine Rolle.

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Die niedere Farbmetrik läßt sich durch einen dreidimensionalen Vektorraum ("Farbenraum") mit (nur) affiner Struktur darstellen (8). Die Wahl der Primärvalenzen (Basisvektoren) kann aufgefaßt werden als eine additive Zerlegung in drei eindimensionale Unterräume des Farbenraumes.

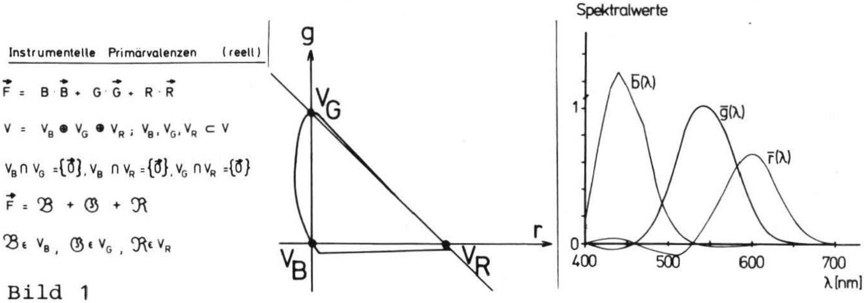

Bild 1

Bild 1 zeigt die additve Zerlegung nach den WRIGHTschen (10) Primärvalenzen, $\vec{B}$(460 nm), $\vec{G}$(530 nm), $\vec{R}$(650 nm). Diese können wegen ihres reellen Charakters unmittelbar zu Meßzwecken verwendet werden. Die negativen Äste der zugehörigen Spektralwertfunktionen (rechts, Daten des von Judd (1) modifizierten Normalbeobachters CIE 1931) zeigen jedoch, daß diese additive Zerlegung nicht von unmittelbarer physiologischer Bedeutung ist.

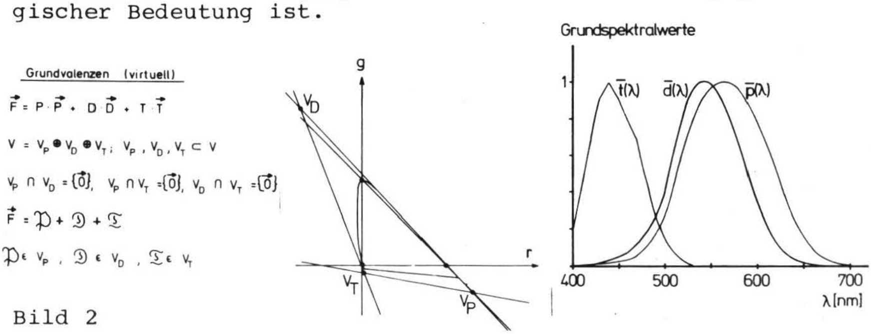

Bild 2

Bild 2 zeigt die additive Zerlegung des Farbenraumes in drei eindimensionale Unterräume, die von den Fehlfarben der drei Dichromat-Typen (Protanop, Deuteranop, Tritanop) aufgespannt werden. Die zugehörigen Spektralwertfunktionen (Grundspektralwertkurven) $\bar{t}(\lambda)$, $\bar{d}(\lambda)$, $\bar{p}(\lambda)$ können - vom Einfluß der okularen Medien abgesehen - mit den Absorptionskurven der drei Sehzapfenpigmente Cyanolab, Chlorolab und Erythrolab identifiziert werden. Sie sind in Übereinstimmung mit dem Univarianz-Prinzip. Die WRIGHTsche grün-rote Primärvalenzen-Normierung (10) ist hier so abgewandelt (7), daß die deuteranopische Fehlfarbe $\vec{D}$ an $\vec{G}$ herangerückt wird.

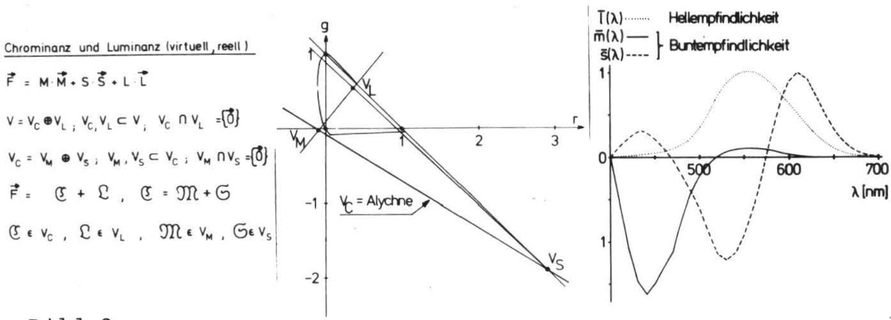

Bild 3

Bild 3 zeigt eine additive Zerlegung des Farbenraumes, deren Spektralwertfunktionen als Bunt- ($\bar{m}(\lambda)$, $\bar{s}(\lambda)$) und Hellempfindlichkeit ($\bar{l}(\lambda)$) im Sinne der Gegenfarben interpretiert werden können (9). Charakteristisch ist, daß der Verbindungsraum der beiden "bunten" Primärvalenzen ($\vec{M}$, $\vec{S}$) die Alychne (8, 9) bildet. Eine solche Alychne kann man durch heterochrome Helligkeitsabgleiche ermitteln, indem man die Helligkeiten der drei instrumentellen Primärvalenzen oder auch indem man - allgemeiner betrachtet - mindestens zwei nicht-parallele helligkeitsfreie Differenzvektoren ("Quervektoren" (7)) bestimmt, die die Alychnenebene aufspannen.

Die Verknüpfung der Systeme untereinander erfolgt jeweils durch radial-affine isomorphe Abbildungen. Die Gleichwertigkeit und Gleichberechtigung solcher Systeme folgt aus der Invarianz des allein affingeometrisch relevanten Informationsgehalts gegenüber derartigen Abbildungen. Mit Hilfe von homomorphen Abbildungen des Farbenraumes mit beispielsweise experimentell bestimmten Kernen können auch spezielle Spektralwertfunktionen berechnet werden. So erhält man im ($\vec{B}$,$\vec{G}$,$\vec{R}$)-System die dichromatischen Spektralwertfunktionen für die verschiedenen Typen von Dichromaten, wenn man den Farbenraum mit deren individuellen Fehlfarben als Kern abbildet (4, 7, 11). Im ($\vec{T}$,$\vec{D}$,$\vec{P}$)-System führt dieses einfach zum Wegfall jeweils einer Grundspektralwertfunktion. Wählt man den Verbindungsraum zweier Fehlfarben als (zweidimensionalen) Kern einer homomorphen Abbildung, so erhält man - unabhängig vom Basissystem - unmittelbar die Spektralwertfunktion zu der Grundvalenz, die nicht im Verbindungsraum enthalten ist. Dieses ist eine Verallgemeinerung eines Satzes von MacADAM (2), wonach eine auf eine Primärvalenz bezogene Spektralwertfunktion durch die Verbindung der beiden anderen Primärvalenzen bestimmt ist. Eine homomorphe Abbildung mit der Alychne als Kern führt direkt auf das Helligkeitssehen (8). Die isomorphe durch (I) gegebene Abbildung des ($\vec{T}$,$\vec{D}$,$\vec{P}$)-Raumes auf den ($\vec{M}$,$\vec{S}$,$\vec{L}$)-Raum beschreibt linear die physiologische Übertragung von den Sehzapfen zum retinogenikularen System:

$$\begin{aligned}
\bar{m}(\lambda) &= -1{,}623\ \bar{t}(\lambda) + 0{,}06589\,\bar{d}(\lambda) + 0{,}01279\ \bar{p}(\lambda)\\
\bar{s}(\lambda) &= 0{,}1933\ \bar{t}(\lambda) - 1{,}8099\ \bar{d}(\lambda) + 1{,}377\ \bar{p}(\lambda) \qquad \text{(I)}\\
\bar{l}(\lambda) &= 0{,}01182\ \bar{t}(\lambda) + 0{,}4033\ \bar{d}(\lambda) + 0{,}6205\ \bar{p}(\lambda)
\end{aligned}$$

Einen umfassenderen Überblick gewährt der Verband von geeigneten Unterräumen des Farbenraumes (3, 5, 6).

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Rolf Thielert, Hamburg:

Untersuchung der Eignung verschiedener psychometrischer Skalierungsverfahren zur Bewertung weißer Proben

Three different psychometric methods of scaling were used for the visual assessment of white samples. By use of the method of rank order a reliable visual assessment was only possible if the principle of order underlying each set of samples was evident. The visual assessment of the samples using the method of paired comparisons was possible with all sets. The same held for the visual assessment using an MDS method. The highest correlation existed between the results obtained with the method of paired comparisons and those obtained by use of method.

On a appliqué trois différentes méthodes psychométriques à l'évaluation visuelle d'un nombre d'échantillons blancs. Par la méthode d'ordre du rang, une certaine évaluation visuelle n'était possible que si le sujet savait reconnaître le principe d'ordre dans la série des échantillons. On réussit dans l'évaluation visuelle avec la méthode de comparaison par paires avec tous les séries, aussi bien que selon la méthode d'ordre multi-dimensionnelle. La meilleure correlation se trouvait entre les résultats des deux dernières méthodes.

Drei verschiedene psychometrische Skalierungsverfahren wurden zur visuellen Bewertung einer Anzahl von weißen Proben benutzt. Mit dem Rangordnungstest war eine sichere visuelle Bewertung nur dann möglich, wenn das jeder Probenreihe zugrundeliegende Ordnungsprinzip erkennbar war. Die visuelle Beurteilung der Proben mit dem Paarvergleich gelang bei allen Reihen. Das gleiche galt für die visuelle Bewertung mit dem MDS-Verfahren. Die beste Korrelation bestand zwischen den Ergebnissen des Paarvergleichs und denen der multidimensionalen Skalierung.

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Einige in letzter Zeit veröffentlichte Arbeiten über die visuelle Beurteilung weißer Proben mit verschiedenen psychometrischen Skalierungsverfahren [1, 2, 3] enthalten widersprüchliche Aussagen und widersprechen z.T. auch den Ergebnissen eigener Untersuchungen. Es sollen daher einige weitere Untersuchungen beschrieben werden, die zur Prüfung der Eignung verschiedener psychometrischer Skalierungsverfahren zur visuellen Bewertung weißer Proben durchgeführt wurden.

Es wurden drei psychometrische Skalierungsverfahren untersucht: Der Rangordnungstest (method of rank order), der Paarvergleich (method of paired comparisons) und ein Verfahren der multidimensionalen Skalierung (multidimensional scaling, MDS). Diese Skalierungsverfahren unterscheiden sich in Bezug auf die Methodik und die Aussagekraft ihrer Ergebnisse erheblich voneinander.

Beim Rangordnungstest werden alle miteinander zu vergleichenden Proben jedem Beurteiler gleichzeitig dargeboten, der sie in Bezug auf die zu bewertende Eigenschaft zu ordnen hat. Als Ergebnis erhält man üblicherweise nur eine Rangfolge der Proben in Bezug auf die skalierte Eigenschaft, wobei jeder Probe eine Rangnummer, bei n Proben im allgemeinen die natürlichen Zahlen von 1 bis n, zugeordnet ist. Eine Skala, deren Werte diese Eigenschaft besitzen, bezeichnet man als Ordinalskala [4]. Da aus den Skalenwerten einer Ordinalskala keine quantitativen Aussagen über die empfindungsgemäßen Unterschiede zwischen den Proben abgeleitet werden können, ist das Rangordnungsverfahren als Skalierungsverfahren im allgemeinen wenig geeignet, wenn die damit erhaltenen Ergebnisse zur Überprüfung der Gültigkeit von Formeln aus dem Bereich der höheren Farbmetrik [5] benutzt werden sollen.

Beim Paarvergleich werden alle Proben jedem Beurteiler paarweise vorgelegt. Sollen insgesamt n Proben beurteilt werden, so gibt es $n(n-1)/2$ mögliche Kombinationen von Probenpaaren. Die Beurteiler haben zu entscheiden, welche der beiden Proben von jedem Paar das zu bewertende Merkmal in stärkerem Maße besitzt. Die Auswertung des Paarvergleichs liefert für jede Probe i einen Skalenwert x_i. Die n Skalenwerte x_i gehören einer Intervallskala an [4]. Aus den x_i lassen sich quantitative Aussagen über die relativen empfindungsgemäßen Unterschiede zwischen den Proben ableiten. Die x_i können auch aufgefaßt werden als n Punkte P_i in einem eindimensionalen euklidischen Raum mit willkürlich wählbarem Nullpunkt. Der Betrag der Differenz zwischen zwei beliebigen Skalenwerten x_i und x_j entspricht dann dem Abstand d_{ij} zwischen den Punkten P_i und P_j. Mit Hilfe des Paarvergleichs erhält man also als Modell des Empfindungsraums einen eindimensionalen Raum mit euklidischer Metrik, in dem der Abstand d_{ij} zwischen zwei beliebigen Punkten P_i und P_j dem relativen empfindungsgemäßen Unterschied zwischen den Proben i und j in Bezug auf das bewertete Merkmal entspricht.

Bei den Verfahren der multidimensionalen Skalierung wird, anders als beim Rangordnungstest oder beim Paarvergleich, keine Bewertung eines spezifischen Probenmerkmals, sondern eine Bewertung der Ähnlichkeit vorgenommen. Die Ähnlichkeits-Bewertung kann nach verschiedenen Verfahren ausgeführt werden. Sie führt bei n Proben zu n(n-1)/2 Werten δ_{ij}, die ein Maß für die Ähnlichkeit zwischen den Proben i und j sind. Die δ_{ij} sind die Eingangsdaten für das weitere Rechenverfahren. Sie können je nach dem benutzten Verfahren der Ähnlichkeitsbewertung einer Ordinal- oder einer Intervallskala angehören. Sind als Eingangsdaten zu einer Ordinalskala gehörende δ_{ij} ausreichend, so bezeichnet man das MDS-Verfahren als nicht metrisch, sind zu einer Intervallskala gehörende δ_{ij} erforderlich, so bezeichnet man das MDS-Verfahren als metrisch. Die Aufgabe des MDS-Verfahrens besteht darin, mit Hilfe mathematischer Verfahren ein Raum-Modell zu finden, in dem n(n-1)/2 zu den Punkten P_i und P_j gehörende Abstände d_{ij} möglichst gut korreliert sind mit den n(n-1)/2 Ähnlichkeiten δ_{ij}. Aus Gründen des mathematischen Aufwands und der Anschaulichkeit der Ergebnisse wurden bisher nahezu ausschließlich Raum-Modelle mit euklidischer Metrik benutzt. Das gilt auch für die sogenannten nicht metrischen MDS-Verfahren. Man beginnt die Berechnungen mit einer willkürlich festgelegten Zahl von Dimensionen m_0 und erhält für jede Dimension l (l=1,2,.., m_0) n Skalenwerte x_{il}. Die Zahl der Dimensionen m_0 entspricht der Anzahl der skalierten Merkmalsattribute, die x_{il} sind die den m_0 Merkmalsattributen zuzuordnenden n Skalenwerte. Anschließend wird die Zahl der Dimensionen schrittweise verringert, bis die zur adäquaten mathematischen Beschreibung des Empfindungsraums notwendige und hinreichende Zahl von Dimensionen $m_{min} < m_0$ gefunden worden ist. Die exakte Bestimmung von m_{min} ist häufig schwierig. Auch die Zuordnung von Merkmalsattributen zu einzelnen Dimensionen des Raum-Modells kann Schwierigkeiten bereiten.

Die visuelle Bewertung der Proben mit den drei beschriebenen Skalierungsverfahren führte zu folgenden Ergebnissen: Mit dem Rangordnungstest war eine sichere visuelle Bewertung nur dann möglich, wenn das den Probenreihen zugrundeliegende Ordnungsprinzip erkennbar war. Das galt für die Probenreihen, bei denen, ähnlich wie z.B. bei den Ciba-Geigy Weißmaßstäben, mit zunehmender Helligkeit der Proben auch der Blauanteil zunahm. War das Ordnungsprinzip nicht erkennbar, so machte die visuelle Beurteilung Schwierigkeiten. Die visuelle Beurteilung der Proben mit dem Paarvergleich machte in keinem Fall Schwierigkeiten. Das gleiche galt für die visuelle Bewertung der Proben mit Hilfe des MDS-Verfahrens. Für alle Probenreihen mit Ausnahme einer war $m_{min} = 1$.

Soweit mit dem Rangordnungstest sinnvolle Ergebnisse erhalten werden konnten, war die Korrelation zwischen ihnen und den Ergebnissen des Paarvergleichs gut. Das gleiche galt für die Korrelation zwischen den Ergebnissen des Rangordnungstests und denen des MDS-Verfahrens. Die Korrelation zwischen den Ergebnissen des Paarvergleichs und denen des MDS-Verfahrens war mit der erwähnten einen Ausnahme, wo $m_{min} > 1$ war, sehr gut. Da mit beiden Skalierungsverfahren Raum-Modelle mit euklidischer Metrik erhalten wurden, war dieses Ergebnis zu erwarten für den Fall, daß der der Weißempfindung zugrundeliegende Empfindungsraum näherungsweise einem eindimensionalen Raum mit euklidischer Metrik entspricht.

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K1

Robert Sève, Vincennes (France):

Erreurs systématiques liées à l'emploi des colorimètres trichromatiques, calculées par une méthode de Monte-Carlo pour des échantillons commerciaux blancs

A computational method, with pseudo-random numbers was used to determine the spectral luminance factor of various white samples (dyed or fluorescent) statistically similar to those evaluated by direct measurements. Then, the results of colour evaluation was computed and compared, as obtained by direct reading on a tristimulus colorimeter in various practical conditions. So we get errors evaluation, comparison between CIE 2^o observer and CIE 10^o observer, comparison between actual filters, sources . . . The study allow us to draw a great number of practical conclusions which could hardly be obtained by direct experiments.

On a utilisé une méthode de calcul avec des nombres aléatoires pour déterminer le facteur spectral de luminance d'échantillons blancs, azurés ou fluorescents, conformes statistiquement aux déterminations expérimentales. On a ensuite calculé et comparé entre eux, les résultats de mesures qui seraient obtenus avec des colorimètres trichromatiques dans diverses situations concrètes. On a ainsi obtenu une évaluation d'erreurs, une comparaison entre l'observateur CIE 2^o et l'observateur CIE 10^o, une comparaison entre divers filtres usuels, une comparaison de diverses sources . . . Les nombreuses conclusions dégagées pourraient difficilement être obtenues expérimentalement.

Es wird eine Rechenmethode nach dem Zufalls-Prinzip beschrieben, um den spektralen Leuchtdichtefaktor von weißen Proben zu bestimmen, die blaumachende oder fluoreszierende Substanzen enthalten, statistisch ähnlich der experimentellen Bestimmung. Die Meßergebnisse wurden mit denen verglichen, die man unter verschiedenen bestimmten Umständen mit Dreibereichs-Meßgeräten erhalten würde. Auf diese Weise erhält man eine Fehler-Bewertung, einen Vergleich zwischen 2^o und 10^o-Beobachter, zwischen verschiedenen üblichen Filtern und zwischen verschiedenen Lichtquellen usw. Die zahlreichen Erkenntnisse, die so gewonnen werden, könnten experimentell nur schwierig erhalten werden.

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La colorimétrie trichromatique est très largement utilisée pour des mesures techniques, mais aussi dans de nombreux laboratoires faisant notamment des recherches de type industriel. Ce genre de mesure colorimétrique est cependant handicapé par le fait que seul un nombre limité de filtres sont disponibles, parmi tous les filtres qui seraient nécessaires. De plus, la réalisation des fonctions représentant les composantes trichromatiques spectrales est très imparfaite et manque de reproductibilité. Il est donc important de connaître les erreurs systématiques ainsi commises, mais il est en même temps très difficile de les évaluer. Par ailleurs un grand nombre de questions pratiques relatives à ces mesures sont sans réponse : par exemple quelle différence y a-t-il entre les mesures faites avec l'observateur normalisé CIE 1931 et l'observateur supplémentaire CIE 1964 relatif à une vision dans un champ de 10 degrés.

C'est ce problème qui a été étudié grâce à une approche théorique, limitée au cas d'échantillons usuels de papiers voisins du blanc. On a utilisé pour cela une méthode de type Monte-Carlo, c'est à dire fournissant une génération aléatoire d'un très grand nombre de courbes spectrales de réflexion, reproduisant les valeurs déterminées expérimentalement pour des pâtes à papier, des papiers azurés avec des colorants, des papiers traités avec des produits fluorescents, avec l'adjonction éventuelle de colorants de nuançage.

La génération de ces spectres a été obtenue à l'aide d'un ensemble de fonctions de base, judicieusement choisies, et dépendant d'un ensemble de nombres au pseudo-hasard. Ceux-ci ont été déterminés pour correspondre à une distribution normale, dont la moyenne et l'écart-type ont été déterminés expérimentalement. Les caractéristiques spectrales des colorimètres trichromatiques ont été obtenues, soit à partir des spécifications auxquelles ils doivent répondre selon les normes usuelles (normes ISO en particulier), soit à partir de déterminations expérimentales.

Les calculs ont porté d'abord sur la comparaison des systèmes CIE 1931, pour l'observateur standard 2 degrés, et pour l'observateur supplémentaire 10 degrés. On a étudié les différences entre Y et Y_{10}, les différences de coordonnées trichromatiques, de longueur d'onde dominante, de pureté d'excitation et dans le système CIELUV 1976 d'angle de teinte psychométrique.

On a étudié ensuite les erreurs systématiques commises du fait :

1) de l'emploi en colorimétrie à 3 filtres de la composante trichromatique Z pour évaluer la portion des courtes longueurs d'onde de la composante trichromatique X ;

2) de la substitution du filtre utilisé pour la composante trichromatique Z au filtre bleu de longueur d'onde efficace 457 nm généralement utilisé dans l'industrie du papier pour évaluer la "brightness" ;

3) des modifications dans les longueurs d'onde des maximas de transmission des filtres trichromatiques, dans la température de couleur des sources ou dans la réponse des photodétecteurs.

On a enfin étudié l'influence de certains de ces paramètres sur les résultats d'application des formules de blancheur en cours d'étude au Comité Technique 1.3 (Colorimétrie) de la CIE.

Les calculs ont permis par ailleurs, dans le cadre limité des échantillons objet de l'étude, d'évaluer l'influence sur les résultats de calculs spectrophotométriques des diverses méthodes d'intégration : de 380 à 780 nm, de 400 à 700 nm par pas de 1 de 5 ou de 10 nm.

Les conclusions de cette étude assez importante ne peuvent être aisément détaillées ici. De plus le travail de calcul et de dépouillement n'est pas achevé. On peut dire néanmoins que des conséquences pratiques intéressantes sont obtenues. Elles peuvent de plus suggérer des tests de vérification pour les appareils et des procédures d'utilisation, suggestions utiles pour l'établissement des normes internationales de mesures colorimétriques.

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Dietrich Gundlach, Berlin

Farbmessung an metallischen Oberflächen

After some general considerations on the properties of metallic surfaces a spectrophotometric method is described for the measurement of metallic surfaces of high gloss as well as of mat ones. As surface of reference a normal white standard is used. The conformity with the ellipsometric method is good. The results of the measurement depend, in both cases, strongly on the preparation of the samples.

Après quelques considérations générales des propriétés de surfaces métalliques on décrit une méthode spectrophotométrique pour mesurer la couleur de surfaces métalliques à brillance éclatante ou mattes. Comme surface de référence on utilise un standard blanc. On a trouvé que la conformité avec la méthode ellipso-métrique est bonne. En tout cas les résultats dépendent considérablement du traitement précedent des échantillons.

Nach allgemeinen Betrachtungen über Eigenschaften von Metalloberflächen wird ein spektralphotometrisches Verfahren zur Farbmessung an hochglänzenden und matten metallischen Oberflächen beschrieben, das als Reflexionsnormal einen Weißstandard benutzt. Die Übereinstimmung mit ellipsometrischen Verfahren ist gut. Die Ergebnisse hängen in beiden Fällen stark von der Vorbehandlung der Proben ab.

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Metalle und Legierungen haben bei reinen Oberflächen zwei visuell auffallende Eigenschaften: hohes Reflexionsvermögen, welches als Glanz wahrgenommen wird und eine charakteristische Farbe. Das hohe Reflexionsvermögen verhindert jedoch oft, die eigentliche Farbe des Metalls oder der Legierung zu erkennen. Erst nach Mehrfachreflexion an der gleichen Oberfläche erkennt man deutlich, daß z.B. Zink blau und Nickel gelb ist. Beim Edelmetall Gold und seinen hochkarätigen Legierungen ist die charakteristische Farbe bereits nach einmaliger Reflexion zu erkennen, doch ist es visuell sehr schwer, die grünlichen bis rötlichen Bunttöne hochglänzender Goldoberflächen miteinander zu vergleichen. Juweliere legen als Hilfsmittel zum Erkennen der Farbe ein Transparentpapier auf die zu vergleichenden Goldoberflächen auf. Die Oberflächen werden so durch auffallendes Licht diffus beleuchtet, und das von diesen reflektierte Licht wird durch das Transparentpapier gestreut. Trotz starker Entsättigung der Farbe der Metalloberfläche durch das aufliegende Papier, tritt der charakteristische Buntton der Goldoberfläche deutlich hervor. Bei nahezu unbunten metallischen Oberflächen versagt dieses visuelle Verfahren. Da in der Industrie der Wunsch besteht, sowohl hochglänzende wie matte, unbunte und bunte Metalloberflächen (aber auch eingefärbte Oxidschichten, z.B. Eloxal) durch Farbmaßzahlen eindeutig zu charakterisieren, mußte hierfür ein objektives Farbmeßverfahren ausgearbeitet werden. Während die Reflexionseigenschaften von matten oder glänzenden nichtmetallischen Körperfarben in Aufsicht durch den spektralen Strahldichtefaktor beschrieben werden, ist hier der spektrale Reflexionsgrad die den visuellen Eindruck der Farbe charakterisierende Kennzahl, die beim Übergang von hochglänzenden zu mattierten metallischen Oberflächen kontinuierlich in den spektralen Strahldichtefaktor übergeht. Ein objektives Meßverfahren für derartige Oberflächen muß also diesen Übergang der Kennzahlen berücksichtigen.

Massive Metalle und Legierungen haben zumindest im langwelligen sichtbaren Strahlungsbereich und weiter im IR ein sehr hohes und gleichmäßiges Reflexionsvermögen, das nahezu 100% erreichen kann. Zu kürzeren Wellenlängen hin treten wie bei nichtmetallischen Stoffen Absorptionsbanden auf. Liegen diese wie bei Kupfer und Gold im sichtbaren Bereich verleihen sie den Metallen, Legierungen und besonders den intermetallischen Verbindungen das bekannte bunte Aussehen. Beide Vorgänge sind zwanglos quantenmechanisch zu erklären (1). Alle Wechselwirkungen zwischen Strahlung und metallischer Oberfläche spielen sich in einem Oberflächenfilm von etwa 10^{-6} Dicke ab, was etwa 40 Atomlagen entspricht. Diese Schicht ist unter üblichen Umweltbedingungen stark der Korrosion ausgesetzt und kann z.B. aus amorphen Metalloxiden bestehen, die das Reflexionsverhalten und damit das farbige Aussehen bestimmen. Mechanisches Polieren der Oberfläche zerstört und verformt die Kristallstruktur bis zu einer Tiefe von etwa 10^{-5}cm. Auch hierdurch werden Reflexionseigenschaften erheblich verändert. Farbänderungen zumindest bei Legierungen sind die Folge. Während die Farbmetrik versucht, das farbige Aussehen einer gegebenen Oberfläche zu beschreiben, ist es das Bestreben der reinen und angewandten Metallkunde, die optischen konstanten Brechzahl n und Absorptionskonstante k von Metallen, Legierungen und Oberflächenfilmen unter definierten Bedingungen zu bestimmen, was ellipsometrisch nach unterschiedlichen Methoden erfolgt (1). Bei Kenntnis dieser Konstanten läßt sich eine theoretische Reflexionskurve errechnen und valenzmetrisch auswerten. Dieses Verfahren wurde von E.F.I. Roberts und K.M. Clarke (2) zur Bestimmung von Goldfarben verwendet. Für praxisnahe Messungen an Proben mit nicht idealen Oberflächen erscheint die direkte spektralphotometrische Messung der Reflexionskurve gegen ein Reflexionsnormal geeigneter. Von H. Knosp (3) wurde hierzu gerichtet reflektierendes Siliciumcarbid (Carborundum) verwendet, dessen Lichtreflexionsgrad bei etwa 20% liegt.

Die Bestimmung der Reflexionskurve metallischer Oberflächen ist aber auch gegen einen Weißstandard nach DIN 5033 Teil 9 mit der Geometrie 8/d möglich. Wenn eine polierte Metalloberfläche an die Probenöffnung einer Kugel gelegt wird, leitet sie unter dem Spiegelwinkel den Strahlungsfluß auf die Kugelwand weiter, die diesen diffus über die gesamte Kugel reflektiert. Es wird ein Meßwert erhalten, der proportional dem von der polierten Metalloberfläche und dem von dem entsprechenden Teil der Kugelwand reflektierten Strahlungsfluß ist. Wenn der spektrale Reflexionsgrad der Kugelwand bekannt ist, es ist gewöhnlich der leicht meßbare Teil der geschlossenen Glanzfalle, kann der spektrale Reflexionsgrad einer hochglänzenden Metallprobe gegen einen matten Weißstandard mit ähnlich hohem Reflexionsvermögen bestimmt werden. Fehler durch zerkratzte, gekrümmte oder windschiefe Oberflächen der Proben werden durch die Kugelmessung gemindert. Matte Metalloberflächen können wie nichtmetallische Körperfarben gemessen werden. Das ausgearbeitete Verfahren wurde bisher mit Erfolg zur Farbmessung an Goldfarben nach DIN 8238, an Rhodiumschichten und an Kupferlegierungen eingesetzt. Die Reproduzierbarkeit der Ergebnisse ist bei gleicher Probenvorbehandlung sehr gut. Die Übereinstimmung mit ellipsometrischen Messungen an denselben Sätzen von Goldfarben ist selbst bei nicht vereinbarter Art der Probenvorbehandlung gut. Messungen an reinen Kupferoberflächen liegen im Rahmen veröffentlichter Ergebnisse. Alle bisherigen Messungen haben bestätigt, daß der Vorbehandlung der metallischen Oberfläche größte Aufmerksamkeit zu widmen ist. Abweichungen im spektralen Reflexionsverhalten von absolut 10% sind leicht hervorzurufen.

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Hans G. Völz, Krefeld:

Vorschläge zur Neufassung von DIN 53 162 (ASTM D 2805): Bestimmung des Deckvermögens von weißen und hellgrauen Beschichtungen

The method of determination has turned out to be in need of improvement in a few points: furthermore it has to be adapted to the general development of colorimetric evaluation. The paper submits proposals for improvement that have already proved their worth in practice. It also shows how to effect the adaptation to the new hiding power criterion (given colour difference between black and white).

Évidemment, cette méthode de détermination a besoin d'être améliorée sur quelques points; en outre, elle doit être adaptée au développement général de l'évaluation colorimétrique. L'exposé montre des propositions d'amélioration déjà éprouvées en pratique. On montre ensuite comment la réponse au nouveau critère du pouvoir couvrant (différence de couleur donnée entre noir et blanc) peut être réalisée.

Es hat sich erwiesen, daß das Bestimmungsverfahren in einigen Punkten verbesserungsbedürftig ist, außerdem muß es an die allgemeine Entwicklung der farbmetrischen Bewertung angepaßt werden. Der Vortrag bringt Verbesserungsvorschläge, die sich bereits in der Praxis bewährt haben. Weiter wird gezeigt, wie die Anpassung an das neue Deckvermögenskriterium (vorgegebener Farbabstand zwischen Schwarz und Weiß) durchgeführt werden kann.

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1 Grundlagen und gegenwärtiger Stand der Technik

Die Norm DIN 53 162 ist inzwischen 14 Jahre alt; eine Anpassung an die fortschreitende Entwicklung ist nötig geworden.
Aus der Deckvermögensvorschrift, "den Kontrast eines schwarz-weißen Untergrundes zum Verschwinden zu bringen", folgt das bekannte klassische Probierverfahren. Die Vorschrift nach DIN 53 162 stellte insofern einen Fortschritt dar, als man nur noch eine einzige Schicht herzustellen braucht, deren gemessene Reflexionsfaktoren über Schwarz und Weiß zusammen mit der gemessenen Schichtdicke die Berechnung des Deckvermögens unter Benutzung der KUBELKA-MUNK -Theorie [1,2] gestatten. Man erhält eine Endgleichung für das Deckvermögen, in die man nur noch die optischen Konstanten und die Schichtdicke einzusetzen braucht.
In den vergangenen Jahren hatten sich im eigenen Labor schon einige Verbesserungen als zweckmäßig und notwendig erwiesen [3] :

- Ersatz der Schwarz-Weiß-Kartons durch ein schwarze Glasplatte, Bestimmung der optischen Konstanten aus der "unendlich dicken" Schicht und einer nicht deckenden Schicht über Schwarz [4]. Beim Ersatz der Kartons durch eine Glasplatte und Bestimmung aus der unendlich dicken zusammen mit einer nichtdeckenden Schicht hatte sich schon früher erwiesen, daß dieses Verfahren genauer arbeitet [5] .
- Oberflächenkorrektur der Reflexionsfaktoren. - Die Oberflächenkorrektur ist notwendig, um die Oberflächenphänomene vor Berechnung der KUBELKA-MUNK -Konstanten k und s rechnerisch zu eliminieren [7] . Hier wird die bekannte SAUNDERSON -Korrektur [8] vorgeschlagen in einer Form, wie sie bereits in DIN 53 234 enthalten ist.
- Bestimmung der Schichtdicke mit einem pneumatischen Gerät [6] . - Das genannte Schichtdickenmeßgerät ist Eigenentwicklung; es hat sich bis heute voll bewährt, besonders wegen seiner hohen Genauigkeit und weil es zerstörungsfrei arbeitet.
- Einsatz von Tischrechnern. - Rechner sind heute eine Selbstverständlichkeit; daneben sollten aber Tabellen und Rechenhilfen weiter zur Verfügung stehen.
- Berechnen eines "Streuanteils" am Deckvermögen. - Die Angabe des Streuanteils ist deswegen wichtig, weil z.B. bei Weißpigmenten nur der durch Lichtstreuung verursachte Anteil am Deckvermögen wertvoll ist, während zunehmend Absorption des Weißpigments gleichbedeutend mit einer Qualitätsminderung ist.

2 Weitere Vorschläge zur Modernisierung der Methode

Seit einigen Jahren hat sich eine weitere Forderung ergeben, nämlich die Einführung des Farbabstandes zwischen den Beschichtungen über Schwarz und Weiß als neues Deckvermögenskriterium[1), um eine bessere Übereinstimmung mit den Bestimmungsmethoden für das Deckvermögen bunter Beschichtungen herzustellen. Da DIN 53 162 in seiner bisherigen Form das Kontrastverhältnis als Deckvermögenskriterium enthält, würde man nach dieser Norm andere Resultate erhalten als nach einer Methode für bunte Beschichtungen (z.B. DIN 55 987). Durch eine weitere Maßnahme soll der visuellen Abmusterung besser Rechnung getragen werden, indem berücksichtigt wird, daß der Kolorist bei glänzenden Proben den Glanzeffekt durch Einstellung eines geeigneten Beobachtungswinkels "wegspiegelt"; das entspricht einem Reflexionsfaktor von $\beta - g r_o$ (g = Glanzgrad, r_o = Faktor der äußeren Reflexion).
Diese Bedingung bildet zusammen mit den übringen Gleichungen ein ge-

1) d.h. $\Delta E^*_{ab} = 1$

schlossenes System, in dem die Größe $\alpha = 1/(sh) = D/s$ und daraus das Deckvermögen D berechnet werden kann.
Da dies Gleichungssystem nicht mehr elementar lösbar ist, wurde es mit einem Rechenprogramm (HEWLETT PACKARD 9835) iterativ über eine Newton-Näherung gelöst; die α-Werte wurden in Abhängigkeit von β^*_∞ [1] und g zu einer Tabelle aufgelistet[2].
Mit der α-Tabelle ist das Problem zunächst gelöst; aus s und α ergibt sich der Deckvermögenswert. Für die Berechnung mit Hilfe von kleineren Tischrechnern oder für die Berechnung "von Hand" wären leicht zu handhabende Gleichungen aber auch zweckmäßig. Hierzu wurde das interessierende Gebiet $0{,}7 < \beta^*_\infty < 1$ in 3 Bereiche[3] zerlegt.
Der Fehler bei der Anwendung dieser Gleichungen[2] liegt in allen Fällen unter 0,2 %. Mit diesen Formeln wird nicht nur dem modernen und verfeinerten Deckvermögenskriterium Rechnung getragen, sondern die Berechnung ist auch wesentlich einfacher geworden.
Bei der Berechnung des Streu- und Absorptionsanteils am Deckvermögen handelt es sich um diejenigen Anteile, die einmal allein durch die Lichtstreuung, zum anderen allein durch die Lichtabsorption bewirkt werden, ein verbleibender Rest ist der Wechselwirkung zwischen Streuung und Absorption zuzuschreiben. Der Streuanteil ergibt sich aus dem KUBELKA-MUNK-Formalismus durch den Grenzübergang $k \to 0$ [9] . Bei Verwendung dieser Gleichung in dem obigen Interationsprogramm erhält man eine neue α-Tabelle $\alpha_1(g)$, deren Werte nur noch vom Glanzgrad abhängig sind und die man ebenfalls durch eine nichtlineare Regression darstellen kann. Bei der Berechnung des Absorptionsanteils geht man in ähnlicher Weise vor (Grenzübergang $s \to 0$).

3 Das modernisierte Verfahren

Ein komplettes Fließschema für die Berechnung des Deckvermögens von Weißpigmenten ist in Abb. 1 gegeben. Die Ausrechnung des Deckvermögens

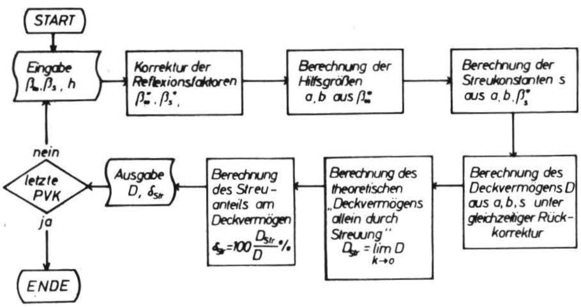

Abb. 1: Ablaufdiagramm der Bestimmung des Deckvermögens von Weißpigmenten in der verbesserten Form

1) β^*_∞ ist der oberflächenkorrigierte Reflexionsfaktor der unendlich dicken Schicht
2) Tab. und Gl. werden in der Zeitschrift "Die Farbe" veröffentlicht
3) Hierfür wurden nichtlineare Regressionsgleichungen aufgestellt.

nach dem modernisierten Verfahren gestaltet sich dann wie folgt: Nach Oberflächenkorrektur der Reflexionsfaktoren werden die Hilfsgrößen a und b errechnet und daraus mit der in DIN 53 162 angegebenen Formel die Streukonstante s. Der nächste Schritt besteht in der Berechnung der Größe α, wobei zwei Wege zur Verfügung stehen, nämlich der über die α-Tabelle oder der über die Regressionsformel. Schließlich werden noch Streu-, Absorptions- und Wechselwirkungsanteil berechnet.
Von den genannten und beschriebenen Vorschlägen sollten die folgenden unbedingt in die Neufassung der Norm übernommen werden:

- Ersatz der Schwarz-Weiß-Kartons durch eine schwarze Glasplatte, Messung von und Rechnung mit β_∞ und β_s.
- Korrektur der Reflexionsfaktoren wegen der optischen Oberflächenphänomene.
- Einführung des Farbabstandes $\Delta E^*_{ab} = 1$ als Deckvermögenskriterium.

Der vollständige Text dieses Beitrages wird in "Die Farbe" erscheinen.

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Karel Turek und Zbyněk Kraus, Pardubice (ČSSR):

Anwendung der phänomenologischen Theorie des Strahlungs-Transports auf koloristische Probleme

Possibilities of application of radiative transfer theory for colorimetry were described. In general, approximative and numerical ways of transfer solution with regard to phase function, additivity and surface reflection of textile and pigment applications are discussed.

On a examiné les possibilités d'une application de la théorie du transfer radiatif aux problèmes colorimétriques et coloristiques. Les voies d'une solution générale numérique ou approximative sont discutées en regard des fonctions de phase, de l'additivité et de la réflexion superficielle.

Die Möglichkeiten einer Anwendung der Strahlungstransport-Theorie auf farbmetrische und koloristische Probleme werden untersucht. Allgemeine numerische und angenäherte Lösungswege werden im Hinblick auf Phasenfunktion, Additivität und Oberflächenreflexion bei der Anwendung auf Textilien und Pigmente besprochen.

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Objektive kolorimetrische Verfahren, die auf Remissions-Spektren des sichtbaren Spektralbereiches der Lichtstrahlung gegründet sind, finden in der koloristischen Arbeit immer größere Bedeutung, besonders in der Beurteilung der Typkonformität der Farbstoffe und der Pigmente, für die Ausrechnung der Färberezepturen und in weiteren Gebieten. Neben der klassischen Kubelka-Munk-Theorie /1/ und deren Bearbeitung wird immer mehr auf diesem Gebiet die phänomenologische Theorie des Strahlungstransfers angewendet. Eine Reihe der Resultate auf diesem Gebiet, speziell für diese Zwecke benutzt, wurde durch die allgemeine Lösung der Differential-Integralgleichung des Transfers für unendliche Schichtdicke gewonnen /2/. Die Gleichungen enthalten die H-Funktion, die in einer Form definiert wurde, die für die praktische Anwendung nicht geeignet ist. Es ist deswegen notwendig, angenäherte Tabellen-Werte zu benutzen, die aber nicht ausreichend genau sind. Besser dürfte die Entwicklung der H-Funktion in Form rationaler Polynome sein. Die numerische Form wurde aber bisher nur für isotrope Streuung veröffentlicht /3/. Die Meß-Geometrie d/ braucht dazu noch den Ausdruck der ersten und zweiten Glieder dieser Funktionen. Nützlicher, besonders für die Voraussetzung der anisotropen Phasenfunktionen, sind Näherungs-Lösungen der Transfergleichungen /4/. Hierbei kann man in entsprechende Modelle auch äußere und innere Oberflächenreflexionen einbeziehen. Für die Meßgeometrie d/ ist dies bei der Anwendung auf matte Oberflächen mit annähernd isotroper Indikatrix gelungen. Für die Winkelfunktion /1/ ist es möglich, diese Lösung durch folgende Gleichungen auszudrücken /2/:

$$p(\cos\theta) = \omega\,(1 + x\cos\theta) \qquad (1)$$

$$R^{d}/_{\sigma} = \frac{n^2(1-J) + R^{d}/_{d}\,(Jn^2 + J - n^2)}{n^2 - R^{d}/_{d}\,(n^2 - J)} \qquad (2)$$

wo

$$R^{d}/_{d} = \frac{\omega}{(3 - \omega x - 2p)}\left\{-x + \frac{6 + 2x(1-\omega)[p - \ln(1+p)]}{p^2}\right\}$$

$$p^2 = (1-\omega)(3-\omega x) \qquad -1 \le x \le 1 \qquad \mu = \cos\vartheta$$

Der Winkel [illegible] stellt einen Winkel zwischen zwei Richtungen der Lichtstrahlen vor, und [illegible] ist der Winkel gegen die äussere Normale der Oberfläche. In der Gleichung /2/ ist weiter ein Brechungsindex n des Mediums einbezogen, was besonders für die Bestimmung der Gesamt-Durchlässigkeit J /3/ wichtig ist.

$$J = \int_0^t t(\mu)\,\mu\,d\mu \qquad (3)$$

wobei $t(\mu)$ die gerichtete Durchlässigkeit der Oberfläche ist. Bei matten Oberflächen nicht-textiler Materialien ist es möglich, durch Integration der Fresnel-Beziehung für den entsprechenden Brechungsindex den J-Wert zu berechnen. Bei den Textilien muß man den Brechungsindex betrachten, der kleiner ist als der der Fasern im Gewebe oder der des Garnes. Noch besser ist es, den J-Wert als empirische Konstante einzuführen, die am besten einer Farbstoffreihe der bestimmten technologischen Klasse auf gegebenem Substrat entspricht.

Ein ähnlicher Ausdruck für $R_{d/d}$ aus der allgemeinen Lösung ist durch die Gleichung /4/ gegeben.

$$R_{d/d} = 1 - 2\alpha_1 \left\{1 - \frac{\omega}{2}(\alpha_0 - k\alpha_1)\right\} \tag{4}$$

wo

$$\alpha_0 = \int_0^1 H(\mu,\omega)\, d\mu \qquad \alpha_1 = \int_0^1 H(\mu,\omega)\, \mu\, d\mu$$

$$k = x(1-\omega)\omega \frac{\alpha_1}{2-\omega\alpha_0}$$

Aus dieser Gleichung ist ein verhältnismäßig kompliziertes Resultat ersichtlich. Erfahrungsgemäß ist eine Verringerung der Genauigkeit bei Näherungs-Methoden nicht wichtig; besonders bei der Anwendung im Textilgebiet sind die Gleichungen /2/ ausreichend. Den Parameter ω, die Helligkeit der einmaligen Streuung, kann man mit der Konzentration der Ausfärbung durch die Gleichung /5/ verbinden.

$$1/\omega = 1/\omega_S + \sum_{i=1}^{n} a_i c_i \tag{5}$$

ω, ω_S muß man aus den entsprechenden Gleichungen und dem gemessenen Spektrum der ausgefärbten und nichtgefärbten Substraten durch ein Iterationsverfahren feststellen. Die lineare Abhängigkeit /5/ wird bei den Ausfärbungen der Konzentrationsreihen in einem verhältnismäßig großen Konzentrationsbereich erfüllt. Die Anwendung auf Modellsysteme hat gezeigt, daß für Textilsubstrate die Phasenfunktion in konkreter Form $\omega(1-0{,}5\cos\theta)$ die günstigste ist. Im Vergleich mit Resultaten von Kubelka-Munk ergibt sich eine Verbesserung der gesamten Farbdifferenz um etwa 50% im Farbsystem CIELAB.

Die angeführten Resultate sind aber nur für genaue Ausfärbungen gültig. Im Bereich der Anstrichmittel und der Drukke ist die Form der Phasenfunktion $\omega(1+\cos\theta)$ besser. Für Oberflächen mit gleicher Reflexion an beiden Grenzflächen und mit komplizierter Phasenfunktion im Inneren des diffusen Mediums hat sich ein numerisches Verfahren "many-flux" bewährt, das schnelle Rechner ausnutzt. Bei der Anwendung hat sich eine Verbesserung des rechnerischen Grundverfahrens bewährt. Ein Nachteil für die praktische Ausnutzung stellt die numerische Form der Daten und die große Rechenzeit dar. Deswegen wurde für jedes Modell eine Tabelle der Abhängigkeiten /6/ errechnet, die weiter mit Hilfe von rationalen Polynomen von Tschebyschew approximiert wurden.

$$R = f(K/S) \qquad K/S = f(R) \qquad (6)$$

K/S ist da Verhältnis des Absorptions- und Streuungskoeffizienten des Transfers. Dieses Verfahren ermöglicht eine Lösung der Probleme auf dem Gebiet der Anwendung von Pigmenten, und zwar in Zeiten, die den Kubelka-Munk-Gleichungen gleich ist.

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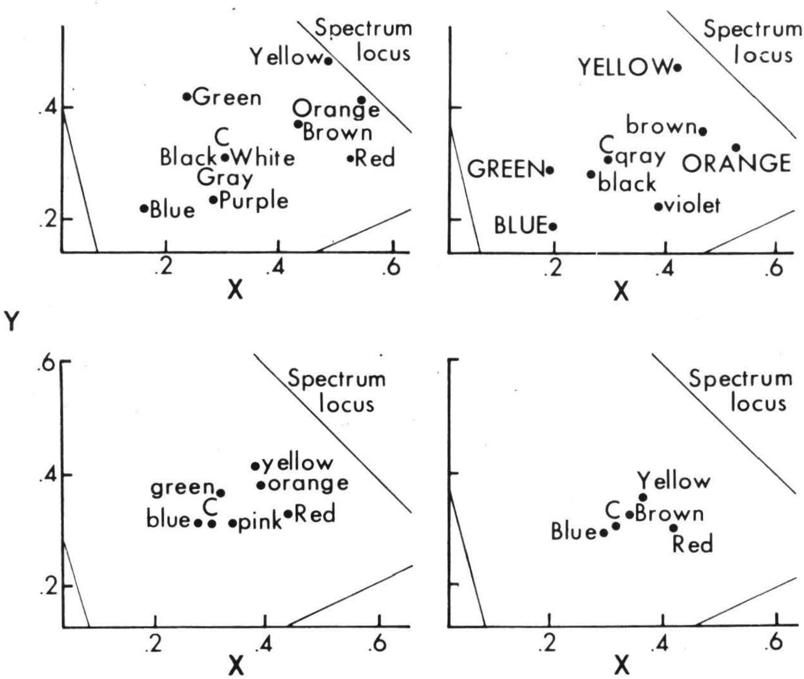
Spectrum
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Y
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pink
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John B. Hutchings and David E.W. Sanderson, Bedford/Bradford (England):

Transreflectance Properties of Lightly Tinted Ancient Glass

The optical signature technique for identification/characterisation of colorants is apparently successful when used in a transreflectance mode on irregularly sized and shaped near-transparent materials. The irregular colouring of the material does not warrant high precision for any estimate of colorant concentration. It is more important for archaeological purposes that the colorant system be correctly identified, and for this we appear to have the individuality of a single colorant system shown by a characteristic chromaticity locus and log transform spectral curve.

L'identification et la caractérisation d'une système de colorants sont évidemment couronnées de succès si l'on fait les mesures sur des échantillons de grandeur et de formes irrégulières d'un matérial presque transparent. La coloration inégale du matérial ne permet pas de haute précision pour l'estimation de la concentration du colorant. Pour le but archéologique, il est plus important de déterminer le système du colorant, et pour cela nous croyons d'avoir trouvé des signes que seulement un colorant unique a été appliqué qui est caractérisé par son point de chromaticité et par sa courbe spectrale de densité.

Die Identifizierung und Kennzeichnung der Färbemittel ist offensichtlich erfolgreich, wenn die Messungen an Proben von unregelmäßiger Größe und Form bei fast durchsichtigem Material gemacht wurden. Die ungleichmäßige Färbung des Materials erlaubt keine hohe Genauigkeit bei der Abschätzung der Konzentration des Färbemittels. Für archäologische Zwecke ist es wichtiger, das System des Färbemittels genau zu bestimmen, und dafür scheinen wir Anzeichen gefunden zu haben, daß nur ein Färbemittel vorliegt, das durch seinen Farbort und die spektrale Dichtekurve gekennzeichnet ist.

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1. INTRODUCTION

This paper describes a short feasibility study on the transreflectance properties of glass fragments. No previous scientific colour specification studies are known to have been made on ancient, near-transparent glass. A proven technique would be invaluable for positive classification and identification of fragments and as a firm scientific foundation upon which, for example, discussions of origin or method of manufacture could be based.

2. THE SAMPLES AND ARCHEOLOGICAL BASIS OF THE WORK

Glass artefacts are known from many prehistoric and historic sites throughout the world. Obsidian, a natural glass produced by volcanic action, is found from about the 8th millenium B.C., whilst our earliest recorded man-made glasses, produced by fusing silicaceous material with alkalis and possibly lime, appear at the end of the 2nd millenium B.C. in the Middle East.

In comparison, glass is relatively young in Britain, although native glass bead production is known in the Iron age (Henderson, 1980), and further archeological research is revealing Bronze age material. Domestic window and vessel glass was not used widely in Britain until the Roman period. Thereafter there was a decline in the use of glass until the 12th century A.D., when the 'forest' glass industry established itself.

Compositional studies of glass through the Roman and early Medieval period (Sanderson and Hunter, 1980) show that there is a major raw material change (in the alkali source) associated with the start of the forest glass industry. However, the basic composition of window and vessel glass in the Dark Ages and Anglo-Saxon period is not different from that in the Roman period.

Analysis of possible alkali raw materials (Sanderson and Hunter, to be published) accounts for the major compositional change in the later Medieval period, and also shows that forest glasses contain both manganese and iron (known to be colorants) from the use of wood ash as an alkali source. The colour of glass depends partly on the presence of transition metal oxides (either introduced deliberately or accidentally in raw materials) and partly as a function of the melting conditions (temperature, time, partial pressure of oxygen) during manufacture (Sellner and Camara, 1979). For this reason, it cannot be accounted for purely by chemical analysis, and must be treated as separate parameter for glass-type classification.

The potential of using the colour of glass in typological work has been partially assessed in a study of lightly tinted fragments from the site of Cadbury-Congresbury. Several hundred fragments were classified using conventional typological methods (Charlesworth, unpublished) and also grouped into visually defined colour categories. The results indicated that it may be possible to ascribe different colours to different periods or sites or methods of manufacture.

The present work was aimed at seeing whether the colour of glass fragments can be specified instrumentally, despite their irregular shape, to provide further information for use in provenance studies. In this initial work, 10 samples were used from Cadbury-Congresbury (5th/6th century A.D.) representing some of the light tints produced by impurity colouring, and one deliberately coloured fragment of copper blue glass was used from Repton, Saint Wystan (8th century A.D.).

3. EXPERIMENTAL AND RESULTS

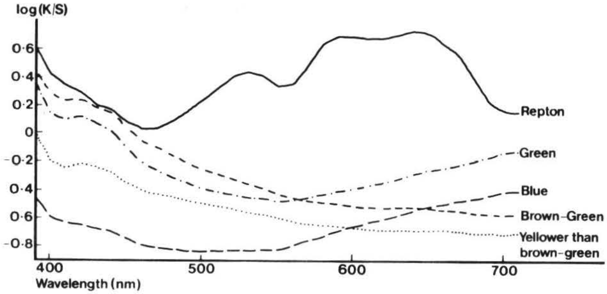
The samples were placed on a white tile and the reflectance spectra measured using a Pretema Reflectance Spectrophotometer. The results were considered in two forms; the chromaticity and the optical signature spectral curve of which the latter is illustrated. Visual examinations were made of the samples on a white backing in a lighting cabinet the illumination of which approximated to illuminant C.

The piece of glass to be measured was placed on a white tile and presented to the spectrophotometer, geometry $180^{o}/0^{o}$, for measurement. The illuminating area had a diameter of 30mm, the viewing area a diameter of 20mm. As well as being of irregular shape and thickness, some of the samples were slightly smaller than the viewing area. It was therefore expected that we would encounter problems of poor precision.

Visual examination showed that the nominally untinted samples could be classified into four hue groups: a series of five green-brown, two slightly redder brown, one green and two light blue. The chromaticity coordinates (illuminant C) show excellent agreement with the visual gradings, both in the relative positions of hue and of the order of colour depth within each hue group. The locus of the points within each group is consistent with the postulate that each group may be the result of one colorant (impurity) system.

It has been found that for transparent materials use of log(-log internal transmittance) yields specific curves which are characteristic of the colorant irrespective of concentration, while for turbid media log(K/S) gives the optical signature of a colorant (Judd and Wyszecki 1963). The internal trasmittance of these samples was not measured, but it was found that log(-log reflectance) and log(K/S) spectra yielded similar shapes and characteristics. Within each hue group the curve shape was very similar, although each hue group gives a different 'characteristic' curve (see the figure). This confirms the earlier observation that we may expect each characteristic curve to result from a different colouring mechanism.

Figure 1 Representative log (K/S) colourant character spectral curves of four lightly tinted and one highly coloured (Repton) glasses



The behaviour of the chromaticity and the spectral data were surprisingly consistent bearing in mind the irregular geometry and size of the samples. It was decided to test the effect of reduction in sample area on the reflectance properties using Rank Strand Cinemoid pale yellow gelatine filter. When the filter material was placed on a white standard tile, its reflectance properties were of similar excitation purity to the range of non-tinted glass samples. Successively narrower strips of the filter were placed on a white tile, starting with complete coverage of the viewing aperture. Reflectance measurements were made on strips 20, 18, 16mm wide. It was found that when the 18mm wide strip was used (i.e. 96% of full aperture area) the colour difference value (ΔE) was 1.3. The 16mm strip (89%) gave a ΔE of 5.2. These differences are probably small compared with the variability of colour occuring within each of the glasses measured. Therefore the transreflectance method of measurement of such irregularly shaped samples appears to be justified. Note that it is only justified for pale-coloured near-transparent materials on a highly reflecting background. The proposed technique of measurement for glasses is designed to yield information diagnostic of the colour, hence hopefully the provenance. Errors caused by sample irregularity and size will merely cause a shift along the particular colorant chromaticity locus, they also should only effect the amplitude of the log transform, and not its shape. Hence this should not lead to any error in identification. However, only further experience of using this technique in conjunction with other evidence will show the confidence limits of this approach.

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Fred W. Billmeyer jr., Max Saltzman and Romesh Kumar, Troy (New York):

Identification of Organic Pigments by Solution Spectrophotometry

Analytical schemes and a library of reference curves, available to interested users, are described for the application of the solution spectrophotometry method for the identification of organic pigments in a wide variety of materials, including paints, plastics, inks, and (by semimicro techniques) works of art.

On décrit des schèmes et une bibliothèque de courbes de référence pour l'application dans la spectrophotométrie des solutions au but de l'identification des pigments organiques que l'on utilise dans une grande variété de matériaux, comme dans la peinture, les matières plastiques, encres et pour des objets de peinture artistique.

Hier werden Schemata und eine Sammlung von Bezugskurven beschrieben, die der Identifikation von organischen Substanzen mittels Spektralphotometrie von Lösungen dienen sollen. Es handelt sich um Pigmente, Kunststoffe, Druckfarben und auch um Gemälde.

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The widespread adoption of organic pigments by the paint, plastics, inks, and other colorant-using industries in recent years lends importance to the development of methods for their identification. For example, knowledge of the pigmentation of a specimen is an important aid in formulating an invariant match to it. Art conservators require the information for the examination, preservation, and restoration of modern paintings.

The objective of this study was to develop the practical utility of the method of solution spectrophotometry for the identification of organic pigments. First used for dyes over 90 years ago [1], it was described in detail two decades later [2], applied to organic pigments in the 1940's [3], and the subject of a few recent publications [4,5]. The present research provides detailed analytical schemes and a library of reference spectrophotometric curves facilitating the practical application of the method.

A few milligrams of the sample to be analyzed (or in the application of semimicro techniques to works of art, a few micrograms) is extracted by brief contact with one or more of a series of organic solvents. Colored solutions result if organic pigments are present. These are measured in an analytical spectrophotometer in the wavelength range 400-900 nm; use of a visible-range color spectrophotometer excludes information on the important phthalocyanine pigments between 800 and 900 nm. A log absorbance presentation is used to provide a spectral curve whose shape is independent, over a wide range, of the concentration of the colorant. Identification is made by comparison of the curve shape to those in a library of reference curves.

A number of other methods can be used for the identification of organic pigments, including spot testing, microscropy of crystals, x-ray diffraction, melting-point determination, chemical reactions, thin-layer chromatography, and infrared or reflectance spectrophotometry, but none of these combines the advantages of solution spectrophotometry for the rapid analysis of small samples, including those containing mixtures of pigments, in the presence of large amounts of binder or other impurities.

If the analyst has no prior knowledge of the nature of the pigments in his sample (an unusual situation), the following analytical scheme provides for the separation of all classes of organic pigments into relatively small groups for further identification. The solvents mentioned below are used in sequence for the extraction, and the classes of pigments indicated are removed in solution:

(i) Cyclohexane (acetoacetarylide azo, 2-naphtol azo)

(ii) Carbon tetrachloride (some 2-hydroxy-3-naphtharylide azo, thioindigo, simple disazo)

(iii) Toluene (remaining 2-hydroxy-3-naphtharylide azos, dioxazine violet)

(iv) Chloroform (basic dye derivatives, some vats)

(v) Methanol (metal-salt monoazo)

(vi) Dimethyl formamide (DMF) (benzimidazolone azo, tetrachloroisoindolinone, quinacridone, indigo, perylene, anthraquinone, monoazo metal complexes)

(vii) Ethanol-sodium hydroxide, 90:10 (EtOH+NaOH) (disazo condensation)

(viii) conc. Sulfuric acid (H_2SO_4) (phthalocyanine).

Further separation can be effected by evaporating the original solvent and extracting as follows:

(ia) After cyclohexane, pentane

(iia) After carbon tetrachloride, (in order) methanol, acetone, chloroform

(iiia) After toluene, acetone

(va) After methanol, ethanol

(via) After DMF, (in order) methyl nitrite, EtOH+NaOH

(viia) After EtOH+NaOH, pyridine

In almost all cases, this scheme can be greatly simplified through knowledge of the types of pigments that can be expected in the samples. For routine work, we utilized that a simple four-solvent scheme using (in order) the four solvents chloroform, methanol, DMF, and H_2SO_4. It is always advisable to confirm the presence of a pigment and to explore the possibility of mixtures of pigments with similar solubility and spectral curve shape by examining pigment curves in different solvents. Due to pigment-solvent interactions, shifts in curve shape from one solvent to another are common. Thus, in the above four-solvent scheme, pigments soluble in chloroform or methanol should be examined by evaporating that solvent and dissolving them in DMF and H_2SO_4, and those originally soluble in DMF should be examined in H_2SO_4 solution.

All organic solvents are potentially hazardous to the health: all appropriate precautions must be observed in their use, and they must be used only in accord with existing laws.

Several hundred organic pigments, obtained from the manufacturers, have been measured (G.E.-Hardy, Diano Match-Scan spectrophotometers) in solution in those of the following solvents in which they are soluble: chloroform, methanol, DMF, EtOH+NaOH, H_2SO_4. The data for over 400 curves are stored, as log absorbance at 2.5-nm intervals, 380-700 nm, on Rensselaer's IBM 3033 computer. The log absorbance presentation gives according to Beer's Law a curve shape independent of solute concentration. This is amply confirmed experimentally for organic pigments.

With the aid of a curve-shape index developed as an extension of that suggested by Shurcliff [6], the reference curves can be retrieved from the collection in small groups or singly to facilitate the identification. The curves can be printed out with scales adjusted to match those of the user's measuring instrument.

As one example of the method, Fig. 1 shows the analysis of an artists' paint containing a quinacridone violet and a Hansa yellow by spectrophotometry of a solution in DMF. The reflectance curve of a drawdown of the paint provides little information on its composition, but the solution curves clearly identify the components. In this case there was no need for further separation of the mixture of two pigments.

As shown by Saltzman and Keay [4], the major absorption peaks for solutions in H_2SO_4 of phthalocyanine blue and green pigments occur in the near-infrared spectral region between 700 and 900 nm. This is the only case observed in which visible-range data must be supplemented. However, we find that phthalocyanine blues (but not greens) can be identified by pouring the H_2SO_4 solution into 15 volumes of water, then shaking with xylene. A small amount of the pigment dispersion transfers to the organic solvent to provide characteristic dispersion curves with

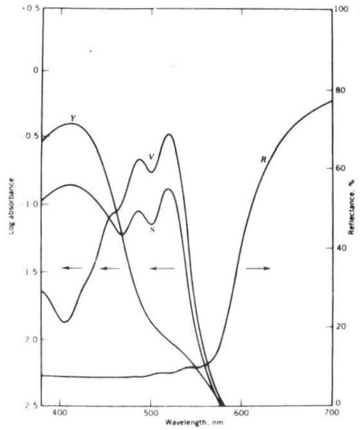

Fig.1. Reflectance (R, right-hand ordinates) of a drawdown and DMF-solution log-absorbance (left-hand ordinates) spectrophotometric curves of an artists' paint labelled "Iridescent Red" (S), Pigment Yellow 1 (Y, Hansa yellow), and Pigment Violet 19 (V, quinacridone violet). From Billmeyer and Saltzman, Principles of Color Technology, 2nd ed., 1981, courtesy of John Wiley and Sons.

absorption maxima in the visible region.

Occasionally the solution curves of difficulty soluble pigments can change with time, and proper precautions must be observed.

To facilitate the application of the solution spectrophotometry technique we are prepared to offer not only the necessary analytical schemes but also (at cost) all or part of our library of reference curves, scaled to correspond in size to those obtained with the user's instrument. Other arrangements for access to Rensselaer's collection can be made.

Acknowledgments. This paper is based on the Ph.D. thesis of Romesh Kumar, and was supported under the National Museum Act by grants FC-807937 and FC-005226, and by a grant from the Color and Appearance Division of the Society of Plastics Engineers. This is Contribution No. 105 from The Rensselaer Color Measurement Laboratory.

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This paper will be published in full in COLOR research and application.

Po5

Roberto Daniel Lozano, Cristina Melcón de Bellora and David Jungman, Buenos Aires (Argentina):

Measurement of Colour as an Indication of Maturity of Salted Anchovy

Colour of meat of salted anchovy can be an indication of maturity. Presently a research on this subject is being carried out at INTI Statistical correlation between days of processing and different relations between the colour parameters for the CIE 1931 XYZ, CIELAB and Hunter's Lab systems are analyzed.

La couleur des anchois salés peut être un indice de maturité. Actuellement l'INTI s'intéresse à ce problème. Nous analysons la corrélation statistique entre le jour de la mesure et les paramètres des couleurs dan les systèmes CIE 1931 XYZ, CIELAB et LAB de Hunter.

An der Farbe eingesalzener Sardellen kann man erkennen, ob sie ausgereift sind. Darüber ist jetzt eine Untersuchung am INTI durchgeführt worden. Die Beziehungen zwischen den Meßzeiten und verschiedenen Farbmaß-Systemen (CIE 1931 XYZ, CIELAB, Hunters L.a.b) wurde statistisch analysiert.

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In the fishing industry, in Argentina, the preparation and control of salted anchovy are mainly done on empirical basis. Expert people see and taste the product and determine if it is ready for commercialization. To find an objective method to evaluate this characteristic, a program to measure the different biological and physical properties during the maturation process was established.

Among one of the most evident parameters which changes in the fish is the colour of its meat around the spine.

The maturation process modifies the colour by diffusion of the haemoglobine or modification of the meat properties. This aspect is under study by another research group. Actually, in this laboratory, it is measured systematically using samples with different ages of maturity process (from 30 to 700 days) sampling about ten fishes each 15/30 days, opening by the center, cleaning and mapping the internal surfaces at both sides of the spine (which is removed). In the process, each part of the surface is measured by means of spectrophotometer Zeiss DMC 25 (with monochromatic light, 8°/Dif. geometry, specular gloss included) to evaluate the spectral reflection factor in the 380 - 720 nm region.

The results are processed by a computer to evaluate the CIE 1931, x, y, chromaticity coordinates and the luminous reflection factor Y, which also are transformed in to CIELAB L , a , b and Hunter's L, a, b coordinates.

This data is analysed by statistical methods to look for a correlation between extension of the colour changes, colour change and time of maturity process.

The present report informs of these results.

Po6

John B. Moser, Northwestern University Dental School, Chicago, IL. U.S.A., and **Wayne T. Wozniak,** American Dental Association, Chicago, IL. U.S.A., Chicago (IL):

Color Changes in Denture Base Resins

Color changes resulted from immersion of denture base resins in hot tea and coffee, and cold cola solutions. Data were obtained on an IDL Color-Eye colorimeter which yielded CIE tristimulus values. Differences between heat cure and cold cure resins were found. Color changes are described in terms of the CIE 1976 L*a*b* system as well as the Munsell system.

On a plongé des prothèses dentaires dans thé et café chaud ou dans cola froid; des changements de couleur y sont observés. Pour la mesure on a utilisé le IDL Color-Eye qui a délivré les valeurs trichromatiques CIE. On a trouvé des différences entre les matières plastiques à durcissement froid ou chaud. Les changements des couleurs sont représentés dans l'espace des couleurs CIE 1976 L*a*b* aussi bien que par le système des couleurs Munsell.

Zahnprothesen aus verschiedenen Kunststoffen wurden in heißen Tee und Kaffee und kalte Cola eingetaucht, was zu Verfärbungen führte. Die Untersuchung wurde mit einem IDL Color-Eye durchgeführt, das die Normfarbwerte anzeigte. Die Unterschiede zwischen heiß- und kaltpolymerisierenden Kunststoffen wurden festgestellt. Die Farbänderungen werden sowohl im CIE 1976 L*a*b* Farbenraum dargestellt als auch im Munsell-Farbsystem ausgedrückt.

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Colorimetric measurements were made on two denture base resins, one a heat-cure and the other a cold-cure polymethyl methacrylate. The resins were mixed and cured according to manufacturers instructions. Specimens 2 mm thick by 10 mm diameter were immersed in the following solutions for various periods of time up to 15 days (only 15 day changes are shown in this extended abstract):

Cold distilled water (23°C)
Hot distilled water (60°C)
Coca Cola (5°C)
Lipton tea (60°C)
Tasters Choice Coffee (60°C)

Colorimetric measurements were made on an IDL Color-Eye colorimeter which was standardized against a Vitrolite tile. The colorimeter values of X', Y', Z' and $\bar{X}$ were converted by means of a series of computer programs to yield CIE tristimulus values and color coordinates. In addition, the tristimulus values were converted to Munsell hue, value and chroma and CIE 1976 L*a*b* coordinates.

Table 1 shows initial x,y,Y coordinates as well as the changes undergone after 15 days immersion in the various test solutions. In order to make the differences more perceptually meaningful, the data was converted into the Munsell system. Cold-cure resin had an initial HV/C = 3.0R5.4/2.9 and hot-cure resin was 8.3R5.2/2.5. Total color differences values (ΔE) are shown in Table II.

Comparing the cold-cure and heat-cure resins in the same solutions, it was found that tea, coffee and hot water stained the cold-cure resin considerably more than the heat cure resin. Smaller differences were found for the cold solutions, i.e., cola and cold water. The color changes can be attributed mostly to changes in hue, with smaller changes in value and chroma. These hue changes were of positive sign, i.e., towards the yellow, while changes in value and chroma were of negative sign, i.e., towards darker and less saturated colors. Color differences (ΔE) expressed in the 3 systems, although numerically different, generally follow similar trends.

Table 1. CIE Color Changes after 15 Days.

	Δx	Δy	ΔY
	Cold Cure Resin (Initial Coordinates x = 0.348, y = 0.317, Y = 23.37)		
Cold Water	+0.001	+0.001	+0.038
Hot Water	+0.008	+0.013	-0.322
Cola	+0.002	+0.003	-1.942
Tea	+0.014	+0.019	-1.032
Coffee	+0.010	+0.016	-2.032
	Heat Cure Resin (Initial Coordinates x = 0.353, y = 0.326, Y = 21.26)		
Cold Water	-0.002	-0.001	-0.269
Hot Water	-0.004	+0.002	+0.945
Cola	-0.001	0	-0.637
Tea	+0.003	+0.003	-1.001
Coffee	+0.003	+0.006	-0.276

Table II. Color Differences (ΔE) after 15 Days.

	CIE	Munsell	L*a*b*
		Cold Cure	
Cold Water	3.93	2.51	1.74
Hot Water	8.23	7.65	4.68
Cola	5.87	3.16	2.46
Tea	11.93	9.54	6.47
Coffee	10.12	9.65	5.92
		Heat Cure	
Cold Water	3.75	0.05	1.33
Hot Water	3.48	0.62	1.30
Cola	3.97	0.81	1.72
Tea	5.55	1.41	2.48
Coffee	4.92	2.13	2.34

CIEΔE: Friekle-McAdam-Chickering

$$\text{Munsell}\,\Delta E = \left[\left(\frac{2C\,\Delta H}{5}\right)^2 + (6\,\Delta V)^2 + \left(\frac{20\,\Delta C}{\pi}\right)^2\right]^{1/2}$$

$$L^*a^*b^*\,\Delta E = \left[(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2\right]^{1/2}$$

Douglas B. MacDougall, Bristol (England):

Visual Estimate of Colour Changes in Meat Under Different Illuminants

The magnitude of the colour-appearance shifts in the lean of red and brown beef and pink and brown bacon between Artificial Daylight fluorescent tubes and a variety of illuminants has been estimated by a direct comparison technique. The colour-appearance shifts are compared with the metric-chroma shifts in 1976 CIELUV colour space.

A l'aide d'une comparaison directe on a estimé la distorsion chromatique de viande maigre de boeuf rouge et brun et de lard rosé et brun quand on change d'une lampe à fluorescence (type lumière de jour artificielle) à des autres illuminants. Ces distorsions chromatiques sont évaluées dans l'espace des couleurs CIELUV 1976.

Mittels direkten Vergleichs wurde die Größe der Farbverschiebung von magerem rotem bis braunem Rindfleisch und rosa bis braunem Speck beim Übergang von Leuchtstofflampenlicht (Typ künstliches Tageslicht) zu einer Reihe anderer Lichtarten bewertet. Diese Farbverschiebungen werden im Farbraum CIELUV 1976 dargestellt.

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1. Introduction.

The ferrous haem pigments responsible for the colour of meat are myoglobin (Mb) which is purple, and oxymyoglobin (O_2Mb) and nitric oxide myoglobin (NOMb) which are the red pigments of oxygenated fresh and cured meats. Ferric metmyoglobin (MMb) is brown {1}. Meat with 10 to 20% MMb is discriminated against by the consumer {2}.

The appearance of meat is greatly affected by the colour rendering properties of the lamps used for display {3,4}. Tungsten filament lamps are unsuitable for lighting fresh meat display cabinets because the radiant heat accelerates MMb formation. Fluorescent tubes recommended by lamp manufacturers for meat display have enhanced red emission that maintains the preferred colour of O_2Mb and NOMb and shifts the early stages of MMb development from brown towards red. The opposite is true of lamps with poor colour rendering which shift brown towards green, which in meat is a colour seemingly associated with bacterial spoilage. Estimates of the visual magnitude of the shifts are possible even though the procedure is confounded by chromatic adaptation and the colorimetric shift of the white test area. This situation is analogous to the visual task confronting purchasers in the supermarket where different commodities are displayed under tubes with widely differing spectral power distributions.

This paper reports results of direct estimation of colour shifts of the lean of beef and bacon under a variety of illuminants and attempts to relate them to the 1976 CIELUV colour space.

2. Procedure.

Adjacent viewing booths, fitted with tungsten filament bulbs and fluorescent tubes (600 mm) whose light output could be adjusted, were located in a room dimly lit by Artificial Daylight (60 lm m^{-2}). The viewing areas were standardised at 1100 lm m^{-2}. The reference illuminant was Artifical Daylight (6500°K) and the test illuminants, representative of poor to very good colour rendering, enhanced red emission and narrow band emission, were Tungsten filament (2700°K), Warm White (3000°K), White (3400°K), De Luxe Natural (3600°K) and Colour 84 (4000°K).

Identical packages of red and brown beef or pink and brown bacon were displayed in each booth. The red beef had been partially oxygenated by exposure to air for 1 h, and the brown beef had approximately 30% MMb on the surface. The pink bacon had been packed under vacuum to ensure complete development of NOMb and the brown bacon with >60% MMb had been exposed to light and air for 2 days. A 10 member panel, with normal colour vision, assessed the magnitude of the colour shifts under the test illuminant in direct comparison to the reference pair under Artificial Daylight. Each observer stated the direction (more red or more brown) of the shift and its magnitude relative to the difference in colour within the reference pair.

Diffuse reflectance spectra of the samples, measured on a Pye Unicam SP8-100 Spectrophotometer, were converted to the 1976 CIELUV colour space {5} for each illuminant.

3. Results and discussion.

Colour shifts are expressed as percentages of the difference within the reference pair (Table 1). A 20% shift in bacon colour, a Δ E* of 2.4 units, is equivalent to 20% oxidation of NOMb. Shifts in beef colour in terms equivalent to pigment oxidation are more difficult to interpret because three pigments are involved. Subsurface Mb dilutes the redness of the O_2Mb surface and MMb forms more rapidly at the limit of O_2 penetration than on the exterior. A Δ E* of 1 unit towards brown is equivalent to approximately 3% MMb.

Table 1. Colour shifts of beef and bacon from Artificial Daylight to test illuminants. Shifts expressed as percentage of difference within reference pair; + more red or pink, - more brown. (Panel mean, ($\pm$ s.d.)).

Test illuminants	Brown Beef	Red Beef	Brown Bacon	Pink Bacon
Tungsten	+42 (44)	+56 (34)	- 2 (40)	- 2 (40)
Warm White	-26 (40)	-16 (22)	-58 (62)	-20 (30)
White	-76 (50)	-78 (60)	-98 (76)	-36 (46)
De Luxe Natural	+86 (68)	+84 (44)	+26 (24)	+66 (46)
Natural	- 4 (20)	- 2 (22)	-22 (30)	+16 (50)
Colour 84	+26 (38)	+34 (26)	-24 (32)	-28 (26)

Bacon illuminated by De Luxe Natural was more pink than if illuminated by Artifical Daylight. Tungsten filament bulbs and Natural tubes had no significant effect on the mean visual score of pink bacon, but observers' comments indicated that the hue required supplementary description. Bacon pinkness under Tungsten was more orange than under Artifical Daylight. Illuminants with poor colour rendering made bacon appear more brown.

Beef colour shifts were similar to bacon; De Luxe Natural made red more red, and White and Warm White made brown more brown. Unlike bacon, Tungsten filament and Colour 84 significantly increased redness.

For Artificial Daylight, mean L* for red beef was 40.8 and for brown was 39.3, and for both pink and brown bacon was 48.1. Changes in L* between illuminants were small compared to the large differences produced in metric chroma. These differences within sample pairs and the effect of the illuminant on their position is shown in the u* v* diagram (Figure 1). Lamps generative of shifts redwards gave larger values of C* and poorer colour rendering illuminants decreased C* for brown samples.

Locating the illuminants commonly at the origin of the u* v* diagram does not give accurate representation of the character of the hue because of the wide range in colour temperature. Even if it were possible to make adequate adjustment for chromatic adaptation it might not be justified because both areas were viewed simultaneously and the white backgrounds assumed different colours. Compared to the large initial shift in meat colour on glancing from reference to test area subsequent changes on prolonged viewing were of less consequence.

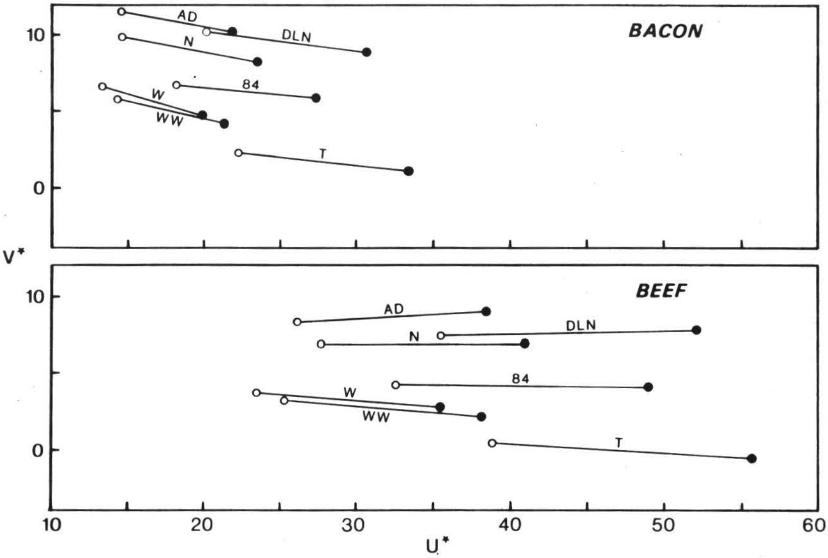

Figure 1. Portion of 1976 u* v* diagram of lean of beef and bacon illuminated by Tungsten filament bulb (T), Warm White (WW), White (W), De Luxe Natural (DLN), Natural (N), Colour 84 (84) and Artifical Daylight (AD) fluorescent tubes; ○ brown, ● red or pink.

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Po8

Andrew Neil Chalmers, Department of Electronic Engineering, University of Natal, Durban, **and Christoffel Johannes Kok**, National Physical Research Laboratory, C.S.I.R., Pretoria (South Africa):

Accuracy and Repeatability in Colorimetry

This paper reconsiders some earlier findings in this area and goes on to discuss some findings from an extensive series of measurements of a set of material colour samples carried out on several colorimeters differing in their principles and methods of operation. These instruments differ markedly in their accuracy and repeatability, and it is demonstrated that repeatability is influenced also by sample chroma and lightness.

Après une considération des résultats précédants on présente des mesures nouvelles que l'on a gagnées par séries extensives avec des couleurs d'objet et avec des colorimètres de construction différente. Ces instruments dévient considérablement en exactitude et en précision de répétition l'un de l'autre, et on a trouvé que la précision de répétition dépend aussi de la saturation et de la clarté des échantillons.

Nach einem Überblick über einige bisherige Ergebnisse werden neue mitgeteilt, die aus einer Reihe von Messungen an Körperfarben mit Farbmeßgeräten verschiedener Konstruktion gewonnen worden sind. Diese Instrumente weichen beachtlich in Meß- und Wiederholgenauigkeit untereinander ab, und es hat sich gezeigt, daß die Wiederholgenauigkeit auch von der Sättigung und Helligkeit der Proben abhängt.

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A.N.Chalmers and Chr.J.Kok

Introduction:

In an earlier assessment of a photoelectric colorimeter that was being used in a colour reproduction study (Chalmers 1979) it was found that there was a clear relationship between the lightness of each sample and the repeatability of its measured chromaticity. The way that this relationship was expressed was in terms of the net standard deviation of the measured chromaticity s(u,v,w) as a function of the normalized sample lightness Y,

where $s(u,v,w) = \{s^2(u) + s^2(v) + s^2(w)\}^{\frac{1}{2}}$

and $s(u)$ = standard deviation of measured u-coordinate

$s(v)$ = standard deviation of measured v-coordinate

$s(w)$ = standard deviation of measured w-coordinate

as determined in the CIE 1960 (u,v,w) system. It was found that the form of the relationship in this instance was a reciprocal function :

$$Y. \, s(u,v,w) = \text{constant}.$$

This form of relationship seems quite plausible on the grounds that a lighter sample will reflect more light into the colorimeter and the measured result would therefore be less influenced by noise, dark current, stray light and other extraneous factors leading to deviations in the calculated results. There would thus appear to be some grounds for assuming that this form of relationship may be more generally applicable.

It was decided, therefore, to examine another body of data that had been accumulated in the calibration of a set of Munsell colour swatches for use as in-house colorimetric standards. A feature of this study is that it also permits some comparisons to be made of the performance of the three different types of colorimeter that have so far been used in the measurement of these samples, viz. a visual colorimeter, a spectrophotometer and a mask colorimeter, details of which have been given in a previous paper (Chalmers and Kok 1977). The calibration samples were 20 swatches that had been selected from a Munsell Color File to give a reasonably representative range of Hues, Values and Chromas, including two neutral greys.

Results:

Each sample was measured on nine separate occasions: four times on the visual colorimeter, twice on the spectrophotometer and three times on the mask colorimeter. Each colour determination comprised a single, complete set of readings of all twenty samples on one instrument, and was quite separate from any other determination on that instrument. In the case of the visual colorimeter, the results quoted here embody the work of two observers each of whom carried out two separate colour determinations of the twenty samples. In all cases, the measurements were performed using the 45°/0° geometry, under both illuminant A and illuminant C, but this paper is confined to an analysis solely of the illuminant C data.

Using CIELAB coordinates, the mean measurement of each sample on each instrument has been compared with the overall mean of the nine measurements of each sample, and also with the Munsell Renotation data (Wyszecki and Stiles 1967) transformed to (L* a* b*) form. The standard deviation s(L* a* b*) of the measurements obtained for each sample on each instrument has also been determined,

where $s(L^* a^* b^*) = \{s^2(L^*) + s^2(a^*) + s^2(b^*)\}^{\frac{1}{2}}$
and $s(L^*)$ = standard deviation of measured L*-coordinate
$s(a^*)$ = standard deviation of measured a*-coordinate
$s(b^*)$ = standard deviation of measured b*-coordinate.

There is no evidence of the previously described reciprocal relationship between standard deviation and Y. On the contrary, both the spectrophotometer and the mask colorimeter show some evidence of s(L* a* b*) and s(u,v,w) increasing with Y (and with L*) while the measurements on the visual colorimeter yield standard deviations that appear to be independent of sample lightness.

The r.m.s. standard deviation s of the three instruments together has also been computed, and the dependence of s on sample chroma C is illustrated in Fig. 1. In Fig. 2 E_{rms}, the r.m.s. deviation of the three instruments' readings from the Munsell Renotation for each sample, has been plotted against C. Linear regression analysis indicates that in both cases the deviations apparently increase with chroma. Each of the instruments taken independently yields similar results. Since the reflectance spectrum of the high-chroma samples tends to be steeper and narrower than for other colours, this finding would seem to be indicative of the presence of wavelength errors. A new analysis of the earlier data obtained on the photoelectric colorimeter shows no evidence of this type of behaviour.

It is apparent that no general conclusions can be drawn concerning the confidence with which samples of differeing lightnesses and chromas can be measured on different instruments. It seems likely that different error mechanisms will predominate in different instruments and that they may be influenced by the measurement technique. Other factors that cannot be excluded but which require further investigation, are: (a) possible non-linearities in the instruments: and (b) the possibility that the two different sets of samples used in the earlier and in the current experiments could have introduced some form of bias into the results.

Acknowledgements:

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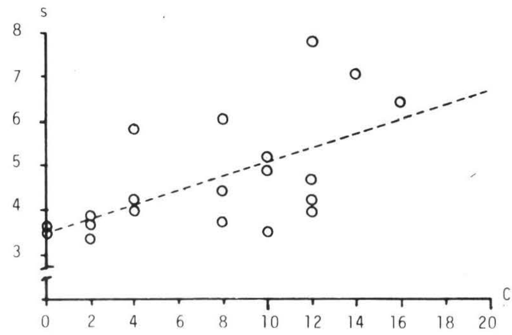

FIG 1: Standard deviation of measured colour in the CIELAB system : (9 measurements of 20 samples on 3 instruments)

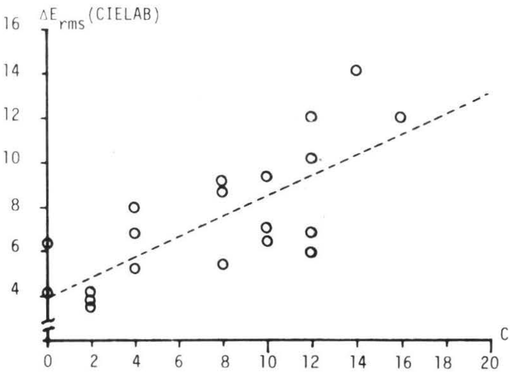

FIG 2: RMS deviation of measured colour from Munsell Renotation (Mean measurement of 20 samples on each of 3 instruments)

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Po9

Masatoshi Tsujimura, Kazuaki Yamada and Minoru Suzuki, Tokyo (Japan):

In Pursuit of the Optimum Colorimeter

Instruments have now been developed by improving the reliability of the optical types which utilize the symmetrical double beam optical system. The functions of spectral diffraction and chopped beams are accomplished with one apparatus, and by compensating the fluctuations of the light source and the photo detector, measured values which have a higher degree of reliability are obtained.

On a développé des instruments nouveaux dans lesquels la sûreté de l'optique est améliorée qui produit les faisceaux symétriques du rayon. Dans un unique appareil les fonctions de la séparation spectrale et de l'interruption sont exercées; les fluctuations de la source et du photo-récepteur sont compensées de sorte que les valeurs mesurées obtiennent un degré plus haut de sûreté.

Es sind neue Geräte entwickelt worden, in denen die Zuverlässigkeit der Optik verbessert ist, mit der das symmetrische Zweistrahl-System gebildet wird. Die Funktionen der spektralen Aussonderung und der Unterbrechung des Strahlenganges werden mit derselben Apparatur bewirkt; die Schwankungen der Lichtquelle und des Photodetektors werden kompensiert. Dadurch erhalten die gemessenen Werte einen höheren Grad von Zuverlässigkeit.

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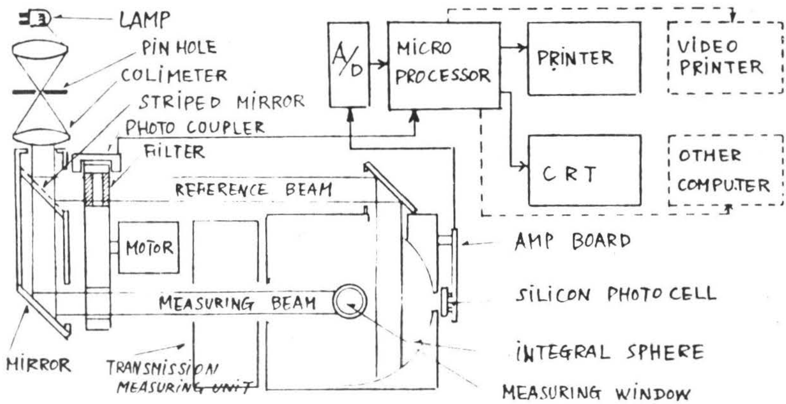
1. Explanation of the System:

The major components of this apparatus are indicated in Figure 1.



The symmetrical double beam optical system generally used, divides the light beam in two directions through the use of a rotating mirror but this apparatus uses a striped mirror which is in a fixed position to divide the light beam and subsequently undertakes spectral diffraction by rotating colored glass filters which have the required sight sensitivity compensation curve, and alternately transmits compensating light and measuring light to the interior of the integral sphere.

In other words, the fluctuations of the light source are discerned by measuring the reflective factor of compensating light that scans the inside surface of the integral sphere. On the other hand, the measuring light which has scanned the sample fluctuates in the same ratio as the reference light beam. When checking out with the standard white panel, the ratio between the two light beams is obtained, whereupon at the time of measurement, if the reflection factor of the reference light beam is measured, it shall be possible to compensate the fluctuations of the measuring light.
Again, in both of the light paths, it is of course necessary to have the number of mirrors, the quality and length of the light paths, etc. identical. By predetermining the position at which both

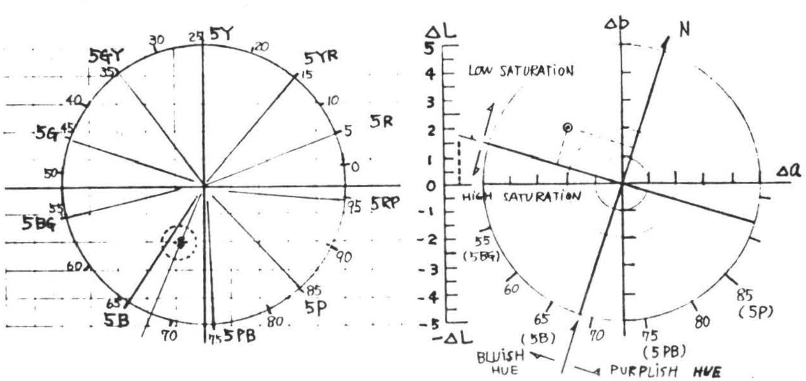
light paths are shut off by the filter wheel, and by correcting zerc every time immediately prior to measuring, the optical zero also automatically compensates the electrical zero.

The light which hits the silicon detector installed on the interior wall of the integral sphere is converted from amperage to voltage, and amplified. This analogue volume is converted to digital expression and transmitted to the microprocessor to produce the necessary data. The microprocessor program seeks out the Hunter L.a.b., CIE L,a,b, systems, etc. obtained from tristimulus values as well as other colorimetric systems. The selection of the program by using the digital switch on the operating panel can be established as desired, and through the use of the integrated printer or CRT, the necessary chromaticity diagrams, color difference control diagrams, measured values, etc. can be either printed out or displayed on the screen.

For peripheral equipment, the unit has been provided with CRT terminals and output for video printer, RS232C and BCD.

2. Color Difference Control Diagram:

Heretofore the analysis of color measurement was determined on the basis of diagrams plotted on paper for each sample. By using a CRT and having it display a diagram on the screen, indication as to which direction and to what degree the color deviates from the target color is delegated to the computer to calculate and convert into a plotted diagram. The chromaticity diagram or color difference control diagram of each colorimetric system is displayed on the screen. An example is given of a color difference control diagram.



The results of the measurements are indicated as L,a,b, ΔL, Δa, Δb.

First of all, the target color is plotted on the chromaticity diagram to determine where its position shall lie. Then the sample that has been measured is plotted on the basis of the measurements obtained, to determine how it differs from the target color by enlarging and redrafting the diagram. At this time, the hue names and hue equivalent and iso - saturation lines are also diagrammed, and these are actually successively plotted on the screen as the various measurements of the sample are made. The difference in brightness is also indicated on the screen. Whenever necessary, printouts can be made of the measurement values of color differentials ΔE,X,Y,Z, L,a,b, ΔL, Δa, Δb. If the permissible margin of difference in color is determined, it is the objective of this color matching work to guide the colors to within the predetermined permissible range of the target colors.

Synopsis:

By also adopting the symmetrical double beam optical system in a colorimeter, a reasonably priced unit with high stability, good reproductivity and ease of handling has been made possible. Necessary data for color matching can be secured instantaneously. As for differences between units, it is not difficult to obtain sufficiently identical performances by severely controlling the filters which are used for spectral diffraction and critically selecting the light sensitive cells.

Special mention must be made of our gratitude for the guidance and co-operation extended by Mr. Hirai of the Japan Color Research Institute in this development work.

Po10

Toshio Yamanaka and Yutaka Kurioka, Hyogo (Japan):

An Apparatus for Measuring Spectral Reflectance of Retroreflective Materials

An apparatus is designed to measure spectral reflectance of retroreflective materials used for traffic signs. The apparatus consists of a compact optical arrangement using a rotating optical bench. By continuous and minute rotation of the optical bench, observation angle can be precisely set from 0 to 5 degrees.

On décrit un appareil pour mesurer la réflexion spectrale de surface rétroréflectives que l'on applique pour les signaux de trafic. L'instrument se compose d'un arrangement optique sur un établi orientable. Par un mouvement continu et précis de l'établie on peut ajuster l'angle d'observation de 0^{o} à 5^{o}.

Es wird ein Gerät zur Messung der spektralen Reflexion von retroreflektierenden Flächen beschrieben, wie sie für Verkehrssignale verwendet werden. Es besteht aus einem optischen System, das auf einer drehbaren Bank montiert ist. Dadurch kann man den Beobachtungswinkel zwischen 0^{o} und 5^{o} genau einstellen.

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Colorimetry of retroreflective materials used for traffic signs is illustrated as a part of the CIE technical report prepared by the subcommittee "Retroreflection" of TC-2.3. Nighttime color of the materials should be measured under the same condition where a traffic sign is illuminated by headlight of a car and observed by the driver's eye. Its colorimetry has some difficulty, since the materials changes its color according to geometric conditions of illumination and observation.

Authors intend to measure the spectral reflectance of materials for the purposes as follows;

1) developement of an apparatus which measures the color of materials under the illuminating and observing conditions of nighttime.
2) calculation of a correction factor due to the deviation of spectral sensitivity of a photometer head from the spectral luminous efficiency curve when coefficient of luminous intensity of the material is measured.

By measuring spectral reflectance of the material and spectral sensitivity of the photometer, the correction factor is calculated under the illumination of the known spectral distribution of the source.

Utilizing a spectrophotometer, Rennilson (1980) measured colors of retroreflective materials at the same distance as their photometry. On the other hand, Czepluch (1973) devised photometry of retroreflective materials under nighttime geometric condition, by use of a compact optical apparatus, in whcih the observation angle was adjusted by both rotation and shift of a half mirror. Using the same method as Czepluch's, Yamanaka et al (1980) measured spectral characteristics of retroreflective matarials under nighttime geometric condition, making use of white, red, yellow, green and blue samples enclosed lens type. The observation angle α was one degree and the entrance angle β was -4, 20 and 50 degrees. Results were as follows: 1) Increasing the entrance angle β, the shape of spectral reflectance curves slightly changed in the direction in which chromatic purity became higher. 2) But a white sample comparatively changed spectral reflectance curve according to the variation of entrance angle (β = -4 - 50 degrees).

This method was convenient and did not require a large testing room. Its another merit is good precision because of sufficient amount of light falling on the entrance slit of a monochromator. Further, we have constructed an apparatus which enables to adjust the observation angle α only by continuous and minute rotation of a optical bench. This apparatus can accurately measure the spectral reflectance of retroreflective materials in comparison with the standard white $BaSO_4$.

APPARATUS

The optical arrangement of this apparatus is shown in Figure 1. The apparatus consists of a monochromator M, a fixed optical bench OBf, a rotating optical bench OBr and sample rotator SR. A tungsten halogen lamp S and a condenser lens L1 are arranged on the optical bench OBr which rotates around the rotating axis of the sample rotator SR. A half mirror HM is set on the fixed optical bench OBf.

Light from the lamp S is collimated by the lens L1, passes through a half mirror HM, and illuminates the surface of the sample RM. Among the lights reflected from the sample surface, parallel component to the optical axis of the bench OBf is reflected on the surface of the half mirror HM, and is forcused by a lens L2 on the entrance slit of the monochromator M.

The angle between the optical axes of the optical benches OBf and OBr is designated as the observation angle α . Using a mechanism of a worm gear, the observation angle α is minutely adjusted between 0 and 5 degrees with precision of 1 minute of arc. The rotation bench OBr is devised to slide into the inside of the fixed bench OBf, as shown in Figure 2, so that the setting of α = 0 may be allowed.

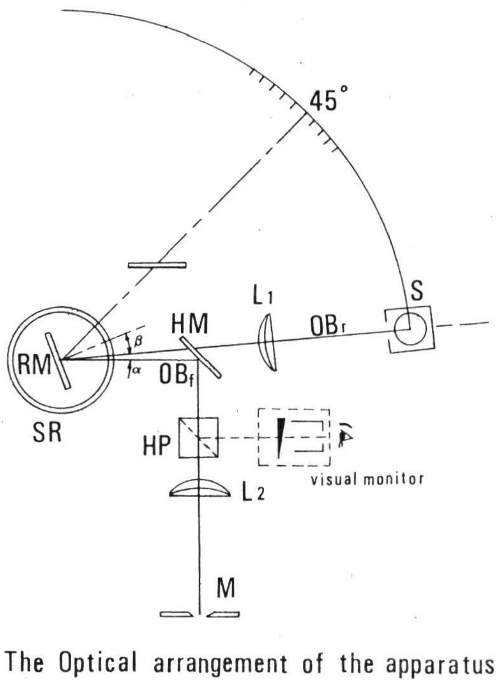

Figure 1 The Optical arrangement of the apparatus

A sample of the retroreflective materials is fixed on the sample holder. The center of the sample surface vertically held is set on the intersecting point of the rotation axis of the sample rotator SR and of the optical axis of the bench OBr. The entrance angle β corresponds to the angle between the optical axis of th bench OBr and the central normal of the sample surface.

A cube biprism HP is used as a visual monitor. In calibration of spectral reflectance, $BaSO_4$ set on the sample rotator is measured under the condition of α = 45, β = -45 (ordinary condition of 45/0).

Results will be illustrated in the short lecture.

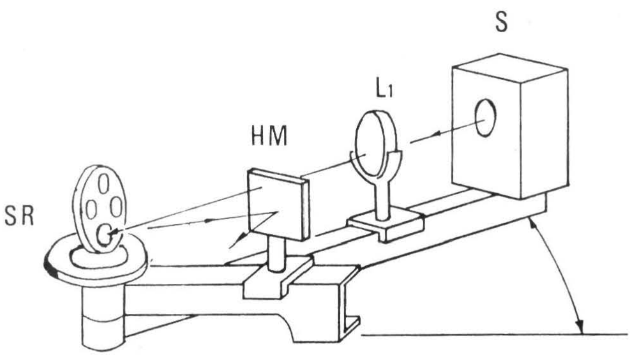

Figure 2 Sketch of the rotating optical bench fitting into the fixed bench of channel steel

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Gerhard Rösler, Fürstenfeldbruck:

ER 10 – ein schnelles mobiles Farbmeßgerät nach dem Spektralverfahren

A new color measuring system is described which opens new applications based on the short measuring time (1/100 sec) the high spectral resolution (1 nm) and the mobile measuring-head.

Un nouveau système pour mesurer la couleur qui ouvre des nouvelles applications en vertu du court temps de mesure (1/100 sec), de la grande résolution spectrale (1 nm) et de la tête de mesure mobile, est ici décrit.

Ein neues Farbmeßgerät wird beschrieben, das aufgrund der kurzen Meßzeit (1/100 s) der hohen spektralen Auflösung (1 nm) und des mobilen Meßkopfes neue Anwendungsbereiche für die Farbmessung erschließt.

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Das Farbmeßgerät ER 10 stellt eine völlige Neuentwicklung dar. Neben den klassischen Anwendungen erschließt es neue, bisher nicht erreichbare Einsatzgebiete. Eine Übersicht über markante Eigenschaften des Farbmeßgerätes ER 10 soll dies verdeutlichen.

Meßzeit
Die Zeit, während der sich die Probe an der Meßöffnung befinden muß, beträgt nur 1/100 Sekunde. Während dieser kurzen Zeit wird die gesamte spektrale Remission der Probe erfast. Damit ist es möglich, auch kleine bewegte Proben zu messen bzw. im mobilen Einsatz einwandfreie Ergebnisse zu erzielen. Nach wenigen Sekunden (falls erforderlich schon nach 1/10 sec) kann die nächste Probe gemessen werden.

Meßverfahren
Nur eine Farbmessung nach dem Spektralverfahren liefert Meßdaten, die z.B. für eine Rezepturberechnung erforderlich sind. Daher wird im Farbmeßgerät ER 10 die spektrale Remission einer Probe im Bereich von 380 nm bis 730nm mit einer spektralen Auflösung von 1 nm gemessen. Wesentlich ist diese hohe Auflösung für eine genaue Wellenlängenzuordnung, die bei jeder Kalibrierung des Gerätes mit einem Weißstandard automatisch überprüft wird (Dauer der Kalibriermessung: 1/100 sec).
Zur Steigerung der Meßgenauigkeit wird mit einem Zweistrahlverfahren gemessen, wodurch im wesentlichen Änderungen der Gesamtintensität und der spektralen Strahlungsverteilung der Lichtquelle erkannt und kompensiert werden. Die Probenbeleuchtung entspricht angenähert der Normlichtart D 65 mit Norm geometrien von 45°/0° oder d/8°.

Auswertung
Der Farbmeßkopf mit der Beleuchtungseinrichtung (l = 400 mm, b = 105 mm, h = 160 mm, Gewicht ca. 4 kp) ist mit dem Auswerterechner über ein Kabel verbunden und kann mobil oder stationär eingesetzt werden.
Der Auswerterechner steuert den Meßablauf, korrigiert und speichert die Meßwerte und berechnet Farbkennzahlen.

Der Rechner ist in einen 19", 3 HE Einschub eingebaut und wiegt etwa 8 kp. In der Grundausführung des Farbmeßsystems ER 10 werden die Meßdaten vom hier aus zu einem Prozeßsteuerrechner übertragen. Für andere Anwendungen kann der Auswerterechner mit Peripheriegeräten ergänzt werden, z.B.

Laboreinsatz:	Tastatur, Grafikbildschirm, Massenspeicher, Drucker
Mobiler Einsatz:	Tastatur, alphanummerische LCD Anzeige, nichtflüchtiger Speicher

Einsatzbereiche

In vielen Anwendungsfällen ist es nicht möglich, große Farbproben (z.B. an Kraftfahrzeugen) zerstörungsfrei mit Laborfarbmeßgeräten zu messen. Nur ein mobiles Farbmeßgerät, dessen Meßkopf zum Objekt gebracht werden kann, ermöglicht diese Messungen. Das ER 10 bietet aufgrund seiner kleinen Bauform auch im mobilen Einsatz keine Handhabungsprobleme. Bei Erreichen der optimalen Meßposition wird automatisch eine Messung ausgelöst (Dauer 1/100 sec), der Meßkopf kann sofort entfernt werden.
Für stationäre Anwendungen, die eine berührungslose Farbmessung z.B. an bewegten Objekten (Druck, Textil) erfordern, kann das ER 10 mit 45°/0° Geometrie ebenfalls eingesetzt werden.
Die Datenübertragung vom Meßkopf zum Auswerterechner erfolgt digital, sodaß beliebige Leitungslängen möglich sind.
Die Konstruktion des Meßkopfes ohne bewegte Teile ergibt ein robustes und stabiles Meßgerät mit hoher Meßgenauigkeit, das sowohl im Labor als auch mobil einsetzbar ist.

Po12

Stephen Brown and Arthur W.S. Tarrant, Guildford (Surrey):

A Sensitive Spectroradiometer Using a Boxcar Detector

A spectroradiometer has been developed for measuring the spectral power distribution and chromaticity of small areas of cathode ray tube face. The increased signal to noise ratio obtained by using a boxcar detector enables measurement to be made at low tube face luminances. The instrument may also be used to examine the decay properties of tube phosphors.

On a développé un spectro-radiomètre pour mesurer la distribution spectrale du rayonnement et de la chromaticité de tubes à surface très petite. La proportion améliorée du signal au bruissement rend possible le mesurage même de luminances très basses des tubes. L'instrument est aussi propre à l'examen de l'affaiblissement des phosphores.

Es wurde ein Spektroradiometer zur Messung der spektralen Strahlungsverteilung und der Farbart von kleinen Flächen an Kathodenstrahlröhrchen entwickelt. Das vergrößerte Signal/Rausch-Verhältnis ermöglicht Messungen selbst bei kleinen Röhren-Leuchtdichten. Das Gerät eignet sich auch zur Prüfung des Nachlassens der Leuchtstoffe der Röhre.

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1. Introduction

The instrument described herein has been designed in order to measure the spectral power distribution (SPD) throughout the visible spectrum of small areas of cathode ray tube (CRT) face. The use of a boxcar detector enables measurements to be made at relatively low tube face luminances (below 10 cd/m^2).

2. Basic method of operation

The instrument is of the single-beam spectroradiometer arrangement, requiring measurements to be made successively on the unknown spectrum and a known standard SPD. During measurement, the monochromator wavelength setting is scanned using a stepper motor, and signal levels are recorded at 5nm. wavelength intervals.

Operation of the instrument is controlled by a desk-top computer (Hewlett-Packard 9815A) which operates the wavelength drive and calculates the chromaticity of the specimen. Results are passed by the computer to a printer or plotter.

3. Description of apparatus

An F/4 double monochromator having additive dispersion is used. Each half of the monochromator is of the Czerny-Turner layout and is equipped with a ruled grating (1200 grooves/mm.) blazed for 500nm.

An EMI 9816B photomultiplier is used as the detector. This has an S-20 photocathode with a workable wavelength range of 370-800nm., and has a 14-stage linear focused dynode chain. The tube is housed in an uncooled RF-shielded housing. In practice, the tube is operated with a high voltage supply of between 1.4 and 1.8 kilovolts.

The signal from the photomultiplier tube is fed to the input of a boxcar detector (Brookdeal 9415/9425). This may be regarded as a gated amplifier with a gain of 10. The output from the boxcar is a D.C. voltage proportional to the value of the portion of the waveform being sampled, averaged over many cycles. This greatly reduces the effect of noise. The output voltage of the boxcar detector is converted to digital form and passed to the system controller.

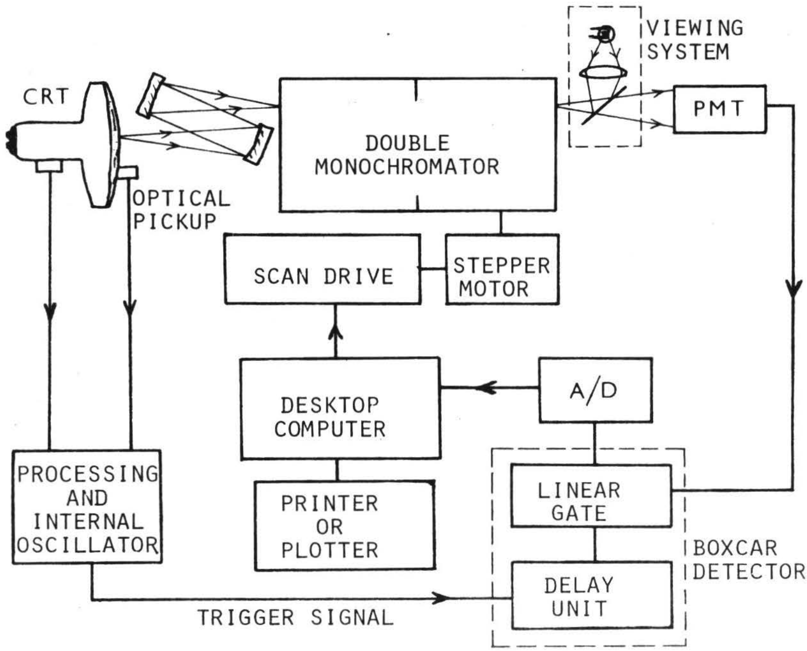
To ensure correct opening of the gate, a trigger signal must be provided for the boxcar detector. This signal may either be derived electronically from the generator circuits of the CRT under measurement, or from an optical pickup attached to a convenient part of the CRT screen. Static sources may be measured by providing a trigger signal from an independent oscillator.

Optical arrangements: A small area, commonly 0.5 mm^2, of the tube face is imaged on the monochromator entrance slit using an arrangement of two concave mirrors. The size and shape, usually square, of the entrance slit determines the area of source viewed and also affects the monochromator bandpass.

A retractable optical arrangement between the monochromator exit slit and the photomultiplier tube allows the user to shine light backwards through the system, illuminating the area viewed by the instrument during normal operation. In an alternative arrangement, the gate output pulse from the boxcar detector may be used to modulate the brightness of the CRT display, causing the area under consideration to appear brighter than the rest of the tube face.

4. Time sampling technique

Considerable flexibility of measurement may be achieved with the boxcar detector by altering the gate width and by controlling the position of the gate with respect to the signal waveform. If the CRT under examination has a phosphor with a relatively long decay time, the gate position may be progressively changed at each scan enabling measurement of the unknown spectrum at various points along the decay curve. Alternatively, the average SPD and chromaticity of a whole pulse may be measured by using a larger gate width.



5. Performance tests

The wavelength accuracy of the monochromator has been checked using spectral line sources of known wavelength, and was found to be better than 0.5nm. throughout the visible range. In addition, line profile shapes were measured in order to test the adjustment of the monochromator optics. Checks were also made to ensure that no significant sources of stray light exist within the monochromator.

The scanning time of the instrument is largely determined by the time constant of the output voltage smoothing circuit. Measurements have been made with tube face luminances down to 3 cd/m^2 using a time constant of 300mS. This results in a total scan time of about two minutes.

Standardisation of the system is achieved by performing regular measurements on a tungsten lamp operated at a colour temperature of 2854K.

The colorimetric accuracy of the system has been assessed by employing standard ceramic tiles illuminated with the standard lamp. At the time of writing, a colorimetric accuracy of 0.0025 chromaticity units (CIE 1931 system) is usually achieved for a blue-green standard, measured at a luminance of 10 cd/m^2.

6. Applications

The instrument has been designed primarily to measure the spectral power distribution of CRT phosphors, but may be used on any source of small area whose intensity varies in a periodic manner.

The development of this instrument has been sponsored by the United Kingdom Ministry of Defence, and is intended for use in a programme of work on the colorimetry of cathode ray tubes.

It is hoped to publish this paper in full in "Optica Acta."

Frank Rochow, Berlin

Über die Messung der ähnlichsten Farbtemperatur

An instrument for tristimulus colorimetry for determining the correlated color temperature T_c will be described.

On décrit un colorimètre tristimulus pour déterminer la température des couleurs T_n la plus ressemblante.

Ein Gerät zur Bestimmung der ähnlichsten Farbtemperatur T_n, welches auf der Basis einer Farbmessung nach dem Dreibereichsverfahren arbeitet, wird beschrieben.

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"Die ähnlichste Farbtemperatur T_n eines zu kennzeichnenden Strahlers ist diejenige Temperatur des Schwarzen (Planckschen) Strahlers, bei der dessen Farbart der des zu kennzeichnenden Strahlers am nächsten kommt".

Nur für Temperaturstrahler gibt es Zusammenhänge zwischen der Farbtemperatur und anderen Temperaturbegriffen wie Verhältnistemperatur, spektraler Strahlungstemperatur oder Gesamtstrahlungstemperatur. Die ähnlichste Farbtemperatur kann daher nur über eine Farbmessung ermittelt werden. Bisher verwendete Geräte arbeiten daher in Anlehnung an das Dreibereichsverfahren mit drei verschieden gefilterten Empfängern, deren relative spektrale Empfindlichkeit jedoch meist keine Ähnlichkeiten mit den Normspektralwertfunktionen aufweisen und daher meist nur für Glühlampenlicht ausreichend genaue Meßergebnisse zeigen. Zur Messung der ähnlichsten Farbtemperatur von Entladungslampen sind diese Geräte weniger geeignet.

An ein allgemein verwendbares Gerät zur Messung von T_n sind die folgenden Forderungen zu stellen:

- Direkte Anzeige von T_n
- Ausreichende Meßgenauigkeit bei allen in der Praxis interessierenden Strahlern
- Ausreichende Empfindlichkeit (Mindestbeleuchtungsstärke auf dem Meßkopf nicht größer als 100 lx)
- Unabhängig von der Netzspannung (Batteriebetrieb)
- G ringes Gewicht, einfache Handhabung
- Preiswert

Ein auf dieser Basis entwickeltes T_n-Meßgerät verwendet drei Si-Photoelemente, deren relative spektrale Empfindlichkeit gut an $\bar{x}(\lambda)$, $\bar{y}(\lambda)$ und die Summenfunktion $(\bar{x}(\lambda) + \bar{y}(\lambda) + \bar{z}(\lambda))$ angepaßt ist.

Die Photoströme der Photoelemente werden durch rückgekoppelte Operationsverstärker (Kurzschlußbetrieb) verstärkt. Mit Hilfe eines Mikroprozessors werden die Normfarbwertanteile berechnet. Daraus wird nach Näherungsformeln für den Zusammenhang von x, y und T_n die ähnlichste Farbtemperatur berechnet, die digital 4-stellig angezeigt wird. Der Meßbereich des Gerätes liegt bei 2500 K < T_n < 10.000 K. Die übrigen vorher genannten Forderungen werden erfüllt.

Gerhard Pausch, Haan:

Reflektometrische Erkennung und Unterscheidung von Objekten mit meßtechnisch ungünstiger Struktur

A measuring unit for the fast differentiation of even small areas on highly textured surfaces in production and quality control, is described. It uses the ratios of simultaneously measured monochromatic reflection signals for sorting decision.

Un système de mesure est décrit avec lequel il est également possible de différencier rapidement les petites surfaces fortement structurées dans le contrôle de production et de qualité. De plus, les rapports des signaux de réflexion mesurés simultanément sont utilisés pour la détermination de triage.

Es wird ein Meßsystem beschrieben, mit dem auch kleine Flächen stark strukturierter Objekte in Produktion und Qualitätskontrolle schnell unterschieden werden können. Dabei werden die Verhältnisse gleichzeitig gemessener monochromatischer Reflexionssignale für die Sortierentscheidung genutzt.

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Objekte mit messtechnisch günstiger Oberflächenstruktur können mit den Methoden der Lichtrückstrahlungsmessung sehr feinfühlig auf Unterschiede der Lichtrückstrahlung geprüft und unterschieden und gegebenenfalls automatisch sortiert werden. Auch die farbmetrische Bewertung solcher Abtastungen ist möglich. Objekte mit grob und stark strukturierter Oberfläche, wie Fasern in Watteform, in Flockenform, Gespinste, Vliese, Körnerschüttungen und Pulverschüttungen entziehen sich hingegen dieser reflektometrischen Unterscheidung, wenn die Grösse der Messfläche beschränkt ist. Die Grösse der Messfläche ist normalerweise bei Garnen in Strähnen, auf Spulen und auf Kettbäumen immer sehr beschränkt.

Die Messfläche muß insbesondere dann sehr klein gewählt werden, wenn Farbabweichungen kleiner Teilelemente des Objektes erkannt werden sollen. Damit entfällt die Möglichkeit, durch Mittelwertbildung die Ungleichmäßigkeiten der Struktur auszugleichen.

Der vorliegende reflektometrische Messkopf verringert durch seine besondere Beleuchtungs- und Beobachtungsgeometrie die störenden Einflüsse der Struktur. Die verwendete Lichtquelle, in der Regel eine Entladungslampe, beleuchtet die Objektoberfläche direkt und indirekt über einen Spiegel, steiler als 45 Grad. Beobachtet wird unter Ø Grad in relativ großer Distanz. Das unter Ø Grad zurückgestrahlte Licht wird gleichzeitig von mindestens 2 Fotoempfänger-Filter-Kombinationen empfangen.

Diese Fotoempfänger-Filter-Kombinationen werden den zu unterscheidenden Objekten angepaßt. Jeder Empfänger empfängt nur eine oder eine genau definierte Kombination von 2 oder 3 Linien. Dies ermöglicht ein monochromatisches Arbeiten bei relativ hohen Messenergien, ohne allzuhohe Strahlungsbelastung der Messobjekte.

Durch die Anordnung von Lichtteilern, die auch als Spiegelstreifenteiler ausgeführt sein können, ist die g l e i c h z e i t i g e Messung von 2 oder mehr monochromatischen oder quasi-monochromatischen Remissionen möglich.

Die Fotoempfänger geben ihr Signal auf einen oder mehrere Analog-Digital-Wandler, die gleichzeitig auch das Verhältnis von jeweils zwei verschiedenen Signalen zueinander digitalisieren.

Die Art der Objekte bringt es mit sich, daß die absolute Lichtrückstrahlung nur sehr ungenau, verglichen mit der repräsentativen Mittelung über eine ausreichend große Fläche, bestimmt werden kann. Für die Sortierentscheidung des Systems kann daher dieses Messergebnis der Rückstrahlung nur mit geringem Einflußgewicht herangezogen werden.

Viel günstiger ist die Ermittlung des oder der Verhältnisse einzelner monochromatischer Rückstreuungen durch das System. Diese Ergebnisse werden durch die ungünstige Struktur der Oberfläche der Messobjekte nur sehr wenig beeinträchtigt und können daher mit hohem Gewicht in die Sortierentscheidung eingehen.

Die gleichzeitige Messung aller monochromatischen Signale erlaubt eine hohe Taktgeschwindigkeit des Sortierbandes. Weiterhin macht die gleichzeitige Messung aller Signale die ermittelten Verhältnisse völlig unabhängig von den Schwankungen der Lichtleistung der Lichtquelle. Von diesen Schwankungen ist also nur die Messung der absoluten Rückstreuung bei irgendeiner Wellenlänge beeinflußt. Da nun aber von der Natur der Messobjekte her diese Messung ohnehin nicht genau und repräsentativ sein kann, muß die Auswahl nicht auf solche Lichtquellen eingeschränkt werden, deren Licht konstant ist. Bei der Auswahl der Lichtquelle kann also mehr auf die gute Eignung der verfügbaren Emmissionslinien Rücksicht genommen werden.

Für die richtige Auswahl der Linien, der Filter und der " In-Bezug-Setzungen " sind vorausgehende, spektralfotometrische Aufnahmen der zu sortierenden Objekte nötig.

Die Signale, die die Analog-Digital-Wandler abgeben, können über eine nachgeschaltete Logik direkt die Sortiermaschine steuern. In vielen Fällen ist es aber zweckmäßig, diese Signale einem Prozess-Rechner zuzuführen.

Der Prozessrechner kann das Sortierergebnis durch Anwendung von Plausibilitätsprüfungen verbessern. Er kann aber auch Trendstudien betreiben, Stückzählungen nach Sortiergruppen speichern und für die Betriebsverbesserungen nützliches Zahlenmaterial erarbeiten.

Po15

Tetsuo Yanase, 2nd Division, Japan Color Research Institute, **Gentaro Ohmi,** Department of Arts, Women's College of Fine Art, **Miho Saito,** Department of Psychology, Waseda University, Tokyo (Japan):

Color Preference in Japan

1400 Japanese, 44 Danes, 30 Papua New Guineans, 40 Australians, 50 Americans and 50 Germans were asked to choose their 3 preferred colors and 3 disliked colors from a color chart which was consisted of 65 colored papers. White, vivid blue, light blue, vivid yellow and vivid red were apt to be preferred in Japan. On the other hand, white, light blue and vivid yellow were not significantly chosen by other countries. Cross-cultural differences was more apparent than cross-sexual difference.

Dans cette recherche on a demandé 1400 Japonais, 44 Danois, 30 Papoux, 40 Australiens, 50 Américains et 50 Allemands à choisir leurs trois couleurs de préférence et trois couleurs de refus hors d'une collection de 65 papiers colorés. Blanc, bleu vif, bleu clair, jaune vif et rouge vif sont préférés en Japon. Mais dans les autres pays blanc, bleu, clair et jaune vif ne sont pas choisis significamment. Les différences entre les cultures étaient plus frappantes qu'entre les sexes.

1400 Japaner, 44 Dänen, 30 Papuas, 40 Australier, 50 Amerikaner und 50 Deutsche sollten ihre drei Vorzugsfarben und ihre drei am meisten abgelehnten Farben aus einer Sammlung von 65 Farbpapieren auswählen. Weiß, lebhaft Blau, Hellblau, lebhaft Gelb und lebhaft Rot wurden von den Japanern ausgewählt, während in anderen Ländern Weiß, Hellblau und lebhaft Gelb nicht so eindeutig bevorzugt werden. Die Unterschiede zwischen den Kulturen sind auffälliger als zwischen den Geschlechtern.

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Though many researches on color preference have been informed since about 1900, no paper has yet maken its function or rule clear. Some investigations were studied cross-culturaly however each research showed the different results: While Eysenck,H.J. reported in 1941 that there was no differences between races, Choungourian, A. declared in 1968 that definite cultural and some sex difference were found in his study. One of the reasons why an unified opinion has not yet gained is because, each research has an different way of approach to the same purpose, so that every informed paper is hardly compared with previous experiences.

This paper represents an investigation based on following points.

(1) What is a general tendency of Japanese color preference.
(2) How do the attributes, e.g. sex, age, living area etc. affect their preference.
(3) How does the Japanese tendency of color preference differ from the foreign one, when the investigations were carried out by the same method and materials.

Method

Subjects:
Japan: 1400 male and female, aged from 18 to 49
Denmark: 44 male and female, aged from 16 to 65
Papua New Guinea: 30 male and female, aged from 13 to 50
Australia: 40 male and female, aged from 18 to 46
West Germany: 50 male and female, aged from 20 to 39
U.S.A.: 50 male and female, aged from 20 to 39

Materials:
The color preference stimulus was a color chart which was consisted of 65 color cards, 20×35mm in size on N7.5 Gray background. (Table 1)

Procedure:
The Ss were interviewed by using questionaire.(Table 2) They were requested to choose 3 colors which they like and 3 colors which they dislike in order of their preferences.

Results

(1) Japanese Color Preference

Table 3. shows the correlation between three prefered-colors chosen in order by Japanese Ss. All the coefficients are over 0.90. This indicates that the analysis can be carried out by using the data of sum of three answers.

(2) Color Preference in Foreign Countries

Coefficient of correlation beween choice ratio of prefered-colors and disliked-colors is -0.28. Although the numerical value rates negatively, prefered-colors and disliked-colors do not show a significant negative correlation. That is, highly prefered-color is not equal directly to highly disliked-color.

Table 1. Color Chart

HUE / TONE	Red	Orange	Yellow	Yellow Green	Green	Blue Green	Blue	Violet	Purple	Red Purple
pale	01	02	03	04	05	06	07		08	
lightgrayish	09	10	11	12	13	14	15		16	
dull	17	18	19	20	21	22	23		24	
light	25	26	27	28	29	30	31	32	33	34
vivid	35	36	37	38	39	40	41	42	43	44
deep	45	46	47	48	49	50	51	52	53	54
dark	55	56	57	58	59	60	61		62	
neutral		White(63)		Gray(64)		Black(65)				

Table 2. Questionaire

I would like to ask your favorite and least favorite colors in general. Here is a selection of various color samples.

A) Please tell me the one color you like **best**.
Color No._____

B) Which color do you like **second best**?
Color No._____

C) Which color do you like **third best**?
Color No._____

A*) Now please tell me which color you like **least**.
Color No._____

B*) Which color do you like **second least**?
Color No._____

C*) Which color do you like **third least**?
Color NO._____

Table 3. Correlation between three prefered-colors.

	Best	Second best	Third best	Sum of them
Best	1.00	.92	.92	.97
Second best		1.00	.91	.96
Third best			1.00	.97
Sum of them				1.00

Table 5. Difference between sex, age and nationality.

1) Nationality

	U.S.A.	Germany	Australia	Denmark	P.N.G.	Japan
U.S.A.	0.00	4.12	3.06	3.19	3.47	4.80
Germany		0.00	4.46	4.48	3.77	6.12
Australia			0.00	2.93	3.70	4.56
Denmark				0.00	3.69	6.30
Papua New Guinea					0.00	4.02
Japan						0.00

2) Sex

	Male	Female
Male	0.00	2.05
Female		0.00

3) Age

	10-19	20-29	30-39	Over 40
10-19	0.00	3.22	2.90	3.03
20-29		0.00	2.39	3.20
30-39			0.00	1.54
Over 40				0.00

Table 4. Color preference in foreign countries.

	Japan	Denmark	Papua New Guinea	Australia	U.S.A.	Germany
Highly prefered-colors	1 White 2 vivid Blue 3 light Blue 4 vivid Yellow	1 vivid Blue 3 vivid Red 4 deep Blue 5 deep Orange	1 vivid Blue 2 vivid Yellow 4 pale sky 5 light Blue Green	1 vivid Blue 2 vivid Yellow 3 vivid Red 4 light Yellow Green 5 deep Blue	1 vivid Blue 2 vivid Red 3 Brown 4 deep Blue	1 vivid Blue 2 vivid Yellow 3 vivid Orange 4 deep Green 5 vivid Red
Highly disliked-colors	1 dark Red 2 dark Purple 3 dark Yellow 4 deep Red Purple 5 light Red Purple	1 pale Pink 2 paleYellow Green 3 Beige 4 Pale Lilac 5 graish Pink	1 deep Purple 2 deep Red Purple 3 dark Purple 4 vivid Red Purple 5 vivid Violet	1 vivid Purple 2 Olive 3 vivid Violet 4 graish Pink 5 dark Purple	1 purplish Pink 2 dark Purple 3 light Yellow Green 4 light Purple 5 Black	1 purplish Pink 3 pale Pink 4 deep Yellow 5 dark Gray pinkish Beige
Lowly prefered and lowly disliked colors	dull Yellow Green light grayish Green pale Blue Green	light grayish Green dull Green dull Blue Green dull Purple	pinkish Beige dull Red dull Yellow Green dull Blue Green light Green	pale Pink pale Green dull Yellow Green dull Green dull Blue Green dull Purple	pale Yellow Green dull Red dull Yellow Green dark bluish Green	dull Red dull Yellow Green light Violet deep Violet Brown
Highly prefered and highly disliked colors	5 vivid Red dark Orange pale Red Black dark grayish Orange	2 vivid Orange vivid Yellow Green vivid Purple	3 vivid Red purplish Pink vivid Orange Black	vivid Orange vivid Green vivid Red Purple	light Yellow Green vivid Yellow Green vivid Purple	2 Black Gray

According to Table 4, vivid blue is the only color which is prefered by all countries. Japanese preference to white is quite apparent and this characteristic is distinctive to the nation.

On the whole, following issues can be suggested.

A) Prefered-colors are somewhat determined by Tone rather than by Munsell Hue.
B) Vivid Tone is generally prefered by all countries. In Japan, Papua New Guinea and Australia, light Tone ranks highly as prefered-colors, while in Denmark, U.S.A. and West Germany, light and pale Tones tend to be ranked as disliked-colors. These countries rather prefer the colors in deep Tone.
C) Blue is the Hue which is prefered in any Tones.

(3) Difference between Sex, Age and Nationality

Many relative researches point out the differences between sex and age in color preference. However the relationship between cross-cultural difference and sex-age(cross-sectional) difference was tried to described in this paper. The analysis was performed by means of Hayashi Quantification-III on Response Pattern.

The results in Japan reveal that sex effects more than the factors of Ss' occupation, living area,education and other circumstances. In addition, the difference in age relates greater than the one in sex.

In Table 5, the distance-scores between three categories(sex, age and nationality) are indicated. The values show that significant difference can be found among the nations rather than in sex and age.

Discussion

The results display that each country has its own identical pattern of preference. Moreover this type is inclined to be influenced by Tone. To sum up, cross-cultural difference is more apperent than cross-sectional difference. The reason why such distinction between cultures occurs more evident still demands further analysis.

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Ohmi G. Yanase T. Tsubaki F. Color Preference of Japanese 2 Studies of Color Vol25 No.2 1978

Paul Green-Armytage, Bentley (Australia):

Colour for Ordinary People

Colour has a strong influence on our lives but ordinary people have limited concepts for dealing with it. This paper suggests that people would benefit from a greater understanding of colour and considers some of the issues which would have to be faced in the design of a "Colour System for Ordinary People": the problem of names, definitions of primary and complementary colours and the structure, if relevant, of a colour diagram.

La couleur a de grande influence sur notre vie, mais l'homme moyen a à sa disposition seulement un nombre limité de notions. C'est pourquoi on propose ici un système de notions pour la description des couleurs dans la vie quotidienne.

Farbe hat einen starken Einfluß auf unser Leben, aber dem Durchschnittsbürger stehen nur wenige Ausdrücke dafür zur Verfügung. Deshalb wird in diesem Beitrag ein Bezeichnungssystem für Farbbezeichnungen im Alltag vorgeschlagen.

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COLOUR IN EVERYDAY LIFE - SOME PROBLEMS

Colour vision provides information about our environment. We use it in many ways for communication. It has a profound effect on our emotions. Our capacity to understand and enjoy the world must be increased if we have a greater understanding of colour.

Ordinary people are limited in their vocabulary and their understanding of colour relationships. Their viewpoints are susceptible to distortion by the terminologies of the marketplace.

Ordinary people	The marketplace	ISCC-NBS Universal Color Language (UCL)	Munsell notation
Red	Mardi Gras	strong red	3.75R 5/14
Red	Madder Carmine	deep red	5R 3/10
Red	Coral Kiss	vivid red - vivid reddish orange	6.25R 5/14

Fig.1: Inadequacies of everyday colour vocabulary

The closest most people ever come to a colour system is the rainbow or, possibly, a simple colour circle. There is nothing between this and the systems designed for professionals which involve difficult concepts.

The basic colour vocabulary - red, orange, yellow, green, blue, purple, pink, brown, black, white and grey - does not begin to cover the range of perceivable colours and the sizes of the colour groups covered by the different names varies enormously; 3.5% of perceivable colours are "yellow", 25% are "blue".

Understanding of basic concepts is greatly hindered by confusions arising out of the application of colour names to colour sensations. Newton's naming of the spectral colours was essentially arbitrary.

Ordinary people would benefit from a model of the world of colour more comprehensive than the rainbow. Such a model would have reference points (primary colours) and would show relationships (complementary colours) but would have to reconcile the various definitions. It would also clarify the relationship between colour sensations and colour names.

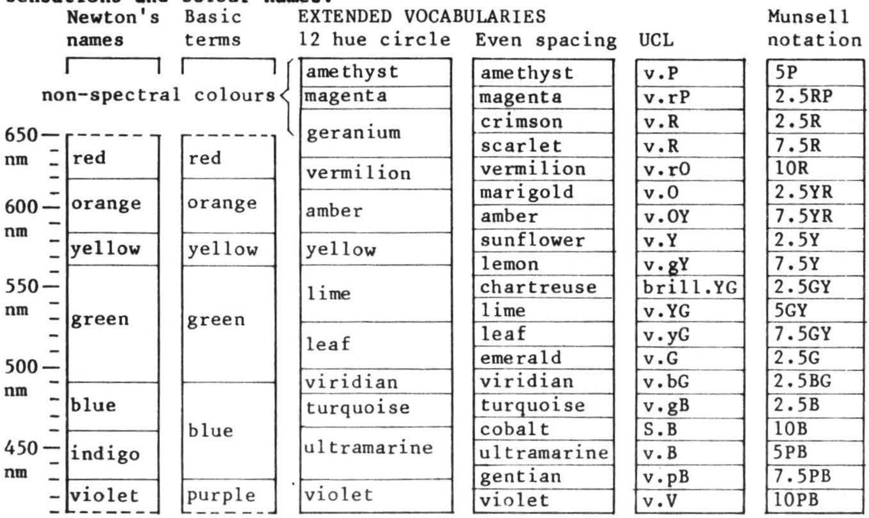

Fig.2. Relationship between colour names and colour sensations - spectral colours and colours needed to complete hue circle.

COLOUR NAMES

Colour names can be said to govern territories of varying sizes within the colour solid. To draw a geographic parallel: Plochere's "Merry Green", a single colour sample, could be described as a 'town', a single point on the map. "Emerald Green", more widely used and applied to a range of samples, is a 'state'. Simple "Green" is a 'continent'. Colour name boundaries will be drawn in different places by different people under different circumstances.

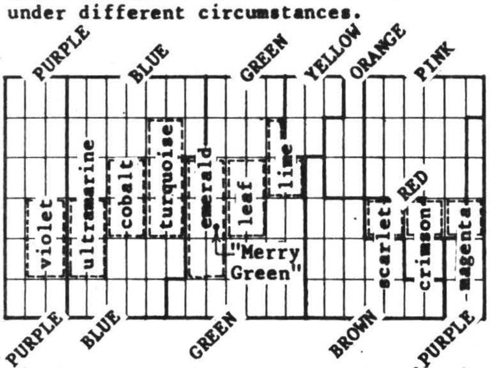

Fig.3: A colour map - territories governed by colour names. Colour array sub-divided by a 3 year old according to basic colour terms - the 'continents'. Dotted areas show ranges of colours governed by other names - the 'states'. One-off names like "Merry Green" refer to single colours - the 'towns'.

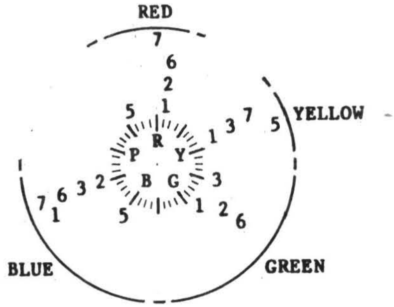

Fig.4: Sets of primary colours (see numbers below) related to Munsell hue circle showing how different hues are covered by the same basic terms.

PRIMARY COLOURS

Different definitions mean different sets of colours, but these differences can be lost because the colour names cover a range of colour sensations. Different colours are given the same name and so are assumed to be the same. Some definitions: Primary colours -

1. are the elementary colour experiences first postulated by Hering - RED, YELLOW, GREEN, BLUE. (These same colours can be thought of as related to the basic elements: fire, earth, water, air, or as those colours which are perceptually salient).
2. have their origin in fundamental colour experiences RED blood, GREEN grass, BLUE sky.
3. are those wavelengths to which the three types of retinal receptor respond most strongly: 570nm "RED" (YELLOW), 535nm GREEN, 445nm BLUE.
4. are those which produce a positive or negative response in only one of the two coding systems which transmit chromatic signals along the optic nerve: RED - GREEN, BLUE - YELLOW.
5. are those used in printing to produce other colours: RED, YELLOW, BLUE (magenta, yellow, cyan).
6. are those used in television to produce other colours: RED, GREEN, BLUE (scarlet, green, ultramarine).
7. according to artists, cannot be mixed themselves but can be used to mix all other colours. In practice artists do not limit themselves to three colours but use the primaries as reference points. These particular colours therefore, fall between definitions 1 and 5 above.

COMPLEMENTARY COLOURS

Depending on how complementary colours are defined an individual colour will have more than one complementary. This set of complementary colours may or may not be covered by the same colour name. Some definitions: Two colours are complementary when -

1. they can be mixed additively to neutral grey.
2. they can be mixed subtractively to neutral grey.
3. they generate each other in afterimages.
4. they generate each other in shadows.
5. one reflects most light at wavelengths where the other absorbs most.

P.Cadmium pale — P.Ultramarine pale | BLUE
P.Cadmium pale — P.Mauve
P.Cadmium pale — P.Violet lake | VIOLET

W.Sky blue — P.Saturn red | ORANGE
W.Sky blue — P.Cadmium orange
W.Sky blue — P.Cadmium middle | YELLOW

1.+++connects colours which can be mixed additively to neutral grey
2.---connects colours which can be mixed subtractively to neutral grey
3.....connects colours which generate each other in afterimages

Fig.5: Different complementary colours for yellow and blue established according to different definitions using Pelikan (P.) and Winsor & Newton (W.) designers' gouache.

A COLOUR SYSTEM FOR ORDINARY PEOPLE

Different needs have produced different systems, but all since Newton have been built round some form of colour "circle" (not necessarily circular) in which the hue sequence is essentially the same and which has some kind of central point through which a line can be drawn to connect complementary colours.

A colour circle can be constructed from fixed points (primary colours) or from established pairs (complementary colours). Colour circles are bound to be subtly different and will represent a single viewpoint or a compromise.

A system for ordinary people would need to be impartial and lead to clarification rather than confusion. It has yet to be designed. It is likely to be a series rather than a single diagram and will probably connect with the Universal Color Language and the Munsell system.

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J.B. Den Tandt, Edegem (Belg):

Die unbewußte Kindersprache

No abstract! — Pas de résumé! — Keine Zusammenfassung!

Günter Schreiber, Köln:

Die Farbe zur Sichtbarmachung mathematischer Strukturen

Memory as well as intelligence of most people work in the visual way. Therefore it is obvious to make mathematical structures clear by means of color. Besides new ways to art may be opened.

La mémoire et l'intelligence de la plupart des hommes sont effectives par la vision. C'est pourquoi il semble rationnel de faire comprendre les structures mathématiques à l'aide des couleurs. Par cela, des voies modernes aux arts peuvent être ouvertes.

Die Erinnerung wie auch das Auffassungsvermögen eines Großteils der Menschen ist visueller Art. Daher liegt es nahe, die mathematischen Strukturen mit der Erscheinung Farbe verständlicher zu machen. Dabei können sich auch neue Wege zur Kunst öffnen.

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G.Schreiber

Strukturen von Restklassen

Als erstes Beispiel von Strukturen wähle ich das einfache Beispiel einer primen Restklasse. Teile ich eine beliebige ganze rationale Zahl durch m, so läßt sie einen der Reste

$$0,\ 1,\ 2,\ \dots\ ,\ m-1\ .$$

Die beliebige Zahl ist einen dieser Reste mod m kongruent. Die Gesamtheit aller der Zahlen, die denselben Rest mod m lassen, bezeichne ich als eine Restklasse. Eine dieser Restklassen besteht so aus allen Zahlen $m \cdot h + 3$, wenn $m > 3$ und h alle ganzen Zahlen durchläuft. Ein vollständiges Restsystem mod 11 ist z.B.

$$11,\ 1,\ 2,\ 25,\ -7,\ 16,\ 39,\ 18,\ -3,\ 9,\ 10\ .$$

Für das Rechnen mit den Restklassen gelten die Rechenbedingungen eines Ringes (1).
Greife ich aus dem vollständigen Restsystem mod m nur die Reste heraus,die mit dem Modul keine Teiler gemeinsam haben, so reduziert sich das Restsystem auf das prime Restsystem mod m. Restsysteme sind z.B. für
mod 7 die Klassen [1], [2], [3], [4], [5], [6]
mod 9 die Klassen [1], [2], [4], [5], [7], [8] .
Die Multiplikationstafeln für die primen Restklassen mod 7 und mod 9 sind

[1]	[2]	[3]	[4]	[5]	[6]
[2]	[4]	[6]	[1]	[3]	[5]
[3]	[6]	[2]	[5]	[1]	[4]
[4]	[1]	[5]	[2]	[6]	[3]
[5]	[3]	[1]	[6]	[4]	[2]
[6]	[5]	[4]	[3]	[2]	[1]

[1]	[2]	[4]	[5]	[7]	[8]
[2]	[4]	[8]	[1]	[5]	[7]
[4]	[8]	[7]	[2]	[1]	[5]
[5]	[1]	[2]	[7]	[8]	[4]
[7]	[5]	[1]	[8]	[4]	[2]
[8]	[7]	[5]	[4]	[2]	[1]

Hier sind nicht sofort Strukturen zu erkennen. Färbt man aber die Klassen ein, z.B.

	mod 7	mod 9		mod 7	mod 9
Weiß	[1]	[1]	Hellblau	[3]	[2]
Grau	[2]	[4]	Blau	[5]	[5]
Schwarz	[4]	[7]	Dunkelblau	[6]	[8]

so ergibt sich ein Bild, das erkennen läßt, daß die unbunten Klassen eine Untermenge bilden. Mit der Abbildung beider primen Restklassen auf die Farben habe ich eine isomorphe Abbildung beider Restklassen untereinander vorgenommen. Die Abbildung zeigt die Isomorphie beider Restklassen, d.h. in beiden Restklassensystemen ist die Mutliplikation die gleiche. Die Strukturen sind einander gleich. Auch habe ich eine weitere Abbildung vorgenommen, indem ich bestimmte Klassen unbunt und die anderen Klassen bunt bezeichnet habe. Dem Mathematiker ist die Untermenge der unbunten Klassen als die Menge der quadratischen Reste und die Untermenge der bunten Klassen als die Menge der quadratischen Nichtreste bekannt. Mit der Farbe ist eine homomorphe Abbildung einer Menge auf eine andere Menge vorgenommen worden. Ich könnte unbunt mit + 1 und bunt mit - 1 deuten. Der Kern dieser Homomorphie ist die unbunte Menge.

Strukturen von Gruppen

Eine Gruppe ist eine algebraische Struktur mit nur einer Verknüpfung. Jedem geordneten Paar A, B von Elementen aus G ist eineindeutig ein bestimmtes Element aus G zugeordnet. Man nennt G eine Gruppe, wenn drei bestimmte Verknüpfungen gelten (2). Beispiele von Gruppen sind

- Die primen Restklassen bezüglich der Multiplikation. Da die Multiplikation der Restklassen kommutativ ist, ist das Schema spiegelbildlich zur Diagonalen. Solche Gruppen nennt man abelsch.
- Die Wurzeln der Gleichung $x^p - 1 = 0$ (p = Primzahl). Aus einer primitiven Wurzel a mit $a^p = 1$ und $a^k \neq 1$ für $k < p$ können alle Elemente der Gruppe erzeugt werden. Die Gruppe ist ebenfalls abelsch.
- Alle Permutationen von n Elementen. Die Gruppe heißt die symmetrische Gruppe S_n. Die geraden Permutationen bilden eine Untergruppe, die alternierende Gruppe A_n.
- Die Drehungen und Spiegelungen regelmäßiger Vielflache (platonischer Körper, wie Tetraeder, Würfel, Dodekaeder usw.), die die Körper in sich überführen.

Jede Gruppe läßt sich isomorph auf eine Permutationsgruppe abbilden. Die Gesetze der Verknüpfungen der Elemente einer Gruppe können nach CAYLEY (3) in einer Gruppentafel dargestellt werden. Diese Tafel ist eine Matrix. Beispiele von Gruppentafeln sind

E	A	B
A	B	E
B	E	A

Zyklische Gruppe der Ordnung drei

E	A	B	C
A	B	C	E
B	C	E	A
C	E	A	B

Zyklische Gruppe der Ordnung vier

E	A	B	C
A	E	C	B
B	C	E	A
C	B	A	E

KLEINsche Vierergruppe

Es werden in farbigen CAYLEYschen Gruppentafeln die Gruppen S_3 und S_4 dargestellt und ihre Unterteilung in Untergruppen bzw. Nebenklassen farbig aufgezeigt. Dabei wird die Farbe auch zur Kennzeichnung der homomorphen Abbildung der Gruppe S_3 auf die Gruppe S_4 benutzt. Der Kern der Homomorphie wird wiederum unbunt dargestellt. Die Nebenklassen nach dem Normalteiler werden in einen Farbton dargestellt, so daß die Faktorgruppe deutlich erkennbar wird.
Eine andere Darstellung der Verknüpfung der Elemente einer Gruppe ist der CAYLEYsche Farbgraph (4). Hier werden die Verknüpfungen zwischen Punkten, die den Elementen entsprechen, dargestellt. Ein Bild zeigt den Graph für die Gruppe S_3.
Eine weitere Darstellung einer Gruppe in einer geometrischen Weise kann auf Flächen vorgenommen werden (5). Dabei können die Flächen die Kugel, die Ebene oder die hyperbolische Ebene sein. Die Abbildungen auf der hyperbolischen Ebene sind besonders reizvoll. Hierfür werden zwei Beispiele gezeigt,

von denen SPEISER (6) sagt, daß sie neue Bahnen für die Kunst aufzeigen können.

EULERsche Quadrate

Quadratische Schemata, wie z.B. CAYLEYsche Gruppentafeln, enthalten in jeder Zeile und Spalte jeweils ein Element der Gruppe nur einmal. Solche Quadrate bezeichnet EULER als lateinische oder griechische Quadrate. Werden zwei solche Quadrate kombiniert, derart, daß jede Kombination lateinischer und griechischer Buchstaben im Schema auftritt,so bezeichnet man dieses Quadrat als EULERsches Quadrat. Ein Beispiel ist

$$\begin{array}{cccc} a\,\alpha & b\,\beta & c\,\gamma & d\,\delta \\ c\,\delta & d\,\gamma & a\,\beta & b\,\alpha \\ b\,\gamma & a\,\delta & d\,\alpha & c\,\beta \\ d\,\beta & c\,\alpha & b\,\delta & a\,\gamma \end{array}$$

Derartige Quadrate können in ihrer Struktur besser erkannt werden, wenn man die Symbole als Farben darstellt. Bei dem hier gezeigten Beispiel der Kombinationen können Spielkarten verwendet werden. da jede Spielkarte zwei Eigenschaften aufweist. Bei einer größeren Anzahl von Elementen können solche Gegenstände nicht mehr verwendet werden. Hier eignet sich wieder die Farbe zur Sichtbarmachung der Struktur, der als zweite Eigenschaft eine geometrische Form gegeben wird. Ein Bild zeigt ein EULERsches Quadrat mit 5x5 Quadraten, das eine hohe Symmetrie aufweist.

Lateinische Quadrate als figurative Permutationen

Lateinische Quadrate lassen figurative Deutungen der Permutationen zu. Während jede Zeile und Spalte des Quadrates eine Permutation darstellt, kann auch die Anordnung eines Elementes oder einer Farbe im Quadrat als Permutation gedeutet werden. Dabei können die verschiedenen Figuren nach ihren Symmetrien klassifiziert und abgezählt werden (7). Hierzu zählen auch einige Bilder von LOHSE (8).

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Jack David Moreland, School of Optometry, University of Waterloo, Waterloo, Ontario, Bradford (England):

Validation of a New Colour Perception Lantern

The new Canadian lantern test has lights which simulate the Red – Yellow – White – Green navigational signal system of ships. The forced choise colour naming of selected groups of normals and of colour defectives are used to establish appropriate Pass/Fail criteria.

Le nouveau test à fanal du Canada montre des lumières qui imitent les signaux rouges, jaunes, blancs et verts de navigation pour le trafic maritime. Par la demande d'appellation des couleurs de groupes à vision colorée normale et défectueuse on a établi des critères appropriés pour la sélection.

Der neue kanadische Laternentest zeigt Lichter, die die roten, gelben, weißen und grünen Signale des Schiffahrts-Signalsystems nachahmen. Durch die Anforderung an Gruppen farbennormalsichtiger und farbenfehlsichtiger Personen, die Farben zu benennen, hat man die geeigneten Auswahl-Kriterien gefunden.

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The Marine Branch of the Canadian Department of Transport has adopted a new colour vision lantern test, replacing the Board of Trade oil lantern (1). The prototype was made by substituting the existing filters of a Champlain lantern (Model C11) with a new set so that its 11 lights simulated ships' navigation lights (2). Presentation of the lights could be single or paired. The new chromaticities are shown in Fig.1 together with the international colour limits for ships' navigation lights (3). Some pairs were chosen to lie on or very near a common dichromatic confusion line and, using the filter numbers in Fig.2, 2 ≡ 3 and 10 ≡ 11 for protanopes, 3 ≡ 4 for deuteranopes and 7 ≡ 8 for both. Illuminances of some pairs were equal or nearly so for protanopes and some others were for normals (see Table I).

Six selected groups were tested on the new lantern: 27 Naive Normals (no special experience with navigation lights), 24 Mariner Normals, 35 Deuteranomals, 20 Protanomals, 7 Deuteranopes and 7 Protanopes. Each subject was dark-adapted and viewed the lantern at 6 m in an otherwise dark room. Lights were presented in numerical sequence in 4 runs: single, paired, single, paired. All lights were attenuated by a factor of about 2.6 and the 4 runs were repeated. Thus each light was presented 12 times. The starting point was shifted progressively from run to run to reduce learning. Responses were restricted to 'Red', 'Yellow', 'White', 'Green' and 'Not Seen'. 'Don't Know' responses were not allowed.

The percentage distributions of responses are collected in Table I. Like signals are grouped together and correct responses are shown boxed for convenience. Normals responded almost perfectly to Reds and very well to Greens. Most of the few errors with Green were 'White', as expected. However, there were large differences in response to the two Yellows (errors for No.8 were mostly 'White' but those for No.5 were mostly 'Red') which were equally marked in both the 'light' and 'dark' runs and were due probably to different pairings and positions in the sequence rather than to different illuminances. Mariners had a higher correct response rate for Whites than did Naive Normals which may well have been due to their experience with navigation Whites.

The overall performance of colour defectives was poorer than normals: many response rates were close to chance (25%; discounting the few 'Not Seen' responses). Their response to the isomeric signals Nos. 9 and 10 being particularly interesting. Some rates were much lower than chance: e.g. the 7% correct protanomalous response to No. 6. Such findings suggest that further analysis, possibly with single and paired responses,

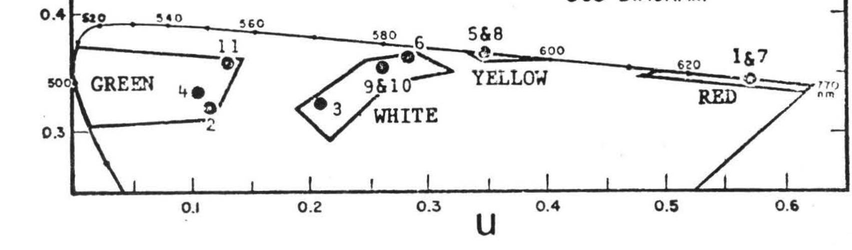

Fig.1. Chromaticities of lantern lights 1 to 11 and the colour limits for ships' navigation lights.

might provide a basis for differential diagnosis but that is outside the scope of this paper.

In deciding on a choice of Pass/Fail criteria, some thought was given to the use of (A) separate scores for each of the 11 lights and (B) a total error score. Both were rejected: (A) was too unwieldy for lay examiners and (B) lost the differentiation between important and less important errors. A compromise was made between the two by pooling responses to like signals: Reds, Yellows, Whites and Greens. Two scoring methods were tried with these signal groups using (C) raw errors and (D) weighted errors. In (C) each incorrect response to a light, whether shown singly or paired with another, was counted as 1. In (D) some account was taken of the idea that some lights, which were confused most frequently with each other, had the smallest differences in colour. Thus the confusions White ≡ Yellow and White ≡ Green counted as 1, Yellow ≡ Red and Yellow ≡ Green counted as 2, Red ≡ White counted as 3 and Red ≡ Green counted as 4. These weights were approximately proportional to the chromatic separations of the lights in Fig.1. The 'Not Seen' response was set arbitrarily as 5.

Cumulative distributions of the pooled raw error scores are shown in Fig.2 for all groups except dichromats. Perusal of Fig.2 suggested error limits of 1 for Reds and 3 for Greens. The corresponding limits, suggested by the cumulative distributions of the pooled weighted errors, were 2 for Reds and 3 for Greens: effectively disallowing Red ≡ White and Green ≡ Red. Limits for Yellow and White were less clear cut. Note the few normals whose responses to Yellow and White were close to chance and the significant proportion of colour defectives whose responses were well below chance. It is worth noting also that, if White ≡ Yellow confusions are discounted then the 'correct' response rate for normals increases dramatically for White lights and we are left wondering to what extent the high frequency of these normal confusions was considered before the addition of Yellow to the marine navigation light system was authorised. Yellow and White responses were pooled and the combined score limit for them was set at 18 and 30 for raw and weighted errors respectively: these being chosen at two thirds of chance level.

TABLE I: PERCENTAGE DISTRIBUTION OF RESPONSES TO THE LANTERN LIGHTS.

SIGNAL				RESPONSE: NORMAL, NAIVE (27/324)					NORMAL, MARINER (24/288)				ANOMALOUS, DEUTAN (35/420)					ANOMALOUS, PROTAN (20/240)					DICHROMATIC, DEUTAN (7/84)					DICHROMATIC, PROTAN (7/84)				
F	I	Ip	C	R	Y	W	G	N	R	Y	W	G	R	Y	W	G	N	R	Y	W	G	N	R	Y	W	G	N	R	Y	W	G	N
1	0.80	0.14	R	100	+				99		1		87	6	3	3		81	4	1	7	7	61	26	6	7		77	1	9	11	1
7	0.80	0.14	R	100	+				99	+	1		82	7	5	6		83	3	2	8	4	36	34	13	17		79	5	8	7	1
5	2.28	1.38	Y	10	89	1			11	84	5		36	30	31	3		40	40	13	7		23	49	26	1	1	31	33	25	11	
8	0.80	0.48	Y	4	58	38	+		6	52	42		24	15	28	33		35	34	19	12	+	26	26	24	24		29	27	20	24	
6	0.54	0.39	W	4	16	75	4	1	1	10	86	3	23	7	21	49		42	10	7	40	1	29	11	12	48	1	52	10	15	23	
9	0.78	0.59	W	1	18	79	2			12	86	2	18	13	31	38		22	22	17	39		20	26	22	32		36	11	30	24	
10	0.78	0.59	W	3	26	70	1		2	18	79	1	20	13	37	30		30	24	20	26		21	24	24	31		30	17	29	25	
3	1.45	1.25	W	+	12	88	+		+	5	91	4	16	24	40	20		12	27	34	27		15	32	43	10		17	21	39	23	
11	1.70	1.67	G		1	4	95				4	96	8	6	22	63		9	14	28	50		17	15	26	42		21	21	37	20	
4	1.33	1.40	G			1	99				2	98	8	5	16	71	+	6	12	25	57		24	13	24	39		21	16	44	19	
2	1.19	1.24	G			2	98					100	6	4	17	74	+	5	10	29	56	+	17	8	29	46		4	23	50	24	

F - FILTER NUMBER; I, Ip - NORMAL AND PROTANOPIC ILLUMINANCE IN $\mu lm\ m^{-2}$; C - COLOUR DESIGNATION; R,Y,W,G AND N - 'RED', 'YELLOW', 'WHITE', 'GREEN' AND 'NOT SEEN' RESPONSES; NUMBERS IN PARENTHESIS - NUMBER OF SUBJECTS/TOTAL NUMBER OF RESPONSES PER SIGNAL; + - SINGLE RESPONSE < 0.4%

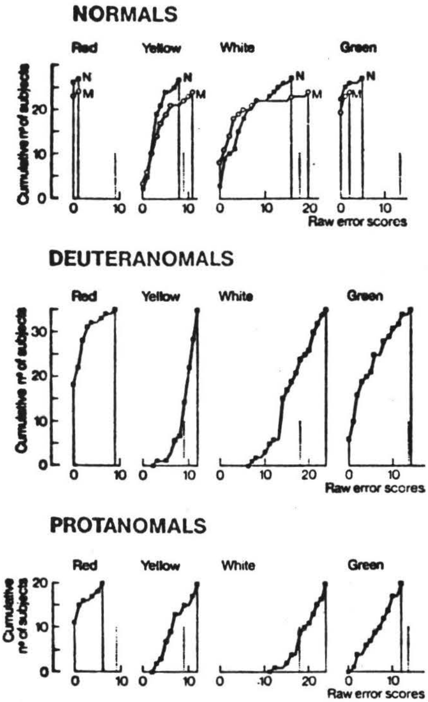

Fig.2. Cumulative distributions of errors for Red, Yellow, White and Green lights. Dotted lines mark the chance levels of response. N - Naive; M - Mariner.

By setting the standard as Pass in the 'light' sequence or as Fail in that sequence and Pass in the somewhat more difficult 'dark' sequence, the rejection rates for raw and weighted errors were 11.2% and 9.4% respectively (calculated in terms of a randomly selected population of males in which the frequency for deuteranomals, protanomals, deuteranopes and protanopes are taken as 5%, 1%, 1% and 1% respectively. The main advantage of the weighted error scale was transferred to raw errors by restricting them qualitatively and this also simplified the assessment procedure for lay examiners. Thus the 1 error allowed for Reds could be 'Yellow' only. Each of the 3 errors allowed for Greens could be 'White' only but if 1 error was 'Yellow' then the limit reduced to 2 of which only 'White' could be the other. No restrictions were applied to the combined errors of Yellow and White except that White called 'Red' would not be allowed in a borderline case. Since the attenuation of the lantern lights had only a negligible effect on the rejection rate, its use was not recommended. The second half of the test was to run simply as a repeat of the first but only when a subject failed the latter.

Models of the new lantern have been distributed to all the testing stations in Canada. The first returns have shown that all candidates who failed the first half of the test also failed on retest. The rejection rate was about 5% and, although that is not significantly different from the 9 or 10% expected, it is known that candidates, who present themselves for examination, are from a selected population in which some colour defectives are excluded by self-screening.

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Po20

R. Lakowski and J.F. Kozak, Vancouver (Canada):

The Use of Colorimetry in Projective Personality Tests

A colorimetric analysis of four psychodiagnostic tests revealed that the colours employed in such tests varied greatly in hue, saturation, and brightness. Colorimetry would appear to provide the means by which one might both standardize the colours used in such tests as well as examine the assumed psychological significance in choosing such colours.

L'analyse colorimétrique de quatre tests psychodiagnostiques a montré que les couleurs employées dans ces tests diffèrent considérablement en tonalité, saturation et luminosité. La colorimétrie rend possible de standardiser les couleurs dans ces tests de même que d'examiner la significance psychologique supposée par la choix de ces couleurs.

Eine farbmetrische Untersuchung von vier psychodiagnostischen Tests hat gezeigt, daß sich die Farben, die in solchen Tests verwendet werden, sehr stark in Farbton, Sättigung und Helligkeit voneinander unterscheiden. Die Farbmessung würde die Mittel in die Hand geben, einerseits die Farben dieser Tests zu normieren, andererseits den vermuteten psychologischen Wert dieser Farben zu untersuchen.

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Introduction

Theoretically, responses made toward colours based upon preferences or associations have been viewed as a form of derived measurement of an individual's personality and unconscious processes. Thus projective techniques such as the Rorschach Inkblot Test and the Luscher Colour Test have been designed to utilize colour as either part of an ambiguous stimulus that is presented to a subject, or, as in the case of the Luscher Colour Test, as the only stimulus dimension to which the subject responds. Such tests usually draw support from numerous studies done on the colour preferences toward colours for both normal and psychiatrically deviant populations and, therefore, primarily emphasize the reactions to the stimuli rather than attending to the actual dimensions of the stimuli themselves. If one assumes that colour may be a valid indicant of an individual's psychological state then the specification and/or measurement of such stimuli should be basic procedure in all psychological research involving responses to colour. For the most part such an approach has largely been neglected. It is the purpose of this study to extend the use of colorimetric measurement to psychological tests using colour, as previously investigated by Lakowski and Melhuish (1973) on various editions of the Luscher Colour Test. This paper reports on the colorimetric analysis of the Luscher Colour Test, the Rorschach Inkblot Test, The Colour Pyramid Test and The Object Relations Technique.

Material and Results

The Luscher Colour Test consists of 73 coloured patches on seven coloured panels. Colour responses are determined by having the subject make 43 different colour selections on the basis of their preferences for the colours. Luscher (1948) claims that both the psychological and concommitant physiological state of an individual can be deduced from the rank orderings of the coloured stimuli, and provides clinical interpretations of the various orderings for the clinician in the test book. The present study used an abridged English version of the test (Scott, 1969) that employs only eight coloured stimuli grouped, according to Luscher, into the two categories of primary (orange-red, blue, yellow and green) and secondary (gray, black, brown and violent) colours.

The Rorschach Inkblot Test consists of a series of cards containing symmetrical ambiguous stimuli, mostly varying shades of gray, that are presented to the individual. Based upon well established scoring techniques (Rorschach, 1942), the individual's psychological status is determined by such factors such as the area on the card focused upon, what the person stated the stimulus represented as well as the time it took the individual to respond. Five cards within the Rorschach utilize colours to produce the clinical response called 'colour shock', and the analysis reported in this paper dealt with the colours from these plates.

The Colour Pyramid Test (Pfister, 1950) assesses personality through the individual's colour preference for 15 out of 360 hue chips, from which a preference pyramid is constructed (most preferred of the 15 on the top). Three pyramids based on preferred colours and three based on the least preferred colours are constructed by the individual, from which one may assess a person on the dimensions of affect expression and impulse control.

The final test, the Object Relations Technique (Phillipson, 1955) is an extension of Murray's Thematic Apperception Test with the added feature of colours. The test consists of twelve cards with ambiguous scenes that the individual uses to construct a story of what he feels is occurring, has occurred and will occur. Themes based on the relationships he believes exist among the various objects in the cards are assessed, from which the psychological state of the individual is inferred. Three of the twelve cards utilize colour, with the assumption that colours produce a strong emotional challenge to the individual (colour shock).

Colorimetric analyses of the colours were obtained with a Zeiss Automatic Colorimeter RFC3, an abridged double beam spectrophotometer that permits one to compute the chromaticity co-ordinates of the sample for illuminants A, C, and D_{65}. Using a modified 2^o standard observer, chromaticity co-ordinates for the colours within the tests were derived for C.I.E. illuminant 'C'.

Results and Discussion

Figure 1 shows the loci for each of the four personality tests. It can be seen that both the Colour Pyramid Test and Luscher employ a variety of saturated colours, whereas the Object Relation Technique and the Rorschach use highly desaturated colours along the 'warm dimension', moreover the colours used within each test are not of equal saturation either. There are also large variations in the brightness of the stimuli, which range on the average from 14 to 60% with the luminance value for the Rorschach and Object Relations Technique having a mean Y% of about 40, whereas it varies from 1% to 78% for the other two tests.

Despite extensive research on the responses made toward such stimuli, little research exists on the psychophysical properties of the stimuli themselves. As pointed out by Lakowski and Melhuish (1973), the use of coloured stimuli must be standardized if one hopes to obtain meaningful interpretation of what the theorist assumes the colours represent.

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Judith Ruttenberg, Herzlia (Israel):

Color as an Essential Component in Bestowing the Human Dimension Upon Paths and Axes of Movement in Architectural Systems

An environment embodying "perceptual content" features a "human dimension", i.e. is capable of creating stimuli leading to a feeling of satisfaction and well-being. These create the positive link between man and his environment – a link essential to the existence of a healthy society. This paper examines the role of color as a crucial component in this context.

Une ambiance qui possède un ,,contenu de perception", représente une ,,dimension humaine", c.-à-d. elle peut créer des stimuli qui produisent la sensation de satisfaction et de bien-être. Et cela produit, de sa part, un lien important pour l'existence d'une société saine. Dans cette communication on examine le rôle de la couleur comme composante essentielle dans ce rapport.

Eine Umgebung, die einen ,,Wahrnehmungsinhalt" besitzt, stellt eine ,,menschliche Dimension" dar, d.h. sie kann Reize schaffen, die zum Gefühl von Befriedigung und Wohlbefinden führen. Dies wiederum schafft das positive Glied zwischen dem Menschen und seiner Umgebung, ein Glied, das für die Existenz einer gesunden Gesellschaft nötig ist. In dieser Arbeit wird die Rolle der Farbe als entscheidendes Moment in diesem Zusammenhang untersucht.

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The Human Dimension

The vast set of pleasurable stimuli upon human consciousness[1] fosters a link between man and his surroundings, thus encouraging man's interest in his environment. A gray or unpleasant environment causes indifference, confusion, or frustration, while comprehension and enjoyment of one's environment represent the power underlying a healthy, civilized society. This "perceptual content" lends the environment an added "human" dimension, extending beyond one's functional, physical needs[2] into the realm of aesthetic enjoyment, orientation, and physical conceptualization with all it implies. Color is an essential component in this dimension.

Axes of movement within urban structuring, act as physically functional spaces[3], but fail to deal with the acute inherent problem of the human dimension.

Axes of Movement Vis-a-Vis Perceptual Content

On city streets and in certain types of "modular" buildings incorporating repetition of identical elements, axes are the key element in environmental conceptualization. Areas in urban space are perceived in the order in which they are encountered; each such spatial element has its role within a dynamic, directional system.[4]

The vertical and horizontal axes embody intrinsic differences: the vertical carries more emotional content (e.g. "rise and fall", Heaven vs. Hell, rising implying victory), while the horizontal axis represents the practical world of human achievement and activity. Man's horizontal frame of reference reflects both the direction of human activity (the notion "forward") and the distance he has covered (the notion "behind").

Whether expressed in terms of specific destination or of general direction, man's path is of great emotional significance (expressed by such linguistic symbols as "at a crossroads", "to stand in one's way", or "the straight and narrow"), as well as embodying a certain sense of tension (the familiar vs. the unknown).

In light of the importance of the human dimension, special consideration must be given in the design stage to axes of movement. Today's enormously spacious, linearly redundant structures, create order at the expense of identity: spaces are not easily identified or identified with, and man loses his way.

Color and Perceptual Content; Axes Vis-a-Vis Human Needs

The environment supplies an aesthetic experience creating the intellectual enjoyment known as "comprehension". Color enhances this comprehension with regard to axes and their organization, from a number of conceptual standpoints:

A. Orientation—Human conceptualization regards a path as a direction to be followed in pursuit of a definite goal, characterized by linear continuity. The path also involves a continuum of experiences which join the tension created by the points of departure and destination.[5] Loss of orientation means more than losing one's way and losing time: it entails the human aspects of fear, frustration, horror, and indifference. All of these are important factors in planning for human needs.

For example: a unique scheme of shapes and colors along a corridor invites forward motion, while a central arrangement of shapes (as in the central circles, stars, or regular polygons characterizing Baroque ceilings) invites pause. Suggested means of enhancing orientation are: diagonally painted strips at key points along a corridor, emphasizing the main direction of movement; arrows at the ends of corridors (painted in warm colors to make the corridors seem shorter) indicating the main direction one must take; use of color on the vertical axes as in differentiating storeys.

The degree of continuity within a passageway is expressed by the number of divergences and intersections, as well as by the number of doorways. Doorways are of the utmost psychological importance: they give life to their surroundings, creating interaction with the environment and the desire to be attached. Color of doorways may be used both on a functional level (e.g. "labelling" different types of rooms with differently colored doors), or to mark explicit or implicit points of reference (e.g. emphasizing alcoves by using warm colors).

Color creates orientation when it is an integral part of the structure of a corridor and the character of the lighting. For example, a section of corridor located opposite an inside courtyard will throw strong natural light onto an opposite wall. The acute transition from natural to artificial light (and/or from a long corridor to a short one), may be emphasized using two "stationary" spots of color, creating a sort of picture projected onto the inside wall from the outside.

Also belonging to orientation are the associative images we relate to colors and color combinations: a given combination may evoke "childishness", "elegance", "dignity", "modernity", "solidity", etc.

B. Components of Interest—Ordered space (i.e. containing interesting sensory stimuli) creates the experience of comprehension and enables many possibilities of identification and interpretation. Such interpretation is impossible in space lacking a frame or central theme, due to the temporary nature of the impression it leaves.

Movement through space[5] involves a sort of "mental corridor" linking man-in-motion with his destination.[4] We can lend interest to these "frameworks of conceptualization" through any of the following means:

. Enrichment and Sophistication of Elements—e.g. breaking surfaces into smaller units using shape and color.

. Rhythm and Tempo of Stimuli—creating "controlled surprise" through the ratio between elements of order and elements of complexity (6)(7).

. Sensation of Dimensions and Proportions—utilizing the inherent tendencies of warm colors to shorten and cool colors to lengthen, in order to affect man's sensation of depth[8] and make paths (notably corridors) more comprehensible.

. Strengthening Interaction Between Path and Environment—Colorful emphasis on doorways; "absorption" of natural light from outside; alteration of the sensation of height using light vs. dark or warm vs. cool colors.

C. Color in Axes Vis-a-Vis the Human Dimension—Proper environmental design, from the standpoint of color, is of crucial importance to emotional balance; it can even be effective in medical treatment. A monotonous environment is thus potentially dangerous, by definition, to emotional health. The influence of environmental complexity upon development of creative ability, intelligence, and mental health, has been established by a number of groups of researchers.(9)(10)(11)

Summary

The architect, responsible for designing the built-up environment in which we live, must be aware of the immense importance of the "human dimension" in that environment. Dismissal of this factor is dangerous to human society.

Paths and axes of movement, in cities and public buildings, are spaces occupied by man, frequently and for long periods of time. Much of his contact with his environment takes place in paths and axes of movement; their effect on him determines to a great extent his attitudes and feelings with regard to them. The set of experiences and stimuli which cause a positive reaction and the tendency to create a link with the environment, are no longer a random concept. Today's research is developing in the direction of determining precise measurements and systematic definitions of these factors, of which one of the most important and essential is color.

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Michael Krystek and Wolfgang Erb, Braunschweig:

Visual Sensation by Flicker Phenomena

The dynamics of light induced processes for flicker phenomena is investigated on the basis of a model for the photochemical kinetics of the visual pigments and the flicker fusion frequency derived. It increases in agreement with daily experience when the intensity of the optical stimulus and the degree of modulation becomes greater. In the case of a 100% modulation the flicker fusion frequency is proportional to the velocity of the decomposition of the visual pigment by exposure, but independent of the image brightness.

La dynamique des processus induits par la lumière est examinée pour les papillotements sur la base d'un modèle de la cinétique photochimique des pigments visuels, et la fréquence de fusion des papillotements est déduite. Conformément à l'expérience, elle augmente quand l'intensité du stimulus optique et le degré de modulation deviennent plus grands. Dans le cas d'une modulation de 100% elle est proportionnelle à la vitesse de décomposition des pigments visuels par exposition mais indépendante de la brillance d'image.

Ausgehend von einem Modell für die photometrische Kinetik der Sehpigmente wird die Dynamik der lichtinduzierten Prozesse für Flimmererscheinungen untersucht und die Flimmerverschmelzungsfrequenz hergeleitet. Sie nimmt mit zunehmender optischer Reizstärke und größer werdendem Modulationsgrad im Einklang mit der Erfahrung zu. Bei 100-prozentiger Modulation ist sie proportional zur Zerfallsgeschwindigkeit der Sehpigmente unter Belichtung, jedoch unabhängig von der Bildhelligkeit.

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The dynamics of light-induced processes for flicker phenomena have been investigated on the basis of a model for the photochemical kinetics of the visual pigments. The following differential equation resulted for the relationship between the optical stimulus intensity J(t) and the visual sensation E(t):

$$\frac{d}{d\tau} E + (B + J) \cdot E = A \cdot J \tag{1}$$

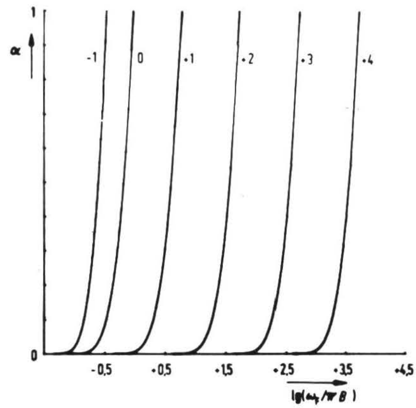
with the physiological constant A (proportional to the concentration of the visual pigment) and B (ratio of the kinetic constants for decomposition and formation of the visual pigment) and τ as the time scaled with the velocity of the formation of the visual pigment. By applying this differential equation to periodical light stimuli the phenomena can be described which can be observed in the case of flickering. Especially interesting is the question as to when the human eye is no longer capable of distinguishing a sequence of light so that the impression of a continuous stimulus is obtained. The frequency at which this occurs is called flicker fusion frequency ω_F.

During experimental investigations of flicker phenomena, sequences of rectangular stimuli with bright and dark phases of equal duration are employed almost exclusively. For the determination of ω_F the following implicit equation results:

$$\frac{1 + \alpha + (1 - \alpha^2)\ \bar{J}/B}{1 + \bar{J}/B} \cot h \left[\frac{1 + (1 - \alpha)\ \bar{J}/B}{2\ \omega_F} \pi B \right] + \frac{1 - \alpha + (1 - \alpha^2)\ \bar{J}/B}{1 + \bar{J}/B} \cot h \left[\frac{1 + (1 + \alpha)\ \bar{J}/B}{2\ \omega_F} \pi B \right] = 2 \tag{2}$$

$\bar{J}$ is the mean value with respect to time of the optical intensity of the stimulus and α the degree of modulation. It should be noted that ω_F has been indicated here in reciprocal units of τ.

The figure shows the graphic representation of the solution of this equation. It appears that the flicker fusion frequency is shifted to greater values when the intensity of the optical stimulus becomes greater. A similar dependence results for the degree of modulation. This behaviour agrees with daily experience.



Degree of modulation α as a function of the flicker fusion frequency ω_F for various mean optical intensities of the stimulus $\bar{J}$ (parameter: lg $(\bar{J}/B)$.

In the case of a 100% modulation ($\alpha=1$), ω_F is proportional to the velocity of the decomposition of the visual pigment by exposure, but independent of the image brightness. This result is important for the application of electronic colour pattern generators in colorimetry.

Takayoshi Kaneko, Tsukuba (Japan):

Presentation of the Benham Color on the Munsell Space and some Analysis of Determiners of the Color

The Benham color was produced by the drum fashion. The color was presented on the Munsell polar-coordinates. Although the presented color dispersed greatly, it was confirmed that the main determiner of the color was the position of stripes. Black and white bands, before and after the stripes, were also effective factors. Short stripes produced clear colors. Red and blue-green were poor colors by any means.

On a produit des couleurs Benham sur un cylindre rotatif et on a présenté les couleurs apparentes dans un système Munsell de coordonnées polaires. Quoique les couleurs représentées soient largement dispersées il est confirmé que les couleurs produites ainsi sont dues, avant tout, à la position des raies. Les bandes noires et blanches devant et derrière les raies sont aussi des facteurs effectifs. Des raies courtes produisent des couleurs claires, mais les couleurs rouge et vert bleu apparaissent toujours très faibles.

Benham-Farben wurden auf einer Farbwalze erzeugt; die Farben wurden in einem Polardiagramm des Munsellsystems dargestellt. Zwar streuten die so erzeugten Farben beträchtlich, aber es hat sich dennoch bestätigt, daß für die Farben vor allem die Lage der Längsstreifen bestimmend ist. Schwarze und weiße Querstreifen vor und hinter den Längsstreifen sind ebenfalls wesentliche Faktoren. Kurze Längsstreifen lieferten helle Farben, Rot und Blaugrün kamen dagegen nur schwach heraus.

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The so-called Benham disc is comprised of the sectors, half white and half black, with some stripes as it is well known. When the disc is spinned with suitable speed, color appears on the stripes and it is called subjective color. Why the color appears we don't know. There have been many studies (cf. Cohen & Gordon, 1949)* and some are very elaborated (e.g., Piéron, 1922)** but what factors of the pattern are determining the color and how, we don't know yet either. Most of the studies are rather qualitative and the observations are not presented in colorimetric terms.

The purpose of the present study is, first of all, to make the phenomena confirmed exactly on colorimetric space and, second, to see what part of the pattern is influential on the color and how. The following is a part of the results so far obtained.

Method: A rotating drum, 8cmø x 4cm in size, was used instead of a disc. The drum face was belted by a strip of paper of the Benham pattern or its variations. The drum was rotated at different steps of speed, i.e., 5, 7, 10, 15, 23 and 35/sec and observed 50cm apart. The illumination was about 3000 lux. The subjects, undergraduate and graduate students with normal color vision, matched the observed color with the color on the polar-coordinated Munsell charts of separate values. They are not specially trained in the matching task excepting some preliminary practices. Each subject did only one matching in one session for every different condition of patterns and speed-steps.

Results: 1. Colors produced by the authentic Benham patterns

Four patterns, I,II,III and IV, of the Benham type were used where the patterns differ in the position of stripes. Thirteen subjects served two sessions of the same experiment one after a week. The range of optimal speed of rotation was found 7-15/sec where more than two third of total responses reported some impression of color. Matched colors were plotted on the Munsell polar-coordinates disregarding values for all speed conditions pooled in Fig. 1, since no significant changes of color were found for different speed. Fig.1 also shows the corresponding Benham pattern of the unfolded belt respectively where the arrow indicates the direction of rotation.

Considerable dispersion of the plots as well as many no-color responses suggest so and so much elusiveness of the Benham color. However grossly, the color changes significantly with the relative position of stripes. Pattern I generates YR-Y-GY, while Pattern IV generates the complemantaries, P-PB-B. This agrees with the known facts as reviewed by Cohen & Gordon.

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* Cohen,J. & Gordon,D.A. The Prevost-Fechner-Benham subjective colors. Psychological Bulletin, 1949,46,97-136.

**Piéron, H. Le mechanisme d'apparition des couleurs subjectives de Fechner-Benham. L'annee psychologique, 1922,23, 1-49.

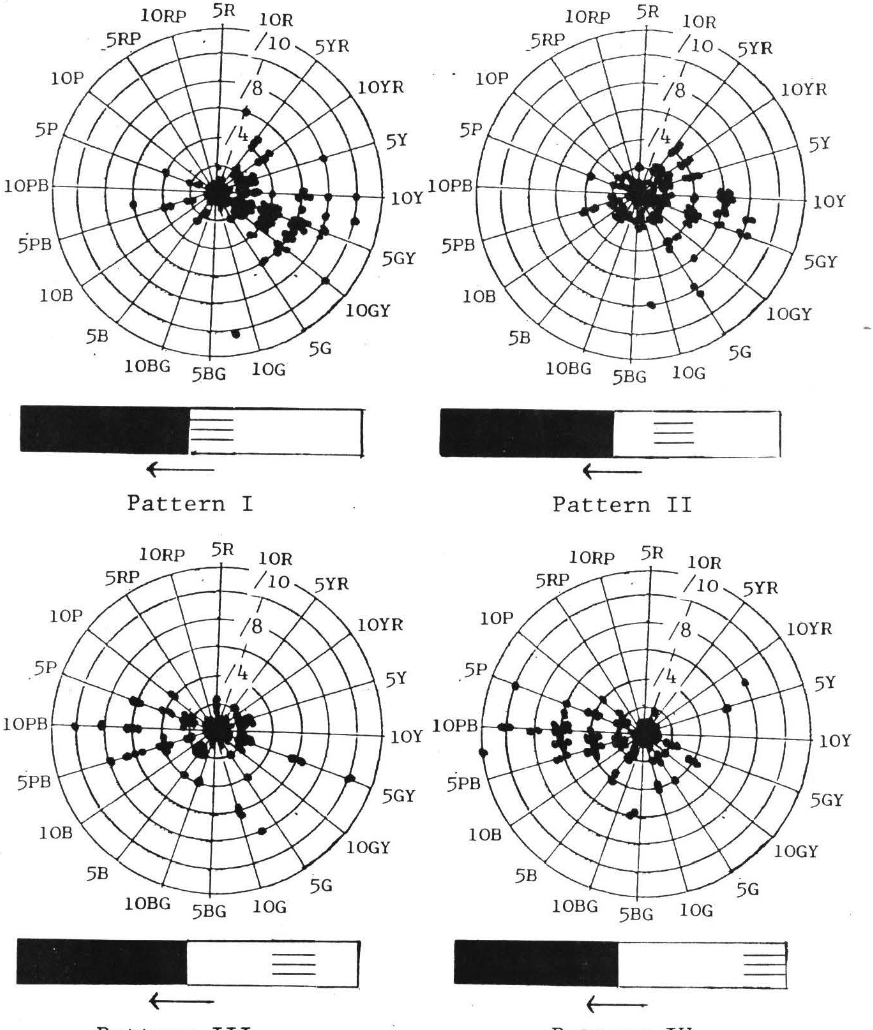

Fig. 1

2. <u>The effect of the black band before the stripes</u> (Fig. 2)

The stripes only, without the black band, is hardly conceivable to produce color. Here is a variation of Pattern I where the length of the black band differs. Eighteen subjects served one-session-experiment (this is the same for the results which follow). It was found the black band of more than half was favorable to produce fairly defined color. Small black band produced only dispersed, some complementary colors.

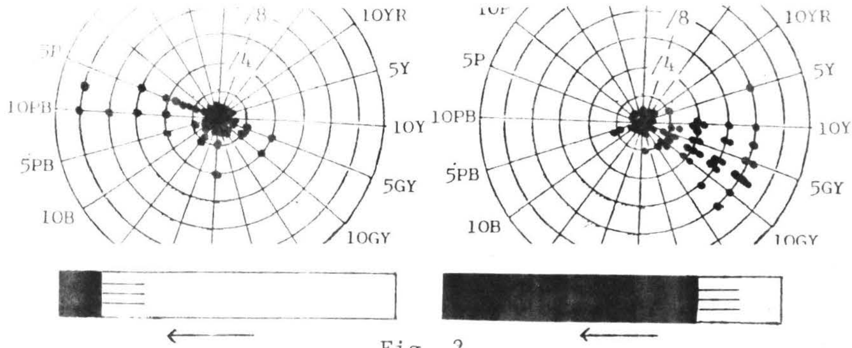

Fig. 2

3. The effect of the white band after the stripes (Fig.3)

Another variation of Pattern I was in the white band. Fig. 3 shows the white band after the stripes is effective in defining the color. A black band immediately after the stripes disturbed the color.

4. The effect of the length of stripes (Fig. 4)

As in Fig. 4, the color of Pattern I was more unique as the stripes were short. Short stripes were supposed to pick up more sharply the undergoing color processes at that phase on the white band.

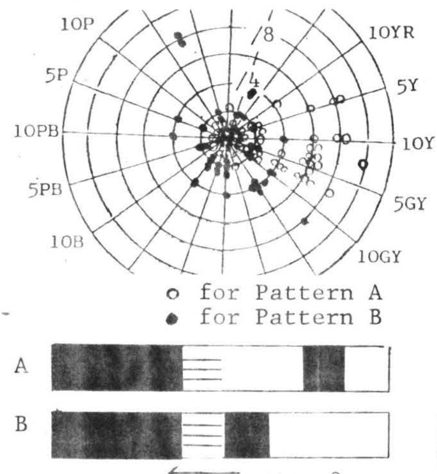

Fig. 3

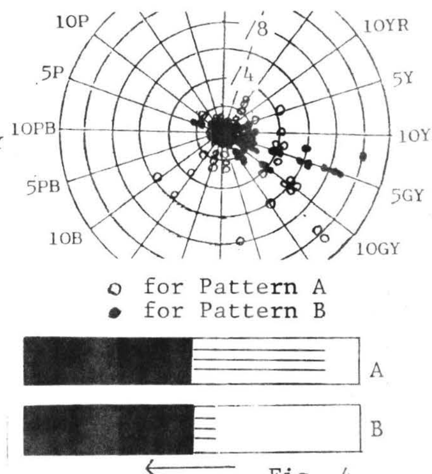

Fig. 4

All through these observations, it was interesting that red and blue-green were always poor colors.

(Presently this paper is not expected to appear in full text any where)

Josef M. Stäck, Stockholm (Schweden):

A Mathematical Model of Hue Perception

Four simple equations determine a wavelength-hue function for monochromatic stimuli that matches empiric values fairly well. Three signals are defined by the Gauss function and known peak values of cone sensitivities. A "leak" of signal between the three channels is presumed which is proportional to the relative numbers of different cones.

Quatre équations simples déterminent, pour les stimuli monochromatiques, une fonction longueur d'onde/tonalité chromatique assez proche des valeurs empiriques. Trois signaux sont définis par la fonction de Gauss et les maxima connus de la sensibilité des cônes. Une perte de signal entre les trois canaux est supposée être proportionnelle au nombre relatif des différents cônes.

Vier einfache Gleichungen bestimmen für monochromatische Farbreize eine Wellenlänge/Buntton-Funktion, die nicht sehr von den experimentellen Werten abweicht. Drei Signale sind von der Gauss-Funktion und den bekannten Maxima der Zapfenempfindlichkeiten bestimmt. Ein Signal-Übergang zwischen den drei Kanälen ist proportional zur relativen Anzahl der verschiedenen Zapfen angenommen.

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The following set of equations represents a hue vision system.

$$
\begin{cases}
Z_i(w) = e^{-\frac{(w-P_i)^2}{2\sigma^2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1) \\
S_i(w) = \dfrac{Z_i(w) + qT_iZ_s(w)}{1 + qT_i} \quad \ldots\ldots\ldots\ldots (2) \\
R(w) = S_l(w) - S_m(w) \quad \ldots\ldots\ldots\ldots\ldots\ldots (3) \\
Y(w) = \mathrm{Min}(S_l(w), S_m(w)) - S_s(w) \quad \ldots\ldots\ldots (4)
\end{cases}
$$

$i = s, m, l$

$P_s, P_m, P_l = 442, 546, 592$

$T_s, T_m, T_l = 1, 20, 40$

$\sigma = 30$

$q = 0.05$

(1) A monochromatic stimulus with the wavelength w generates signals Z_s, Z_m, Z_l from three cone systems whose sensibilities are normal distributed. Peaks at 442,546,592 nm (Thomsson-Whright) Standard deviation = 30 (Estimated to match empiric data)

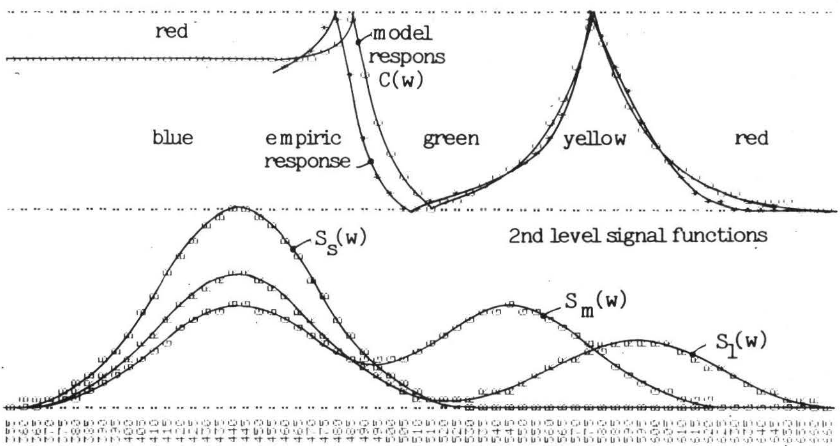
(2) The three Z signals are mixed with Z_s signal. This "leak" is proportional to an estimated constant q = 0.05 and to the relative numbers T_s, T_m, T_l = 1,20,40 (Walraven) of s,m,l cones. The resulting signals S_s, S_m, S_l are moderated by an adaption factor $1/(1 + qT_i)$ which makes the three S signals equal for equal energy stimulus.

(3,4) The three S signals are transformed into two signals R,Y (red-green and yellow-blue) The equations represent the opponent color theory.

In the diagram below the wavelength- hue function is represented by a compact graph

$$C(w) = \frac{|Y(w)|}{|Y(w)| + |R(w)|}$$

which shows the percentage of yellow or blue corresponding to different wavelengths. The rest is red or green. Empiric data (Celander-Tonnquist) are also plotted.



Comments

The model shows that a simple logic can "explain" the quantitative relation between wavelength and hue value.

The model has a "leak" of signal from the shortwave cone system into both the medium and the longwave system (and into itself too for symmetry). It has been tried to let leaking occur in all directions between all three systems. The equation (2) becomes then more complicated

$$S_i(w) = \frac{Z_i(w) + qT_i(Z_s(w)/T_s + Z_m(w)/T_m + Z_l(w)/T_l)}{1 + qT_i(1/T_s + 1/T_m + 1/T_l)}$$

The model works almost as well but not quite.

The standard deviation σ of eqation 1 may vary between 28 and 32 and the "leak" constant q of equation 2 between 0.25 and 1.0 without any really bad behavour of the model.

There is a mismatch in the blue region (around 480 nm). The match becomes much better if the sensibility peak wavelength of the shortwave cone system is assumed to be 430 instead of 442 nm.

An enlarged mathematical model is outlined which, if given a reflectance spektrum, responds with values for hue, blackness and chroma.

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Celander-Tonnquist: Plottning av NCS färgkoordinater i CIE-rymden. FOA 2 Rapport D 2114-E1. Stockholm June 1974.

Appendices

1. BASIC computer program and plot of model functions and interpolated empiric values (not included in this short version)

2. An Outline of a General Mathematical Model of Color Vision.

Appendix 2

AN OUTLINE OF A GENERAL MATHEMATICAL MODEL OF COLOR VISION

$$\begin{cases} G_i(w) = \dfrac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(w-P_i)^2}{2\sigma^2}} \quad \ldots\ldots\ldots\ldots (1) \\ Z_i(w) = \dfrac{G_i(w) + qT_iG_s(w)}{1+qT_i} \quad \ldots\ldots\ldots\ldots (2) \\ S_i = \int F(w)Z_i(w)dw \quad \ldots\ldots\ldots\ldots (3) \\ x = S_i - S_m \quad \ldots\ldots\ldots\ldots (4) \\ y = \mathrm{Min}(S_m, S_l) - S_s \quad \ldots\ldots\ldots\ldots (5) \\ z = \mathrm{Min}(S_s, S_m, S_l) - \int F(w)\mathrm{Min}(Z_s(w), Z_m(w), Z_l(w))dw \; . (6) \end{cases}$$

$i = s, m, l$

$P_s = 430$
$P_m = 546$
$P_l = 592$

$T_s = 1$
$T_m = 20$
$T_l = 40$

$$\text{blackness} = 1 - \frac{1 - b^{\frac{1-b^{\mathrm{Max}(S_s,S_m,S_l)}}{1-b}}}{1-b} \quad \ldots\ldots\ldots (7)$$

$$\text{chroma} = \frac{1 - c^{\frac{|x|+|y|}{|x|+|y|+|z|}}}{1-c} \quad \ldots\ldots\ldots (8)$$

$$\text{redness} = -\text{greeness} = \frac{x}{|x|+|y|} \quad \ldots\ldots\ldots (9)$$

$$\text{yellowness} = -\text{blueness} = \frac{y}{|x|+|y|} \quad \ldots\ldots\ldots (10)$$

Estimated constants:

$q = 0.05$
$\sigma = 30$
$b = 0.1$
$c = 0.75$

$G_i(w)$ = Cone system sensitivities. A Gauss function. P_i = peak sensitivity wavelengths. σ = standard deviation.

$Z_i(w)$ = Intermodulated sensitivity functions. T_i = relative number of cones q = intermodulation constant.

S_i = Integrated signal response to a stimulus defined by the function $F(w)$. w = wavelength.

x = Intermediate level redness (- greeness) signal
y = " " yellowness(- blueness) "
z = " " visible whiteness "

blackness, a "cascaded" non linear function
chroma, a simple non linear function
b,c = signal transmitting agent residue at signal strength 1 ("full signal")

Comment: A first test on 8 arbitrarily selected NCS color samples with known reflektance spektra gave a medium failure of predicted blackness, chroma and hue of about 7.5%.

Ken Sagawa, Ibaraki (Japan):

Wavelength Discrimination in the Presence of Dichoptically Added Field

In order to investigate dichoptic color mixture, wavelength discrimination threshold was measured in the presence of dichoptically added field for the wavelengths from 450 to 650 nm. It was shown that the discrimination thresholds were about twice as large as those with no added field, the monocular thresholds, but they were not affected by the luminance of the added field. These results indicate that the dichoptic color mixture indeed occurs but the additive color mixture fails in the dichoptic mixing of colors.

Pour l'investigation de la vision colorée binoculaire, la discrimination pour les longueurs d'onde entre 450 nm et 650 nm est mesurée à l'aide d'un champs additionnel. On a trouvé que les seuils différentiels sont à peu près deux fois plus grands que les seuils monoculaires. Mais ils ne sont pas influencés par la luminance du champs additionnel. Ces résultats montrent qu'il existe en vérité un mélange binoculaire, mais que les lois du mélange additif ne sont pas valables dans ce cas.

Für die Untersuchung des binokularen Farbensehens wurde die Unterschiedsempfindlichkeit für Wellenlängen mit Hilfe eines binokular zugefügten Feldes im Gebiet zwischen 450 und 650 nm bestimmt. Es hat sich gezeigt, daß die Unterschiedsschwellen etwa zweimal so groß sind wie die monokularen Schwellen ohne das zugefügte Feld, aber sie werden nicht durch die Leuchtdichte des zugefügten Feldes beeinflußt. Diese Ergebnisse zeigen, daß tatsächlich eine binokulare Farbmischung stattfindet, daß aber die Gesetze der additiven Farbmischung dabei nicht gelten.

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Introduction

Dichoptic color mixture has been demonstrated in a number of studies. However, it is quite difficult to obtain stable color mixtures, particularly for widely separated colors, because of rivalry. This difficulty might have caused a large variety in previous results.[1-3] In the present study, to obtain reliable mixtures only colored lights with small hue difference are used. The chromatic discrimination of the mixed colors is measured to study the dichoptic mixing.

Method

A bipartite field of monochromatic light subtended 1.1° was presented to right eye as a discrimination field. The same field was presented to left eye, the wavelength of which being equal to the standard wavelength of the discrimination field. Subject viewed both field dichoptically and shifted the wavelength of one side of the discrimination field toward longer or shorter-wave region until two sides of the dichoptic field were appeared to be just noticeably different. The difference between the average of resulting settings and the standard wavelength gave the discrimination threshold, $\Delta\lambda$. Luminance of the discrimination field was set at 80 td and that of the dichoptically added field was varied from 40 to 160 td.

Results and discussion

Fig.1 shows discrimination thresholds obtained with the dichoptically added field of three different luminances ranging from 450 to 650 nm in 10 nm steps. Positive and negative $\Delta\lambda$ values indicate the thresholds for longer and shorter-wave regions respectively. The discrimination thresholds with no added field, that is, monocular discrimination thresholds, are also shown for comparison.

As can be seen Fig.1, discrimination thresholds with the dichoptically added field are shown to be larger than those with no added field for each added field luminance. This indicates that the discrimination is deteriorated by the dichoptically added field. The discrimination steps are about twice the monocular steps. If the dichoptic discrimination is determined solely by the discriminable signals originating from one eye, the discrimination step with the dichoptically added field should be equal to the monocular one. But the present results show that this is not to be the case. This suggests that the right and left eye stimuli fuse into an intermediate color in the brain and, consequently, the deterioration would occur. It is also shown that discrimination thresholds for different added field luminances are almost the same. This cannot be interpreted from the additive color mixture law, in which the luminance change is expected to affect the discrimination step in a manner that the higher the added field luminance the larger the discrimination step.

The insensitivity of the discrimination threshold to the luminance change of the dichoptically added field is demonstrated more clearly in Fig.2 with the comparison of monocular mixing of the same procedure. In this figure, $\Delta\lambda$ is plotted as a function of the added field luminance (1.0 corresponds to the discrimination field luminance). As expected from the additive color mixture law, the discrimination step for monocular condition increases as the added field luminance increases.

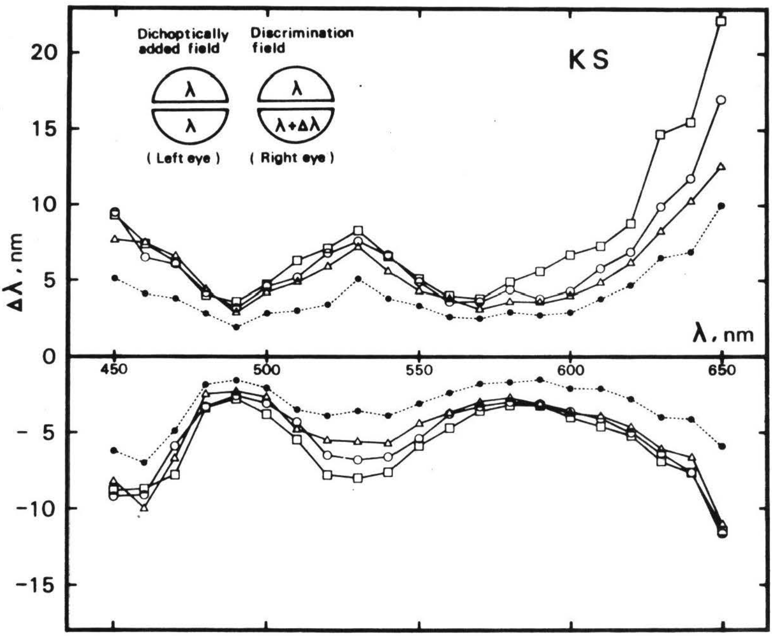

Fig.1. Wavelength discrimination threshold with the dichoptically added field. The added field luminances are (△), 40 td; (○), 80 td; (□), 160 td; and (●), no added field.

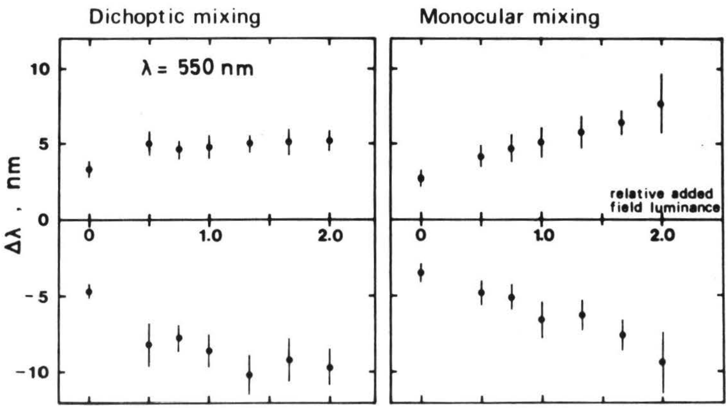

Fig.2. Wavelength discrimination threshold as a function of the added field luminance for the dichoptic and monocular mixing conditions.

However, such increase is not found for the dichoptic condition, where the discrimination step is almost constant for any added field luminance employed. This implies that the additive color mixture law does not hold for the dichoptic mixing of colors.

To summarize, the results of the present experiments show that the dichoptic color mixture indeed occurs but the additive color mixture fails in the dichoptic case.

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(2) Hoffman, C.S. (1962) Comparison of monocular and binocular color matching. J. Opt. Soc. Am. 52, 75-80.

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Charles M.M. de Weert, Nijmegen (NL):

A Versatile Colour Stimulus Generator and its Application in Colour Vision Research

A computer driven colour television monitor is used to generate coloured figures, with 8 colours present simultaneously. The colours can be changed in very small steps. The application, dealt with in this paper is the investigation of the colour dependence on the formation of subjective contours.

Sur un moniteur de télévision en couleurs qui est réglé par un ordinateur, des figures colorées sont produites qui contiennent huit couleurs en même temps. On peut régler les couleurs en petites marches. La communication présente montre, comme une application de la méthode, la dépendance de la couleur de la formation des contrastes subjectifs.

Auf einem Computer-gesteuerten Buntfernseh-Monitor werden Figuren gezeigt, die acht Farben gleichzeitig enthalten. Die Farben können in kleinen Stufen geregelt werden. Die vorliegende Arbeit zeigt als Anwendung des Verfahrens die Farbabhängigkeit der Gestaltung subjektiver Konturen.

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Ch. M.M.de Weert

A relatively inexpensive colour picture generating system has been developed. The basic equipment comprises a microprocessor, colour television monitor with R, G, B inputs, and a number of videomemories. The most important characteristic of the apparatus here proposed is the way in which videomemories are used in combination with a set of colour registers and very fast DA-converters. The equipment permits display of any kind of programmable figure with a maximum of 8 colours simultaneously present. Colours can be changed in very small steps with the R, G and B channels each receiving one out of 256 possible values. The paper describes the basic equipment and gives a few indications of its possible applications. The particular experiment, dealt with in this paper concerns the colour dependence of the formation of subjective contours. Fig. 1 gives an example of subjective contours.

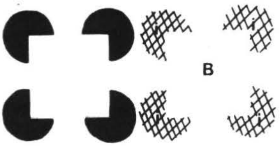

Figure 1. Example of a subjective contour.
I: induction field, B: background.

If the induction fields(I) and the background (B) differ in colour, the thresholds for the luminance differences between induction fields and backgrounds necessary to obtain the subjective contour effect are different from the thresholds when induction fields and background are of the same colour. In de Weert (1980) these difference thresholds were measured for spectral lights. Part of the results are shown in Fig. 2, in which the pairs of wavelengths used in induction fields and background are represented along the absciss and the luminance difference thresholds (for different types of thresholds) along the ordinate. The colour dependence is revealed by two characteristics:

a) By an overall difference in threshold between the homochromatic pairs (left part of Fig. 2) and the heterochromatic pairs
b) By a systematic asymmetry in pairs in which the colours of induction fields and of background are interchanged.

As a matter of fact similar characteristics have also been found in the study on the role of colour in stereopsis (de Weert, 1979). The asymmetry can be described in a model in which an alternative, colour dependent luminance measure is used. For the explanation of the overall differences between homochromatic and heterochromatic thresholds, and especially for the growing thresholds with growing difference in wavelength additional assumptions are needed, and also new measurements. These additional data, collected with the equipment described above will be presented.

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Wittebrood, J., Wansink, M. & De Weert, Ch.M.M. A versatile colour stimulus generator. Perception, 1981 (in press).

Note: The part of the paper on the role of colours in the formation of Subjective Contours will be submitted to Perception.

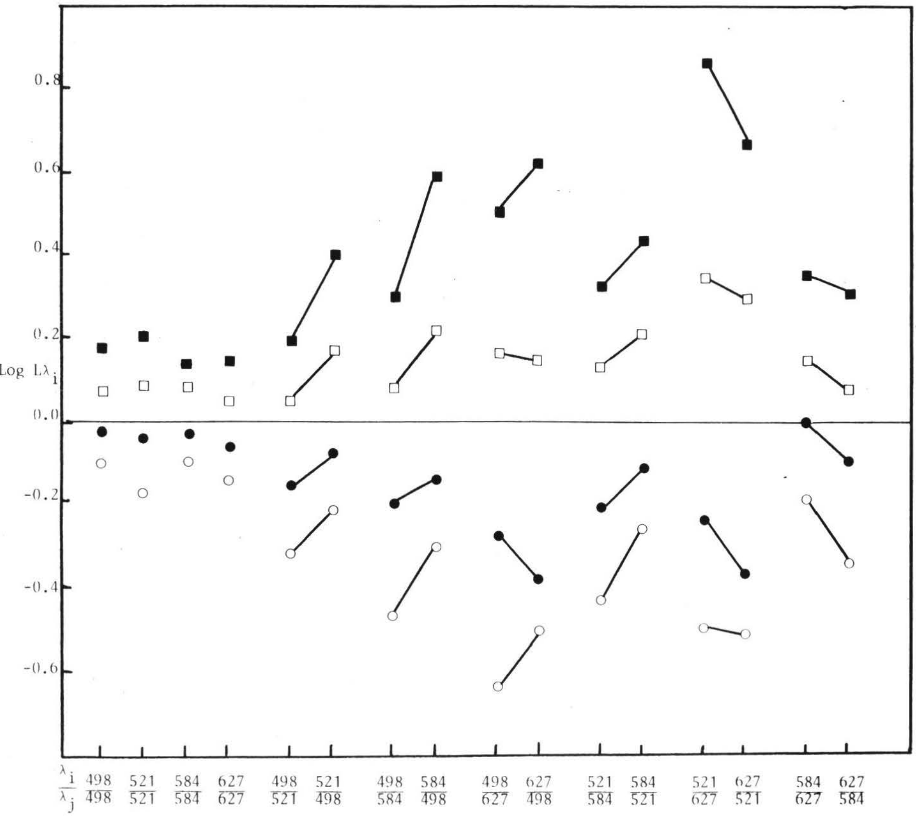

Figure 2. Along the ordinate the luminance difference threshold for different types of thresholds are represented.
■: appearance threshold for an increment in the luminance of the induction field, □: disappearance for the incremental case, ○: appearance threshold for a decrement in luminance of I, ●: disappearance threshold for the decremental case. λ_i is the wavelength of the induction field. The value of L is normalized. 300 troland is given the value of 1. At log L = 0.0 inducing field and background have the same luminance.

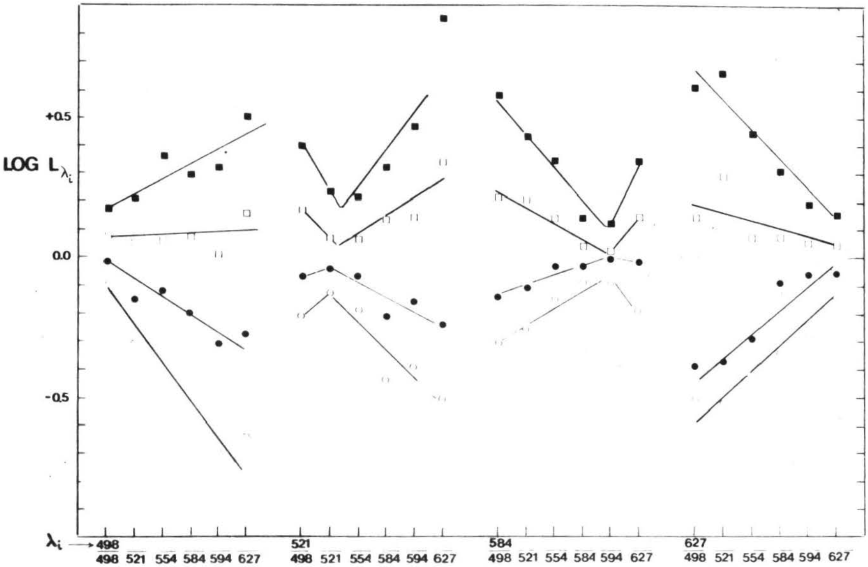

Figure 3. Dependence of difference thresholds on the distance in wavelength between induction fields and background. See legend of Fig. 1 for symbols.

Po27

Heinwig Lang, Darmstadt:

Farbwiedergabeindex und visuelle Beurteilung von Bildern im Fernsehen

For the determination of the colour rendering or consistency index of a transmission system test colours are used. Their reproduction by this system is compared with their reproduction by a reference system. Certain systematic shifts of all reproduced colours, for example by a change of reference white or saturation, are weighted differently by an observer from random shifts. It is therefore suggested to split the index into systematic parts, describing common transformations of all colours, and a random part, describing the unsystematic errors of the system.

Pour la détermination de l'indice du rendu des couleurs d'un système de transmission on utilise des couleurs-tests dont le rendu par le système est comparé à celui par un système de référence. Certaines distorsions systématiques de toutes les couleurs, p.e. par le déplacement du point achromatique ou par un changement de la saturation, sont évaluées par l'observateur d'une manière différente que les distorsions accidentelles. C'est pourquoi on ici propose de partager l'indice du rendu: l'une part systématique qui décrive les transformations communes à la totalité des couleurs, l'autre part pour les déviations restantes.

Bei der Bestimmung des Farbwiedergabeindex eines Übertragungssystems werden Testfarben benutzt, deren Wiedergabe durch das System mit der durch ein Bezugssystem verglichen werden. Bestimmte systematische Verschiebungen aller Wiedergabefarben, z.B. durch Änderung des Unbuntpunkts oder der Sättigung, werden vom Beobachter anders bewertet als zufällige Verschiebungen. Es wird deshalb vorgeschlagen, den Farbwiedergabeindex aufzuteilen in systematische Anteile, die gemeinsame Transformationen aller Farben beschreiben, und einen Anteil für die restlichen Fehler.

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Einleitung:

Es ist heute in der Fernsehtechnik vielfach üblich, die Qualität der Farbwiedergabe eines Übertragungssytems durch einen Farbwiedergabeindex zu kennzeichnen. Dieser Farbwiedergabeindex beschreibt die Unterschiede der Farbwiedergabe zwischen dem zu kennzeichnenden und einem Bezugssystem.

Es ist offensichtlich, daß die Größe des ermittelten Farbwiedergabeindex davon abhängt, wie das Bezugssystem definiert wird. Die erste Frage, mit der sich dieser Vortrag befaßt, heißt deshalb:

1. Wie muß das Bezugssystem beschaffen sein, und inwieweit soll es auf das reale System Rücksicht nehmen .

Die zweite Frage betrifft den Vergleich zwischen beiden Systemen. Üblicherweise bestimmt man von einer Anzahl von Testfarben die Wiedergabe-Farbkoordinaten der beiden Systeme und berechnet nach einer Farbabstandsformel den Mittelwert der Farbabstände bzw. den Wiedergabeindex. Die wichtige Frage, welche Testfarben dafür geeignet sind und welche Farbabstandsformel, soll hier nicht diskutiert werden. Unabhängig davon ist jedoch für die Anwendung dieser Methode zu berücksichtigen:

2. Jede Farbabstandsformel beruht auf der Farbunterschiedsempfindlichkeit bzw. dem Abstandsmaß für einzelne Farbenreihen. Tatsächlich werden jedoch durch ein Farbfernsehsystem Bilder übertragen, deren Farben in einem bestimmten Zusammenhang stehen und an die der Beobachter bestimmte Erwartungen knüpft.

Bezugssystem:

Obwohl der Farbfernsehbildschirm ein "Fenster zur Realität" sein soll, ist es aus verschiedenen Gründen nicht möglich, die Wiedergabefarben direkt mit denen des Originals zu vergleichen. Am Wiedergabeort sind unter anderem Leuchtdichte, Farbart von Unbunt, Umfeld und Bildwinkel sehr verschieden vom Original. Man definiert deshalb ein Bezugssystem, das die Eigenschaften hat, die man für das reale System anstrebt.

In ihm sind folgende Größen festgelegt:

a) Beleuchtungsstärke und Lichtart des Lichts, das die Objekte beleuchtet
b) spektrale Empfindlichkeit des idealen Bildaufnahmegerätes
c) Verlauf der Überalles-Kennlinie
d) Farbarten der Primärvalenten des Wiedergabesystems
e) Farbart und Leuchtdichte von Unbunt auf der Wiederagebseite.

Um die Verhältnisse am Wiedergabeort besser beschreiben zu können, ist es unter Umständen sinnvoll, auch den Einfluß von Raum-Streulicht auf die Farben des Bildschirms zu berücksichtigen oder eine Verschiebung des Unbuntpunkts.

Letzteres ist besonders wichtig, wenn man die Praxis einer Bestimmung des Farbwiedergabeindex berücksichtigt. Dabei werden z. B. die Farben von Testfarben auf dem Bildschirm oder die Farbwertsignale einer Kamera gemessen.
Zuvor muß die Kamera mit Hilfe eines Weißstandards auf Unbunt eingestellt werden. Dabei kann es leicht vorkommen, daß man sich auf ein Unbunt (Weißstandard, Grautreppe) bezieht, das von dem des Bezugssystems abweicht. So können sich zwischen den einzelnen Farbkanälen durchaus Fehler von etwa 2 % ergeben. Dieser Fehler kann in dem Farbwiedergabeindex Unterschiede bis zu 8 Einheiten erzeugen. Dieser Fehler ist aber ohne Bedeutung für die subjektiv empfundene Farbwiedergabe. Denn er bedeutet nur eine geringe Verschiebung der Farbart von Unbunt auf dem Bildschirm, die durch die chromatische Adaption des Auges ausgeglichen wird.

Bewertung der Farbunterschiede:
Bei der Ermittlung des Farbwiedergabeindex werden die Farbabstände zwischen Wiedergabe- und Referenzfarbe für alle Testfarben unabhängig voneinander ermittelt und betragsmäßig addiert. Nun ist aber offensichtlich, daß bestimmte systematische Verschiebungen der Wiedergabefarben von einem Beobachter eher toloriert werden als andere Verschiebungen. So wird z. B. die erwähnte Verschiebung der Farben durch Veränderung des Unbuntabgleichs vom Beobachter durch die chromatische Adaption weitgehend kompensiert.

Aber auch eine gemeinsame Vergrößerung oder Verringerung der Chrominanzvektoren, die zu einer Erhöhung oder Erniedrigung der Buntheit der Wiedergabefarben führt, wird vom Beobachter eher toleriert als eine Drehung der Chrominanzvektoren in Ebenen gleicher Leuchtdichte. Aus diesem Grund wurden mit einer Anzahl von Beobachtern die Korrelation zwischen dem Farbwiedergabeindex und der subjektiv beurteilten Farbwiedergabe ermittelt bei verschiedenen Transformationen im Farbraum.

Es wird deshalb vorgeschlagen, den gemittelten , allgemeinen Farbwiedergabeindex in mehrere Anteile aufzuspalten. Zuerst sollte versucht werden, durch gemeinsame Transformationen aller Testfarben, wie Verschiebung des Unbuntpunkts, Änderung der Übertragungskennlinie und Veränderung der Chrominanzkomponenten, die Sollfarben möglichst an die Wiedergabefarben anzupassen. Die durch solche Transformationen kompensierbaren Farbabweichungen sollten getrennt angegeben und anders bewertet werden als die verbleibenden Restabweichungen.
Dies würde zu einer anschaulicheren und empfindungsgemäßeren Kennzeichnung der Farbwiedergabe eines Übertragungssystems führen.

Die vollständige Arbeit wird in "COLOR research and application" veröffentlicht.

Po28

Takayoshi Fuchida and Leo Mori, Consumer Products Engineering Laboratory, Toshiba Corporation, Kawasaki (Japan):

Comparison of Correcting Methods for Chromatic Adaptation Used for the Color Rendering Specification

According to several methods for correcting the chromatic adaptation, psychometric chroma diagrams are calculated for saturated surface colors illuminated by various kinds of light sources, and they are compared with the subjective diagram. The proposal by Nayatani et al. improves the CIELAB space in simulating the subjective appearance of surface colors.

D'après quelques méthodes de considérer l'adaptation chromatique, ,,psychometric chroma" diagrammes sont calculés pour les couleurs de surface saturées éclairées par différentes sources de lumière, et ils sont comparés avec le diagramme subjectif. La proposition par Nayatani et al. améliore l'espace CIELAB en simulant l'apparence subjective de la couleur de surface.

Entsprechend verschiedenen Verfahren zur Berücksichtigung der Farbstimmung werden psychometrische Chroma-Diagramme für gesättigte Körperfarben unter Beleuchtung durch verschiedene Lichtarten berechnet und mit dem subjektiven Diagramm verglichen. Das von Nayatani et al. vorgeschlagene Verfahren beschreibt das subjektive Aussehen der Körperfarben besser als der CIE-Farbenraum.

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In the previous paper [1] on the subjective evaluation of the uniform color spaces, the authors suggested that the CIELAB formula includes a practical correction for the chromatic adaptation at least in the specification of the surface color rendering by various light sources. Since a number of transformations are proposed [2], this paper searches for some transformations which match better with the subjective estimation than the simple CIELAB formula.

At first, the reference stimuli in the CIELAB formula are changed to the Judd-Pitt primaries as follows:

$$\begin{aligned} R &= 1.00Y \\ G &= -0.46X + 1.36Y + 0.10Z \\ B &= 1.00Z \end{aligned} \qquad \text{-----------(1)}$$

$$\begin{aligned} a^{**} &= 700[(R/R_n)^{1/3} - (G/G_n)^{1/3}] \\ b^{**} &= 200[(G/G_n)^{1/3} - (B/B_n)^{1/3}] \end{aligned} \qquad \text{-----------(2)}$$

Fig. 1 shows the psychometric chroma diagram in this space indicating the highly saturated eight surface colors illuminated by the HID and incandescent lamps corresponding to Fig. 3(B) in the previous paper. Then the cube-root formula proposed by Reilly and reported by Wyszecki [3] are tested. Fig. 2 shows the calculated diagram in this space. Figs. 1 and 2 do not show any significant improvement as compared with the CIELAB psychometric chroma diagram.

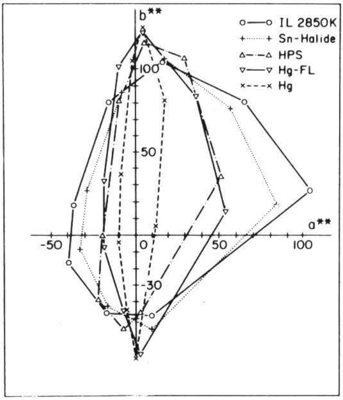
K. Richter [4,5] has proposed color appearance formulae under the variable chromatic adaptation. One type of his formulae is expressed by chroma coordinates A^* and B^* in simple equations as follows [5]:

$$\begin{aligned} A^* &= 500(A' - A'_n)Y^{1/3} \\ B^* &= 500(B' - B'_n)Y^{1/3} \\ A' &= 1/4\ (x/y + 1/6)^{1/3} \\ B' &= -1/12\ (z/y + 1/6)^{1/3} \end{aligned} \qquad \text{-------------(3)}$$

Fig. 3 shows the psychometric chroma diagram in this space for the saturated colors under the HID and incandescent lamps, and it is very similar with the CIELUV diagram (Fig. 3(A) in [1]) and quite different from the subjective diagram (Fig. 2 in [1]). The reason of this is perhaps related to the fact that this formula is based on the experiment using the matching stimuli of aperture colors.

Nayatani et al. [6] recently proposed a nonlinear model of chromatic adaptation. Fig. 4 shows the CIELAB psychometric chroma diagram of the saturated colors under the HID and incandescent lamps after the transformation to change the D_{65} adaptation. In this figure a little improvement of the CIELAB diagram (Fig. 3(B) in [1]) are shown for simulating the subjective diagram (Fig. 2 in [1]) for the illumination with low color temperature sources.

The effect is somewhat distinct, if the color rendering of a source with quite different colors such as a fluorescent lamp for plant growth (FL-BRF) is considered. Fig. 5 compares the subjective chroma diagram of saturated colors under FL-BRF and a standard cool white lamp (FL-W) with the



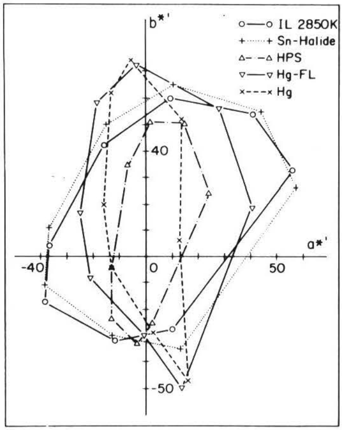
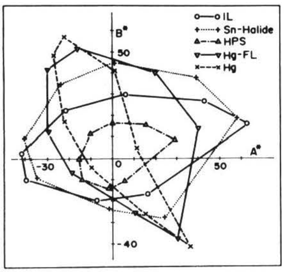


Fig.1 (left) Fig.2 (right)



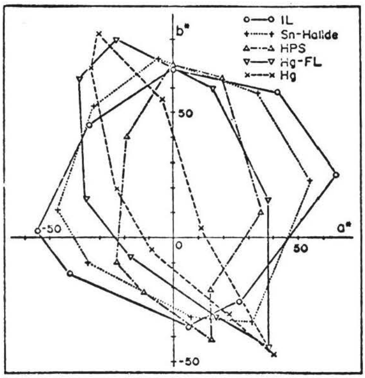


Fig.3 (left) Fig.4 (right)

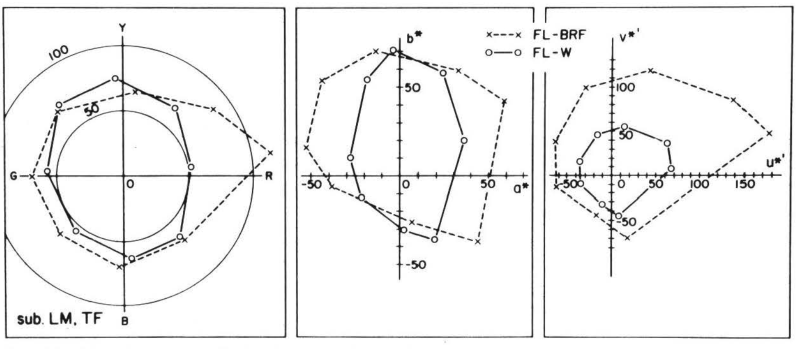
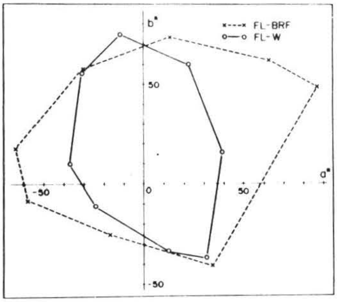


Fig.5 (left to right) Subjective chroma diagram, calculated chroma diagrams in CIELAB and CIELUV spaces



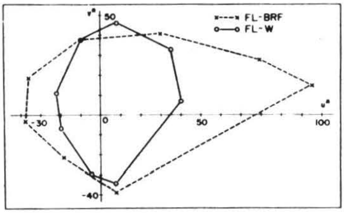


Fig.6 (left), Fig.7 (right)

CIELAB (Fig.6) and CIELUV (Fig.7) chroma diagrams applied chromatic adaptation correction to D_{65} according to the non linear model by Nayatani et al.

calculated psychometric chroma diagrams in the CIELAB and CIELUV spaces. In the case of CIELUV space, the von Kries transformation is applied to correct the chromatic adaptation to the chromaticity of Planckian radiator with the same color temperature as the fluorescent lamps. Without this correction, difference between the gamut areas of FL-BRF and FL-W is more exagerated.

Figs. 6 and 7 show the CIELAB and CIELUV psychometric chroma diagrams after the transformation to D_{65} adaptation for illumination of two kinds of fluorescent lamps. It is to be emphasized that not only the CIELAB diaram but the CIELUV one is markedly improved according to Nayatani's model to simulate the subjective diagram.

In conclusion, CIELAB space gives an appropriate approximation for the correction of chromatic adaptation for the application to the surface color rendering specification. If we want to improve the accuracy of the chromatic adaptation transformation, the method proposed by Nayatani et al. seems to be the best one for this application.

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Hans-Joachim Heinrich, Berlin:

Farbmetrische Festlegung von Druckfarbenreihen

Multicolour prints are among other reasons colorimetrically unsatisfactory because there is no way to produce screen patterns with sufficient precision. In the following the production of a series of colours in printing technique is described, which is achieved by varying the size of the screens. This procedure enables one to produce and alter colorimetrically defined colours with screens and printing inks.

Une cause essentielle pourquoi les imprimés en couleurs souvent ne satisfont pas, du point de vue colorimétrique, c'est le fait que l'on ne sait pas produire les plaques tramées avec une précision suffisante. Ici on décrit la production des séries de telles plaques qui sont formées par la variation des grandeurs des point de la trame. Cela rend possible d'imprimer des couleurs définies par frames et avec des encres d'imprimerie et de les changer.

Mehrfarbendrucke sind unter anderem deswegen farbmetrisch unbefriedigend, weil die Rastervorlagen für den Druck bisher mit nicht ausreichender Genauigkeit hergestellt werden können. Im folgenden wird die Herstellung von Druckfarbenreihen beschrieben, die durch Variation der Rasterpunktgröße entstehen. Damit besteht nun die Möglichkeit, farbmetrisch definierte Farben mit Rastern und Druckfarben zu erzeugen und zu verändern.

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Einleitung

Im Mehrfarbendruck werden die gedruckten Farben durch den Nebeneinander- und Uebereinanderdruck von Rasterpunkten gesteuert. Der Farbeindruck eines Buntdruckes wird durch die Druckfarben und durch die Groesse der Rasterpunkte bestimmt. Da es bisher kein optimales Verfahren fuer die Erzeugung von Rastervorlagen mit definierten Flaechendeckungen gibt, sind die Mehrfarbendrucke, vom farbmetrischen Standpunkt her unbefriedigend.

Aufgabenstellung

Die Aufgabe dieser Arbeit bestand darin, fuer den Offset-Druck Rastervorlagen mit definierten Flaechendeckungen herzustellen, die durch die Variation der Rasterpunktgroesse entstehen, und die damit die Herstellung von Druckfarbenreihen fuer farbmetrisch definierte Farben ermoeglichen.

Durchfuehrung

Mit einem Computer-Zeichengeraet wurden Rastervorlagen mit definierter Flaechendeckung und der entsprechenden Winkelung der Rasterpunkte fuer die drei bunten Farben Gelb (Y), Magentarot (M) und Cyanblau (C) sowie fuer die unbunte Farbe Schwarz (S) hergestellt. Die Flaechendeckung wurde von 0% bis 100% um jeweils 25% variiert. Von diesen Rastervorlagen wurde im Offset-Druckverfahren eine Druckfarbentafel hergestellt. Fuer die Herstellung der Druckfarbentafel wurden die fuer Kunstdruckpapier geltenden Druckfarben nach der "Europaskala" verwendet, deren Normfarbwerte in der Norm DIN 16538 angegeben sind. Die Rastervorlagen wurden mit dem Rastermass von 60 Linien/cm gezeichnet. In Bild 3.1 sind je zwei Rasterpunkte in Originalgroesse sowie in 10-facher Vergroesserung fuer die Flaechendeckungen 4. 9, 16, 25, 36, 49, 64, 81 und 100% dargestellt.

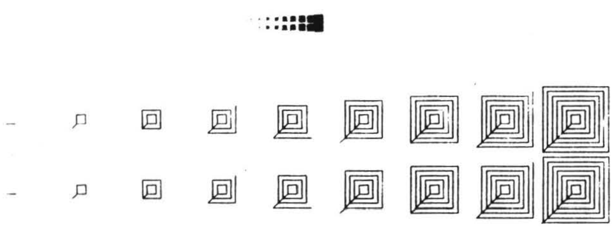

BILD 3.1:
Rasterpunkte der Rastervorlagen in Originalgroesse und in 10-facher Vergroesserung. Fuer den Druck wurden die Rastervorlagen fotografisch 9-fach verkleinert.

Messung und Auswertung der Druckfarbentafel

Die einzelnen Felder (1x1cm) der Druckfarbentafel wurden farbmetrisch mit dem Spektralphotometer DMC 25 fuer Tageslicht D 65 mit der 8°/diffus-Messgeometrie mit Glanzfalle ausgemessen. Die Normfarbwertanteile x,y der Druckfarben maximaler Buntheit, das heisst diejenigen der 99%-Felder in der S=0%-Reihe, zum Beispiel der drei Grundfarben Gelb (Y 99), Magentarot (M99), Cyanblau (C99), und die Normfarbwertanteile der 24 Mischfarben, zum Beispiel von Orangerot (Y99M99), Violettblau (M99C99) und Laubgruen (C99Y99), wurden in die Normfarbtafel eingetragen. Zeichnerisch wurden die bunttongleichen Wellenlaengen fuer alle Farben dieses 27-teiligen Bunttonkreises ermittelt.

Ergebnis

Hiermit konnte fuer Farben beliebiger bunttongleicher Wellenlaenge genau die Rasterpunktgroesse fuer den Offset-Mehrfarbendruck angegeben werden. Zum Beispiel wurde zum Druck eines Spektrums (inklusive Purpurfarben) die Rasterpunktgroesse ermittelt und das Spektrum gezeichnet.

Anwendungsmoeglichkeiten

Mit dieser Methode kann man Farbtesttafeln (Normtesttafeln) in Mehrfarbendrucktechnik mit bisher kaum moeglicher farbmetrischer Genauigkeit herstellen. Eine andere Moeglichkeit der Anwendung ist das Grafik-Design. Die Herstellung von Rastervorlagen ist in Zukunft auch als Filmausgabe (Mikrofiche) ohne Zeichengeraet denkbar. In diesem Fall zeichnen Elektronenstrahlen verschiedener Intensitaet auf eine Roehre, deren Bild auf Mikrofiche projiziert wird.

Die Ergebnisse der Arbeit werden in der Zeitschrift Farbe + Design erscheinen.

Po30

Danny C. Rich and Fred W. Billmeyer jr., Chicago (Ill.)/Troy (N.Y.):

Small and Moderate Color Differences IV.
Color-difference-perceptibility Ellipses in Surface-color Space

Moderate (0.5–1.5 CIELAB units) color differences in surface colors were scaled visually to obtain color-difference-perceptibility ellipses. The ellipse orientations were independent of the size of the color differences over the range indicated, and were consistent with literature results obtained with visual colorimeters. In the vivid greenish yellow region, the ellipse orientation agreed with the Munsell spacing but not with the orientation of the CIELAB ellipse. In the deep greenish blue region, the ellipse orientation agreed better with the results of Wyszecki and Fielder than with the MacAdam PGN ellipse.

On a arrangé des échantillons à différence de couleurs modérés (0.5–1.5 unité CIELAB) visuellement pour gagner des éllipses de perceptibilité des différences de couleurs. Les positions des éllipses sont trouvées au dedans de la région examinée, indépendantes de la grandeur des différences de couleurs et elles sont en accord avec les résultats gagnés avec des colorimètres visuels comme décrit dans la litérature. Dans la région du vert-jaunâtre vif la position de l'ellipse correspond à l'espace Munsell mais pas aux éllipses CIELAB. Dans la région du bleu-verdâtre forcé la position de l'éllipse correspond mieu aux résultats de Wyszecki et Fielder comme à l'éllipse PGN de MacAdam.

Proben mit mäßigen Farbunterschieden (0.5–1.5 CIELAB-Einheiten) wurden visuel zur Gewinnung von Farbabstands-Wahrnehmbarkeits-Ellipsen geordnet. Die Ellipsenlagen erwiesen sich innerhalb des untersuchten Bereiches als unabhängig von der Größe des Farbunterschiedes und stimmen mit den in der Literatur beschriebenen Ergebnissen an visuellen Farbmeßgeräten überein. Im Gebiet des lebhaften Gelbgrün entsprach die Ellipsenlage der Munsell-Anordnung, aber nicht den CIELAB-Ellipsen. Im Bereich des tiefen Grünblaus war die Ellipsenlage in besserer Übereinstimmung mit den Ergebnissen von Wyszecki und Fielder als mit der MacAdam-PGN-Ellipse.

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Danny C. Rich and Fred W. Billmeyer, Jr.

An experiment in the visual scaling of moderate color differences, 0.5-1.5 CIE 1976 L*a*b* (CIELAB) units, to obtain color-difference-perceptibility ellipses for surface colors was designed and performed utilizing an extension of the Rich, Billmeyer, and Howe technique [1]. The modification was devised by the present authors and presented to the color-difference subcommittee of CIE Technical Committee 1.3, Colorimetry, at its meeting in Troy, New York, in 1977. A description of it was subsequently published by the subcommittee chairman [2].

Two color centers were selected for study, in regions of chromaticity where commonly used color-difference equations (MacAdam [3] and CIELAB [4]) give widely different results: Munsell 7.5Y 8/12, vivid greenish yellow, and Munsell 2.5B 3/8, deep greenish blue. A custom computer-color-matching program [5] was used to predict colorant concentrations for sets of samples around each of these color centers at constant lightness and each of three levels of color difference: level 1 = 0.5, level 2 = 1.0, and level 3 = 1.5 CIELAB units. Six sets of samples were prepared from drawdowns of Sherwin-Williams color-card lacquers. The samples were measured in duplicate on a Kollmorgen KCS-40 abridged spectrophotometer. Spectral reflectance factors at 10-nm intervals were integrated to CIE tristimulus values using the spectral irradiance of the visual source and the CIE 1931 and 1964 standard observers. A pair of neutral gray samples was similarly prepared and measured for each color-difference level, to be used as reference pairs in the visual scaling.

Ten observers were used to obtain 46 series of observations for each of the six sample sets. The observations were carried out under a filtered-incandescent source, Macbeth 6500 K Daylight in a Macbeth Spectralight booth. The observers were required to determine whether the perceived color difference between a chromatic sample and the color-center standard was greater than or less than the perceived color difference between the two samples of the appropriate neutral-gray reference pair.

The method for data treatment in this research differs from that of Rich [1] primarily in that a "false-alarm parameter" is not needed in the present study since the observer is never allowed to judge two stimuli to be exactly equal. A likelihood function L for describing the judgments was derived [1,2] and the inverse of the natural logarithm of L was minimized using an iterative algorithm [6]. From variance-covariance estimates the parameters of an elliptical probability contour in the chromaticity diagram were calculated.

The numerical analysis was more difficult than that encountered by Rich et al. The maximum likelihood routine would often exceed its numerical precision and stop the iteration before the global minimum was reached. Manual modification of the parameters in the fourth and fifth significant digits was employed to obtain the optimum set of estimates.

The most significant results of this research are the orientations of the major axes of the color-difference-perceptibility ellipses. They are given in Table IA for both color centers and both CIE standard observers. The orientations of the corresponding MacAdam and CIELAB ellipses are included for comparison. The range of orientations of other ellipses reported in the literature for similar color centers is illustrated for comparison in Table IB.

Table I. Ellipse Orientation, degrees

A. This Work

Color	Blue		Yellow	
Std. Obs.	1931	1964	1931	1964
Level 1	43°	41°	32°	36°
Level 2	34	19	55	42
Level 3	36	23	34	29
MacAdam	99	101	75	73
CIELAB	51	55	141	138

B. Literature

Ref.	Obs.	Blue	Yellow
[3]	PGN	104°	70°
[7]	GF	50,19	47,53
	AR	71,62	67,49
	GW	66,79	60,50
[8]	WRJB	92	49
	DLM	89	3
	PGN	91	68
[9]	Unwt.	7	123
	wtd.	6	86

This research has shown that it is possible to obtain color-difference-perceptibility ellipses directly for surface-color differences greater than the threshold limit. Significance tests showed that only the second level for the yellow color center exhibited statistically significant differences in angular orientation from that at the other two levels. Thus, there is now evidence to support the assumption (always made) that there is little or no change in ellipse orientation with size of the color difference, at least up to color difference of about 1.5 CIELAB units. Thus one should be able to build a metric capable of predicting the orientation of all levels of color difference by fitting only one level.

One should exercise some care when applying the same color-difference formula to the two different CIE standard observers. This may be especially true in the blue region where the two observer functions have the greatest difference.

Even at high chroma, observations on visual colorimeters yield the same results as observations on surface-color samples. The comparisons shown in Table IB seem to indicate some consistency between the results of several different visual-colorimeter studies and the current work. This is a very positive result for model builders who need more and more data to perform their analyses. It is speculated that analysis regimes such as those suggested by Friele [10] could be implemented without the fear of incompatibility between aperture- and surface-mode experiments.

This study disagrees with the predictions of the CIELAB equation in the yellow region. The differences can probably be attributed to inadequacy of the CIELAB equation in that region. The results do appear to be consistent with the spacing of the Munsell color-order system. Disagreement between this study and the MacAdam data in the blue region can be attributed to difficulties in estimating the lines of constant value of the metric coefficients; or it may be that observer PGN's discrimination in the blue region is not representative of a typical observer. Perhaps the results of Wyszecki and Fielder [7] are closer to the central tendency, since those results tend to lie between the PGN results and the results of this study.

Acknowledgments. This paper is based on the Ph.D. thesis of Danny

Danny C. Rich and Fred W. Billmeyer, Jr.

C. Rich at Rensselaer Polytechnic Institute. We thank the Munsell Color Foundation for financial support of this work. This is Contribution No. 109 from the Rensselaer Color Measurement Laboratory.

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This paper will be published in full in COLOR research and application.

Dietrich Strocka, Andreas Brockes, W. Paffhausen, Leverkusen:

Zur Methodik der Untersuchung von Farbabstands-Ellipsoiden

Using a set of red samples, we investigated the influence of several parameters on the accuracy of experimentally evaluated colour difference ellipsoids. The results show, that an ellipsoid evaluated from 20–30 visual assessments of about 50 samples has an accuracy, which corresponds to a mean error of calculated colour differences below 10%. The border line between the samples, the direction of the reference difference and even the use of a grey reference pair had no serious influence.

On a étudié l'influence de divers paramètres sur la précision avec laquelle on a trouvé par expérience les ellipsoïdes des différences des couleurs avec un groupe d'échantillons rouges. Les résultats montrent que l'on peut gagner, avec 20 à 30 contre-typages de 50 échantillons à peu près, un éllipsoïde avec une précision, qui correspond à une faute moyenne inférieure à 10% des distances des couleurs. On n'a observé aucune influence essentielle de l'acuité de la ligne séparative entre les échantillons, de la direction de la différence de référence et même de l'usage d'une paire grise de référence.

An einem Satz roter Proben wurde der Einfluß verschiedener Parameter auf die Genauigkeit experimentell ermittelter Farbabstands-Ellipsoide untersucht. Die Ergebnisse zeigen, daß mit ca. 20–30 Abmusterungen von ca. 50 Proben ein Ellipsoid mit einer Genauigkeit erhalten wird, die einem mittleren Fehler der damit berechneten Farbabstände unter 10% entspricht. Die Schärfe der Trennlinie zwischen den Proben, die Richtung der Referenz-Differenz und selbst die Verwendung eines grauen Referenzpaares hatten keine wesentlichen Einflüsse.

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Die Farbabstandsformeln CIELAB und CIELUV sind von der CIE nur vorläufig zur Anwendung in der Praxis empfohlen, solange keine ausreichenden experimentellen Daten für eine bessere Farbdifferenzbewertung vorliegen. Zur Sammlung solcher Daten hat die CIE ein Arbeitsprogramm aufgestellt (1). Im Rahmen dieses Arbeitsprogramms haben wir folgende Fragen untersucht :

- Wie viele Proben werden um eine Standardfarbe benötigt, und wie sind diese Proben im Farbraum anzuordnen ?
- Wie viele Beobachter sind erforderlich ?
- Wie können die Ellipsoidgrößen um verschiedene Farbstandards auf einen gleichen empfindungsgemäßen Farbabstand bezogen werden ?

Die Untersuchungen wurden an 51 Textilfärbungen um die rote Standardfarbe der CIE (im folgenden "Standard" genannt) ausgeführt. Die Proben wurden im CIELAB-Farbraum planmäßig um den Standard herum auf 32 Richtungen verteilt, die den 12 Ecken und 20 Flächenmitten eines Ikosaeders entsprechen, mit CIELAB-Farbabständen von 0,4 bis 4.

Bei der visuellen Abmusterung waren die Größen zweier Farbabstände zu vergleichen. Der Beobachter hatte anzugeben, ob der Farbabstand zwischen Probe und Standard größer oder kleiner ist als eine feste Referenz-Differenz ($\Delta E=2,0$). Das Urteil "gleich groß" war nicht zugelassen.

Aus den Einzelurteilen einer Abmusterungsserie wurden mittlere Bewertungen als Prozentsatz der Größer-Urteile berechnet. Mit Hilfe eines aufwendigen Computer-Programms konnte aus den Farbmeßwerten und einem Satz von mittleren visuellen Urteilen ein Farbabstands-Ellipsoid ermittelt werden. Das Programm optimiert die in (1) angegebene "logistic function" P_i nach der Methode der kleinsten Quadrate.

Die Abweichung der Formen der Ellipsoide, die sich so aus verschiedene Datensätzen mit variierten Parametern ergaben, läßt sich mit dem Abweichungskoeffizienten V nach Schultze (2) charakterisieren. Er gibt die mittlere prozentuale Abweichung für die mit den beiden Ellipsoiden berechneten Farbabstände an.

Durch Parameter-Variation der experimentellen Daten wurde der Einfluß folgender Parameter auf die Ellipsoide untersucht :

1. Anzahl der Beobachter
2. Anzahl der Proben
3. Meßgenauigkeit
4. Trennung der Proben durch schwarzen, 1mm breiten Strich
5. Richtung der roten Referenz-Differenz
6. Graues Probenpaar als Referenz-Differenz

Einige der Ergebnisse zu 1. bis 3. und 5. wurden bereits in (3) mitgeteilt.

1.+2. Der volle Datensatz hierfür umfaßte 96 Beobachtungssätze an 51 Proben, wobei 34 Beobachter mit je 2 - 4 Beobachtungssätzen beteiligt waren. Die Untersuchungen zum Einfluß der Beobachter- und Probenzahl hatten ergeben, daß die Abweichungskoeffizienten für Ellipsoide, die aus unabhängigen Teildatensätzen mit ca. 20 -30 Beobachtungssätzen durch 7 - 10 Beobachter ermittelt wurden, etwa bei V= 0,05 lagen, was einem mittleren Relativfehler von 5% für die Farbdifferenzen entspricht, die mit den beiden Ellipsoiden berechnet werden. Bei einem mittleren ΔE=2,0 ist das nur eine Unsicherheit von ΔE=0,1. Für Teildatensätze mit nur 25 (bzw.17) Proben ergaben sich mit V= 0,13 (bzw. V= 0,25) bereits erheblich größere Abweichungen.

3. Unter Verwendung des oben erwähnten vollen Datensatzes wurden aus drei verschiedenen Sätzen von Meßdaten Ellipsoide berechnet. Die Ellipsoide aus der ersten und zweiten Meßreihe (RFC3 v. 2.5.78 bzw. MS-2000 v. 18.6.79) weichen voneinander nur um V= 0,03 ab, während das Ellipsoid aus der dritten Meßreihe (MS-2000 v. 9.10.80) vom Mittel der beiden ersten um V= 0,06 abwich. Möglicherweise haben sich die Proben bei den insgesamt 177 Beobachtungen zu 1.-6. in über zwei Jahren doch geringfügig geändert.

4. Um zu untersuchen, ob die unvermeidliche Trennlinie zwischen den auf Karton geklebten und scharf abgeschnittenen Gewebestreifen von Probe und Standard einen Einfluß hat, wurde sie bewußt vergrößert durch einen 1 mm breiten schwarzen Trennstreifen. Der mit 26 Beobachtungssätzen durch 13 Beobachter erhaltene Abweichungskoeffizient von V= 0,08 gegenüber dem vollen Datensatz ohne Trennstreifen liegt nur wenig über dem Wert, der bei Wiederholung der Abmusterung unter unveränderten Bedingungen zu erwarten ist. Der Trennstreifen hat demnach keinen wesentlichen Einfluß auf das Farbabstands-Ellipsoid.

5. Ein weiterer Einwand gegen die gewählte Beobachtungstechnik könnte aus der Verwendung einer bestimmten Referenz-Differenz resultieren, die bei 1. - 4. in Richtung gelber, stumpfer lag. Deshalb wurden mit einer Referenz in Richtung heller weitere 28 Beobachtungssätze durch 14 Beobachter ausgeführt. Gegen die Gesamtdaten mit der ersten Referenz ergab sich V= 0,04, die Richtung der Referenz-Differenz spielt hier also keine Rolle.

6. Um mit der hier dargestellten Methodik vergleichbare Ellipsoide in allen Bereichen des Farbraumes ermitteln zu können, muß noch der bisher offen gelassene Parameter für die Ellipsoidgrößen ermittelt werden. Der einfachste Weg wäre die Abmusterung aller Ellipsoide gegen eine einzige Referenz-Differenz, z.B. gegen ein graues Referenzpaar statt der bisher verwendeten roten Referenz.

Mit 26 Beobachtungssätzen durch 13 Beobachter mit einem grauen Probenpaar als Referenz-Differenz ($Y= 12, \Delta E= 2,2$) ergab sich wie erwartet eine höhere Streuung der visuellen Urteile. Das resultierende Ellipsoid wird durch diese Art der Abmusterung aber nicht wesentlich verändert (Abb.1). Mit V= 0,06 gegen die Serie mit der ersten roten Referenz-Differenz ist die Abweichung wieder nicht größer als bei einer normalen Wiederholungsserie.

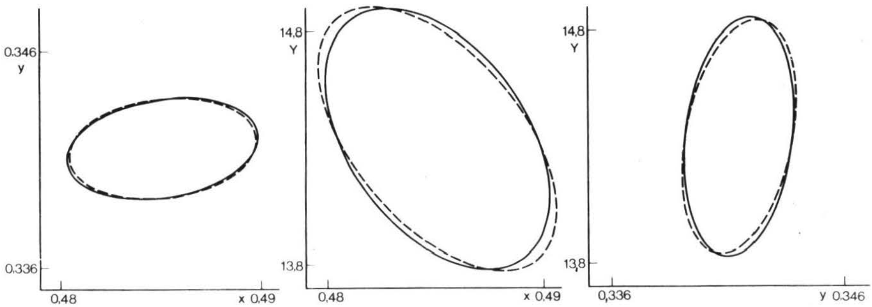

Abb.1 Schnitte durch die beiden Ellipsoide mit der roten (———) bzw. grauen (- - - -) Referenz-Differenz.

Die Ermittlung eines befriedigend genauen Farbabstands-Ellipsoids erfordert also 20-30 Beobachtungssätze durch ca. 10 Beobachter an etwa 50 Proben, sowie die zugehörige Computer-Auswertung. Der Bezug aller Ellipsoide auf ein einziges graues Referenzpaar erscheint möglich. Ein so ermitteltes Ellipsoid ergibt einen mittleren Fehler der Farbabstände unter 10%, bei einem Farbabstand von 1,0 also kleiner als 0,1.

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Die ausführliche Fassung dieser Arbeit wird in der Zeitschrift "Applied Optics" veröffentlicht.

Klaus Witt und Günter Döring, Berlin:

Schwellenwertellipsoid für CIE-Farbbereich Grün an Lackmustern

According to the CIE guidelines for coordinated research on colour-difference evaluation a range of 60 green painted colourpairs (average tristimulus values for light source D65: x_{10} = 0,2514, y_{10} = 0,3638, Y_{10} = 24,30) has been chosen for first experiments. The ellipsoid of colour-difference perceptibility has been estimated by direct comparison of colourpairs for 25 observers. Some parameters influencing the result (mathematical model, groups of observers) are discussed.

En considérant les règles que la CIE a établies pour la coordination des investigations des problèmes de l'évaluation des distances des couleurs on a déterminé l'ellipsoïde différentiel pour un groupe de 60 paires d'échantillons vernis verts (mesures moyennes pour l'illuminant D65: x_{10} = 0,2514; y_{10} = 0,3638; Y_{10} = 24,30); on a fait ces expériences avec 25 observateurs et par comparaison directe des couleurs. On discute quelques influences, comme du genre du modèle mathématique ou des groupes d'observateurs.

Im Rahmen der von der CIE angeregten koordinierten Untersuchungen zur Problematik der Farbabstandsbewertung wurde an einem Satz von 60 Lackprobenpaaren im Farbbereich Grün (mittlere Farbmaßzahlen für Normlichtart D65: x_{10} = 0,2514, y_{10} = 0,3638, Y_{10} = 24,30) das Schwellenwertellipsoid für direkten Farbvergleich von 25 Beobachtern bestimmt. Verschiedene Einflußgrößen (Art des mathematischen Modells, Beobachtergruppen) werden diskutiert.

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Im Rahmen der von der CIE vorgeschlagenen koordinierten Untersuchungen zur Farbabstandsbewertung {1} wurden Sätze von hochglänzenden Lackmustern mit kleinen Farbunterschieden um die 5 Sollfarben herum ausgefärbt. Die visuellen Arbeiten begannen mit dem Farbbereich Grün, über deren erste Ergebnisse hier berichtet werden soll.

Material: Für die Herstellung von Farbmustern wurde ein Zweikomponenten-Acryllack verwendet, wie er in der Autoreparaturbranche eingesetzt wird. Die auf Karton aufgerakelten Lackproben wurden später zur besseren Planlage auf Aluminiumblech aufgeklebt. Für die Ausfärbungen auf Sollfarbbereich wurde die Farbrezepturberechnung ausgenutzt, mit deren Hilfe eine gute Streuung der Farbörter der Proben in der Nähe der Sollfarbe erreicht wurde. Die Farbmessungen erfolgten an einem Spektralphotometer der Firma Zeiss (DMC 25) mit einer Meßgeometrie 45/0 bei farbmetrischer Auswertung für den 10^{o}-Normalbeobachter und Normlichtart D65.

Insgesamt standen 54 Farbmuster zur Verfügung, deren Farbabstände ΔE-CIELAB zwischen 0 und maximal 5 {2} betrugen. Aus diesem Satz wurden 60 paarweise Kombinationen ausgesucht, deren Farbabstände von 0,05 bis 1,14 Einheiten reichten bei einigermaßen gleichmäßiger Berücksichtigung aller Richtungen im Raum der Normvalenzen. Aus ihren Farbmaßzahlen errechneten sich folgende Mittelwerte mit Standardabweichungen:

$$x_{10}=0,2514 \pm 0,0010, \quad y_{10}=0,3638 \pm 0,0011$$
$$Y_{10}=24,30 \pm 0,45$$

Die Farbmaßzahlen der Proben wurden vor, während und nach der visuellen Abmusterungsserie bestimmt.
Zur visuellen Abmusterung stand eine Abmusterungskabine der Firma AEG zur Verfügung, die mit zwei Xenon-Hochdrucklampen bestückt war. Die Anpassung der Strahlungsquelle an Normlichtart D65 war im sichtbaren Spektralgebiet nach CIE-Empfehlung {3} als gut einzustufen. Die Beleuchtungsstärke in Probenhöhe betrug ca. 1900 lx. Die Proben wurden auf einen 45^{o}-Bock gelegt, so daß sie unter 45^{o} beleuchtet und unter 0^{o} abgemustert wurden.

Methode: Die Proben wurden paarweise auf den Abmusterungsbock mit unmittelbarem gegenseitigen Kontakt gelegt und mit einem grauen Karton (Y_{10}=19,6) großflächig abgedeckt, der zur Aussparung eines 10^{o}-Gesichtsfeldes ein kreisförmiges Loch für ca. 30 cm Beobachtungsentfernung hatte. Die Probentrennlinie halbierte das Gesichtsfeld.
25 normalsichtige Beschäftigte der Bundesanstalt für Materialprüfung (6 weiblich, 19 männlich) im Alter von 24 bis 59 Jahren, mehr oder weniger erfahren mit visuellen Abmusterungen, dienten als Versuchspersonen. Ihnen wurden die 60 Probenpaare vorgelegt mit der Frage, ob ein Farbunterschied zu erkennen sei. Als Entscheidungshilfe wurden ein Nullprobenpaar mit verschwindend geringem Farbunterschied

und ein Probenpaar mit bereits deutlich erkennbarem Farbunterschied vorgelegt, bevor die erste Serie begann. Auf Wunsch wurden sie erneut bei späteren Serien gezeigt. Insgesamt hatte jeder Beobachter 4 mal den vollständigen Probensatz abzumustern, dessen Reihenfolge randomisiert war und von einem Versuchsleiter verändert werden konnte. Hierbei wurde darauf geachtet, daß die rechte und linke Lage der Proben eines Paares von Serie zu Serie vertauscht wurde.

Auswertung: Für jeden Beobachter und jedes Probenpaar wurde die Zahl der Ja-Urteile festgehalten. Ein nicht-parametrischer Friedman-Test auf Homogenität der Beobachterurteile ergab mit $P < 0{,}001$ eine hohe Signifikanz für Inhomogenität. Die bei diesem Test ermittelten Rangzahlen für die Beobachter wurden verwendet, um die Variabilität von Beobachtergruppen zu untersuchen.
Entsprechend den CIE-Empfehlungen {1} wurden aus den beobachteten Häufigkeiten der Ja-Urteile und den gemessenen Differenzen Δx, Δy, ΔY der zugehörigen Probenpaare unter Annahme einer logistischen Wahrscheinlichtsverteilung und Anwendung der Maximum-Likelihood-Methode Ellipsoidparameter berechnet. Das zur Optimierung verwendete mathematische Programm nutzt keine Ableitungen aus. Es führte nicht zu Konvergenzschwierigkeiten, wie sie an anderer Stelle für die Maximum-Likelihood-Methode angegeben wurden {5}.
Das Ergebnis für die Ellipsoidparameter des vollen Datensatzes lautet:

$g_{11} = 725\,000$ $\quad g_{22} = 684\,600$ $\quad g_{33} = 11{,}09$
$g_{12} = 193\,900$ $\quad g_{13} = -\,40{,}63$ $\quad g_{23} = -\,534{,}8$
$\alpha = 1{,}672$

Bei einem Vergleich der Ergebnisse mit denen, die über ein Gauß-Verfahren gewonnen werden, konnten keine bedeutsamen Unterschiede festgestellt werden.
Wegen der Inhomogenität der Beobachterurteile schien es wichtig zu sein, den Einfluß von Beobachtergruppen auf das Ergebnis zu untersuchen. Hierzu wurden die nach Rangzahlen extremen Beobachter ausgesondert und 4 5er-Gruppen gebildet, die von schwach zu scharf urteilenden Beobachtern rangierten. Die Ellipsoidparameter für die am schwächsten urteilende Gruppe lauten:

$g_{11} = 524\,100$ $\quad g_{22} = 478\,400$ $\quad g_{33} = 6{,}482$
$g_{12} = 162\,300$ $\quad g_{13} = -\,146{,}8$ $\quad g_{23} = -\,406{,}2$
$\alpha = 2{,}288$

Das gleiche Ergebnis für die am schärfsten urteilende 5er-Gruppe ist:

$g_{11} = 1\,000\,000$ $\quad g_{22} = 1\,190\,000$ $\quad g_{33} = 17{,}48$
$g_{12} = 58\,870$ $\quad g_{13} = -\,145{,}7$ $\quad g_{23} = -\,1077$
$\alpha = 1{,}444$

Entsprechend verändern sich die Ellipsenformen in der xy-Ebene von einer Exzentrizität von 1,4 auf 1,11 und in der xY-Ebene von 229 auf 237 bei allgemeiner Schrumpfung der Ellipsengröße und Drehung der Ellipsenachsen.

In einer anderen Arbeit {5} wurde die Wahrscheinlichkeitsfunktion für Nein-Urteile als standardisierte Gaußsche Dichtefunktion angesetzt, die mit einem multiplikativen Faktor für irrtümliche Ja-Urteile versehen war. Da die Irrtumswahrscheinlichkeit dort erhebliche Werte bis zur Größenordnung von 0,5 erreichte, sollte auch dieser Ansatz überprüft werden. Es zeigte sich bei dem Vergleich der fehlerbehafteten Dichtefunktion mit der logistischen Funktion, daß für alle 25 Beobachter die Varianz der Daten bei logistischer Funktion etwas niedriger lag, daß aber bei Untersuchung der obigen Beobachtergruppen die am schärfsten urteilende 5er-Gruppe mit entsprechend höherer Irrtumswahrscheinlichkeit der Ja-Urteile eine geringfügig niedrigere Varianz für die standardisierte Dichtefunktion aufwies. Weitere Befragungen zum Paarvergleich sind begonnen worden.

Danksagung: Herrn P. Otto sei gedankt für seine Mithilfe bei der Farbmusterherstellung, Herrn Dipl.-Math.D. Amthor für Hilfe bei der Bewältigung der mathematischen Probleme und dem Großrechenzentrum für die Wissenschaft in Berlin für die Bereitstellung von Rechenzeit an der Rechenanlage TR 440. Weiterhin sei allen Beobachtern für ihren bereitwilligen Einsatz gedankt.

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Andrew Neil Chalmers, Department of Electronic Engineering, University of Natal, Durban **and Christoffel Johannes Kok,** National Physical Research Laboratory, C.S.I.R., Pretoria (South Africa):

The Durban Daylight Spectrum

Measurements were made of global, diffuse sky and direct solar radiation at Durban over the wavelength range 295 to 770 nm. CIE chromaticity coordinates and correlated colour temperatures have been calculated and are quoted in this paper. The normalized ultraviolet and blue spectral values were found to be higher than many of those reported for the Northern hemisphere. The Durban spectral power distributions for correlated colour temperature 6 500 K show considerably higher shortwave content than CIE illuminant D65.

On a exécuté des mesures du rayonnement global, de la lumière diffuse du ciel et du rayonnement direct du soleil à Durban dans la région spectrale de 295 à 770 nm. De ces mesures on a calculé les coëfficients trichromatiques et la température correspondante de couleur; ces valeurs sont communiquées ici. Les portions de l'UV et du bleu sont plus grandes que l'on les connaît de l'hémisphère Nord. Pour la température correspondante de couleur 6500 K les valeurs de rayonnement sont considérablement plus hautes que chez l'illuminant-standard D65 de la CIE.

Es wurden Messungen der Globalstrahlung, des diffusen Himmelslichtes und der direkten Sonneneinstrahlung in Durban über das Spektralgebiet von 295 bis 770 nm gemacht. Daraus wurden die Normfarbwertanteile und die ähnlichste Farbtemperatur berechnet; die Ergebnisse sind hier mitgeteilt. Die Anteile an UV und an blauer Strahlung liegen höher, als sie für die nördliche Halbkugel angegeben werden. Für die ähnlichste Farbtemperatur 6500 K liegen die spektralen Strahlungswerte beträchtlich höher als bei der CIE-Normlichtart D65.

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A.N.Chalmers and Chr.J.Kok

Introduction:

A project to measure the UV and visible spectral irradiance of global and diffuse daylight and direct sunlight over a one-year period was undertaken at Durban, the geographical location of which is at sea level, latitude 30° South, longitude 31° East. (Kok, Chalmers and Turner 1979). Measurements were made of the spectral irradiance of daylight on a horizontal plane in the 295-770 nm wavelength range. These continued over an active period of some twelve months between April 1976 and June 1977.

Some 250 sets of usable spectral measurements were obtained and they included measurements taken at various times of the day (except within two hours of sunrise and sunset) and through all the seasons of the year. There were, however, fewer than average sets of readings taken during the spring since windy and rainy conditions prevail in Durban at this time of the year: and there were more than average taken during the autumn when fine weather tends to prevail. Also, the autumn months of April, May and June were included twice (i.e. in both 1976 and 1977).

Results and Discussion:

The CCT, CIE chromaticity and UV content of a number of typical forms of daylight are given in Table 1. The UV content has been expressed in terms of milliwatts of ultraviolet radiation per 100 lumens of light flux, a measure that appears to be meaningful in conservation studies, and is useful here for purposes of comparison. It is seen that the integrated UV content of daylight at Durban is some 12% higher than that given by the CIE D-illuminants.

Over the twelve months of the experiment, the range of daylight spectra measured at Durban yielded CCT's between about 5 500 K and 22 000 K. The average locus of chromaticities, when plotted on the CIE 1931 (x,y) diagram, is somewhat above (i.e. to the green side of) the full radiator locus. However, it is closer to the full radiator curve than is the CIE TC-1.3 curve. (Judd, MacAdam & Wyszecki 1964). It is notable that very few of the measurements yielded daylight chromaticities between CCT's 6 500 K and 7 500 K, while a significant number gave CCT's close to 5 800 K and above 8 000 K. The high incidence of CCT's greater than 8 000 K may be partly attributed to the generally cloud-free atmosphere of Durban during the autumn and winter months when the greater proportion of observations was carried out. During summer, when Durban has a high incidence of cloud cover, relatively few readings were taken owing to rainy conditions and equipment breakdowns. Nevertheless, there are sufficient grounds to suggest that a daylight SPD of 10 000 K (for south sky) might be more appropriate for colour grading and assessment than CIE D_{65} for local conditions. However, it is recognized that worldwide uniformity should be exercised wherever possible.

The relative SPD of global horizontal irradiance (at least for wavelengths above 340 nm) was found to be largely independent of the position of the sun, except for very large zenith angles. As zenith angle increases (and, with it, the air mass) the direct solar SPD becomes 'more red' but the contribution of the diffuse sky irradiance (with its relatively high blue content) becomes a larger proportion of the total irradiance, thereby 'balancing' the global SPD. Increasing cloud cover caused a considerable decrease in the CCT of the diffuse sky radiation but the presence of clouds had far less influence on global SPD's. Even so, the lowest CCT's measured were for heavily overcast skies.

An important finding was the fact that the Durban results show considerably higher normalized values for wavelengths from 300 to 450 nm than those obtained previously by some workers in the Northern Hemisphere. However, they are not as high as those reported for an earlier series of observations that were made at Pretoria (Winch, Boshoff, Kok and Du Toit 1966). Possible explanations for these discrepancies relate to: (a) the altitude and latitude of each observation site since these factors affect the average air mass: (b) the variation of the atmosphere's ozone content with latitude since ozone is responsible for UV absorption, particularly below 330 nm: and (c) the method of sampling the daylight for spectroradiometric measurements. With reference to this last point, it should be noted that both the Durban and Pretoria measurements made use of integrating spheres with good cosine correction to measure the irradiance on a horizontal surface. In this way, no part of the sky was screened or shielded. Recent measurements of the daylight spectrum in Australia (Dixon 1978) show good agreement with the South African measurements of relative ultraviolet content.

The colorimetric importance of this finding lies in the fact that the spectra of the CIE standard daylight illuminants may require revision to make them more fully representative of the actual properties of daylight. The enhanced UV and blue values that were found to be present in the Durban daylight spectra would certainly be noticeable in the case of fluorescent materials, and should properly find a place in any mathematical or physical model of daylight, as it is difficult to accept that local daylight SPD's are inherently different from those elsewhere on this planet.

Acknowledgements:

We acknowledge the cooperation of the University of Natal in kindly making available the roof of the Electrical Engineering Building as a measurement site and we thank Prof. H.L. Nattrass of the University and Dr. R. Turner of the C.S.I.R. for their encouragement and assistance in this work.

Colorimetric research at the University of Natal is supported by a research grant from the Council for Scientific and Industrial Research whose assistance is gratefully acknowledged.

TABLE 1 : PROPERTIES OF SOME TYPICAL FORMS OF DAYLIGHT

Type	Chromaticity x	y	UV content (mW/100 lm)
Durban Average Global 5 780 K	0,3269	0,3387	
Durban Direct Solar 4 975 K for m = 2	0,3470	0,3564	
Durban 6 500 K	0,3133	0,3262	67,2
Durban 7 500 K	0,2998	0,3132	89,8
Durban 10 000 K	0,2791	0,2918	121,3
CIE D-55	0,3324	0,3475	39,4
CIE D-65	0,3127	0,3290	60,0
CIE D-75	0,2990	0,3150	80,3

Data for CIE D-illuminants extracted and calculated from Wright (1969).

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María L.F. de Mattiello and Miguelina Guirao, Laboratorio de Investigaciones Sensoriales, Consejo Nacional de Investigaciones Cientificas y Técnicas, Facultad de Medicina, UBA, Buenos Aires (Argentina):

Saturation Contours at Different Levels of Illuminance

The influence of illumination on the perception of coloured samples was measured by numerical estimation and by matching judgments. Blue, green, yellow and red samples were presented at three levels of reflectance and at nine levels of illumination. The data collected in 108 experiments were used to draw a map of equal saturation contours. The increment of illumination affects saturation in different ways depending on the hue and levels of reflectance.

L'influence de l'illuminance sur la perception d'échantillons colorés a été mesurée par une estimation numérique et par des comparaisons. On a présenté des échantillons bleus, verts, jaunes et rouges dans trois niveaux de réflexion et dans neuf niveaux d'illuminance. On a utilisé les dates qu'on a gagnés avec 108 expériences pour dessiner des courbes de saturation égale. Une élévation de l'illuminance influence la saturation dans des degrés différents qui dépendent de la tonalité et du niveau de réflexion.

Der Einfluß der Beleuchtungsstärke auf den Farbeindruck von Körperfarben ist durch zahlenmäßige Schätzung und Vergleiche untersucht worden. Blaue, grüne, gelbe und rote Proben wurden in drei verschiedenen Helligkeitsstufen und bei neun verschiedenen Beleuchtungsstärken vorgelegt. Die in 108 Experimenten gewonnenen Ergebnisse wurden benutzt, um Kurven gleicher Sättigung zu zeichnen. Eine Steigerung der Beleuchtungsstärke beeinflußt die Sättigung in verschiedener Weise je nach Farbton und Helligkeitsstufe.

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In a previous work we analyzed the influence of different levels of reflectance and illumination on the amount of color of pigmented surfaces (1). In that study we presented 108 experiments showing that perceived purity grows as a power function of colorimetric purity. The exponents of those functions varied with changes in both reflectance and illumination A close examination in the change of exponents lead us to the following conclusions: low exponents were observed at the mesopic range for hues falling into the range between 460 and 620 nm. At median levels of the photopic range values kept relatively unchanged suggesting a region of constant saturation. At high levels, the exponents fell abruptly at 1700 lux indicating a possible limit of the cromatic photopic range.

In order to verify if, in fact, power function with the same exponent are related to constant saturation, we performed an experiment in which we used a matching procedure.

The samples were the same as in the previous experiments - blue 460 nm, green 510 nm, yellow 580 nm and red 620 nm - at three levels of reflectance -12,40 and 65%R- and at nine different levels of illumination - 2.4, 23, 300, 500 , 800 , 1000, 2000 and 3400 lux.

This time, the task of the Os was to compare samples of the same hue and to point out the ones that were equal in the amount of colour. In this way we were able to normalize the data in twelve sets of power functions from which it was possible to draw constant saturation contours at various levels of illumination. The resulting contours of constant saturation, scaled in cromes, are represented in the figure: 40 cromes (solid lines), 20 cromes (dashed lines), and 10 cromes (pointed lines).

At first glance the general shape of the contours seems to suggest that the increment of illumination increases saturation up to an approximate value of 1000 lux. Above this value saturation seems to keep constant. However, if we disregard the interpolated data at 40 cromes, we can see that the effect of illumination is not so important and it is practically negligible in the greens at 40 and 65 %R, in the reds at 65% R and in all the blues.

It can also be observed that, at a given value of crome and level of illumination, saturation grows with the increment of reflectance. Yellows are an exception.

Furthermore, if we observe the distance between one contour and the other, we can deduce that the range of purity is larger for yellows and greens than for blues and reds . This difference in the range of purity might be indicating a correlation between perceptual responses and the typical opponency red-green and blue-yellow, in the visual receptors. In brief, the increment of illumination affects saturation in different ways depending on hue and levels of reflectance.

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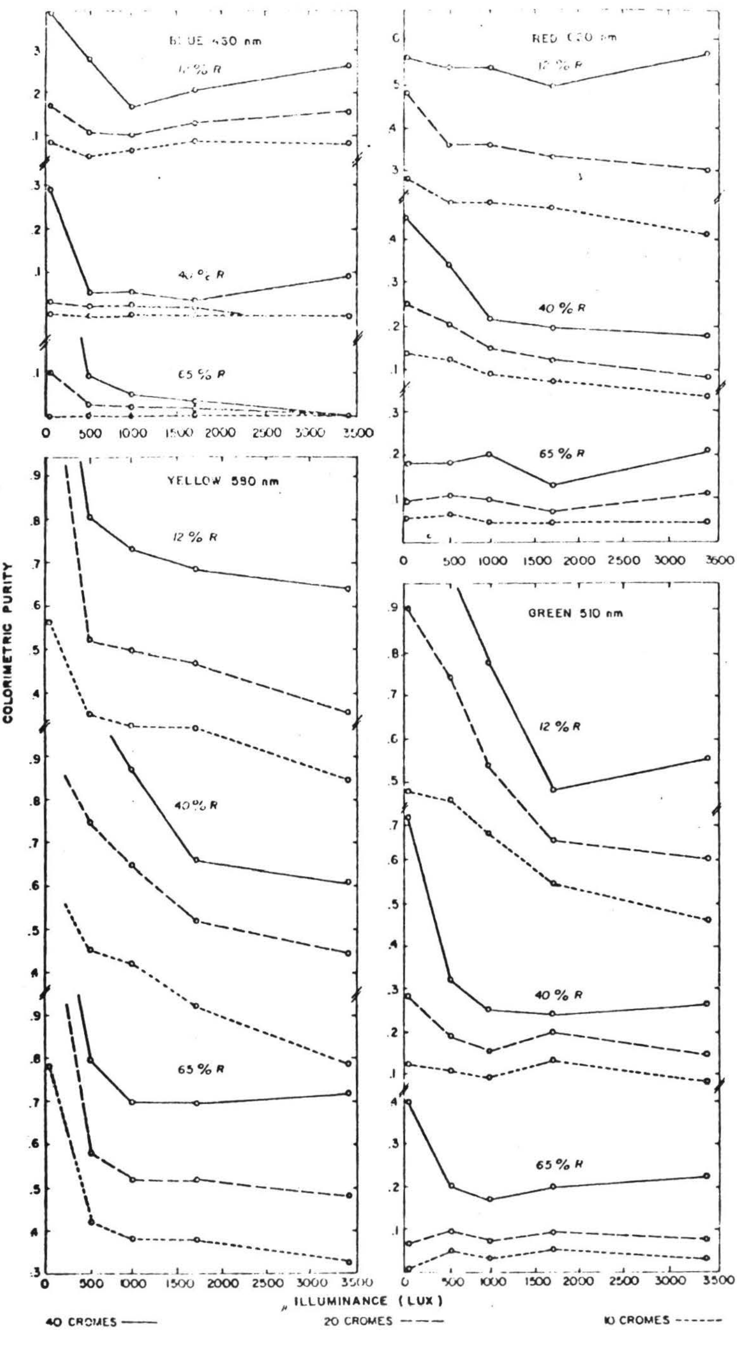
This paper will be published in full in the Journal of the Optical Society of America


BLUE 450 nm
40 % R
65 % R
RED 630 nm
12 % R
40 % R
65 % R
YELLOW 590 nm
12 % R
40 % R
65 % R
GREEN 510 nm
12 % R
40 % R
65 % R
COLORIMETRIC PURITY
ILLUMINANCE (LUX)
0
500
1000
1500
2000
2500
3000
3500
40 CROMES
20 CROMES
10 CROMES

Witold Chróścicki, Warszawa (Polska):

Visual and Instrument Evaluation of Lightness of Colored Surfaces with Different Light Sources

Comparison of the results of instrument measurements of the reflection factor performed with 'real' lighting conditions with the results of visual estimation of the lightness of the same colored samples obtained with the same lighting conditions indicates that the results of both evaluations (relative to daylight) show a high degree of correspondence.

La comparaison des résultats des mesures instrumentales du facteur de réflexion effectués dans des conditions d'éclairage réelles avec les résultats d'estimation visuelle de clarté des mêmes échantillons de couleur, des estimations réalisées dans les mêmes conditions d'éclairage, démontre que les résultats de deux genres d'estimation (par rapport à la lumière du jour) se distinguent par un haut degré de convergence.

Der Vergleich der Ergebnisse instrumenteller Messungen des Reflexionsgrades mit denen der visuellen Bewertung (der Helligkeit) zeigt unter ‚tatsächlichen' Beleuchtungsbedingungen, daß die Ergebnisse beider Meßmethoden relativ zur Messung mit Tageslicht denselben Kurvenlauf und für jede farbige Probe ein hohes Maß an Übereinstimmung zeigt.

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Nowadays the lightness/reflection factor of colored surfaces is an important factor in lighting technology, particularly in interior lighting. We utilize it in an interior to control the luminance distribution, to state the indications of seeing comfort, etc. Since more than 95 per cent of the lightness estimations in our everyday life are visual, not instrumental, we feel a necessity for formulation, on a scientific basis, of laws which combine visual estimation with instrument measurement.

Today we state that: (i) measurement results of a reflection factor of one and the same colored sample are often different depending on the measuring method employed; (ii) comparison of the results of instrument measurement of the reflection factor with the results of visual estimation of the lightness of the same sample also reveals great divergences. These divergences result primarily from two conditions: a. currently used measuring methods are based on the isolation of the measured sample from its surroundings (seeing-angles of measuring instruments are 1-4°). By these means we eliminate the influence of surroundings on accuracy of measurement, but simultaneously we introduce artificial conditions of estimation, which do not exist in normal perception of colored surfaces; b. measuring instruments are calibrated with standardized lighting conditions, while ordinarily we estimate colored surfaces with normal light sources (incadescent lamps, fluorescent lamps, etc and natural daylight) and with very different quantitative and qualitative parameters of lighting. The divergences between the results of instrument measurement of the same colored sample, performed under standardized laboratory conditions and measurements taken with 'real' lighting conditions are very great. These two factors - the influence of the surroundings and the influence of light character - cause very great visual changes in the color of the evaluated surfaces. These color changes are called 'relative changes' since they do not have physical form and until now they have not been instrumentally measured. The investigations discussed in this paper concentrated only on the change in the lightness/reflection factor of colored surfaces with different light sources (normally used for interior lighting) and with two general methods of evaluation: visual and instrumental.

In our investigations we assume, among other things, that: (i) natural light (daylight) is the 'standard' and the reference point for results of instrument measurement as well as the results of visual estimation; (ii) the grey scale is the reference point for results of visual estimation. Introduction of the grey scale as 'standard' for lightness is justified because the visual estimation of the lightness of grey samples is in practice constant, and is independent of the spectral character of light. Similarly the reflection factor of grey samples with different measuring methods and with light of different spectral character is also in practice constant, whereas the reflection factor of colored samples has until now been measured with small accuracy (with systematic error from one to several dozen per cent, depending on the method of measurement). Also the lightness of colored samples with visual estimation is different with different light sources.

The basic investigations are based on: (i) Observers (about 80 students) employing visual estimation established the lightness of a given colored sample with reference to a grey value, by comparison with the grey scale using daylighting ca 1000-3000lx and different artificial lighting (incadescent ca 400lx; fluorescent ca 500lx; mercury ca 1000lx and candle ca 10lx).(ii) Next we performed instrument measurements of the reflection factor for the same colored samples and with the same lighting conditions (as visual estimation). (iii) Next we compared the results (of visual estimation and of instrument measurements), obtained with different artificial lighting, with the results (of visual estimation and of instrument measurements) obtained with daylight, as a standard.

Results obtained.

1. Comparison of the results of instrument measurements performed with 'real' lighting conditions (not in standardized laboratory conditions) with the results of visual estimation obtained with the same lighting conditions indicates that the results of both evaluations (relative to daylight) follow the same graphic curve, i.e. the variations of estimated (lightness) and measured (reflection factor) values of the same colored samples show a high degree of correspondence. For example, with incadescent lighting, the lightness (visual estimation) as well as the reflection factor (instrument measurement) of all the orange red and purple hues produced greater values than with daylighting (neutralization of color into white). On the other hand, with the same lighting conditions the lightness as well as the reflection factor of all the blue, blue-green and green hues, produced lower values than with daylighting (neutralization of color into black). A similar agreement of the results of visual estimation with the results of instrument measurements for particular color hues was also obtained for fluorescent and mercury lighting.

2. The quantitative differences between the results of instrument measurement obtained with different artificial light sources (in relation to daylight) exceeded 10 per cent and the results of visual estimation for particular observers, even 20 per cent.

3. Comparison of the results of visual estimation obtained with incadescent lighting (ca 400lx) and with candle lighting (ca 10lx) indicates the same change of lightness for particular color hues and this means that of decisive significance here is the spectral character of lighting, not the illuminance.

4. Knowing the theoretical principles, we can prognosticate the direction of change in the lightness (reflection factor) of the colored surface when we know the spectral character of the light source which illuminates it.

Tomas Hård, Stockholm (Schweden):

Procedure in Production Control of Samples for the NCS Colour Atlas

Based on nominal values in CIE-X Y Z paints for 1412 NCS-colours were produced from reference-standards and coated on paper.

Sur la base des valeurs trichromatiques nominales on a coloré 1412 échantillons du système NCS sur papier.

Auf der Grundlage der Soll-Farbwerte wurden 1412 Farben des NCS nach Vorlage auf Papier ausgefärbt.

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When starting production of samples for the NCS Colour Atlas only a few perfectly correct standards were available according to the NCS-CIE NOMINAL specification.

The manufacturer was given a standard-sample that represented an approximate value of what was wanted. The sample was measured and its correct NCS-coordinates were calculated from X, Y, Z via the INVERS-program, and the deviation from NOMINAL-value was given together with acceptable tolerances, specified in the standard publication.

A special control-diagram was designed and acted as a communication between the Scandinavian Colour Institute and the manufacturer.

The first MIX from the manufacturer was measured, converted to NCS-coordinates and plotted in the control-diagram and instructions for adjustments given.

When finally falling within acceptable tolerans the paint was coated on paper and the result controlled once more. One example of this procedure is given in the figure next page.

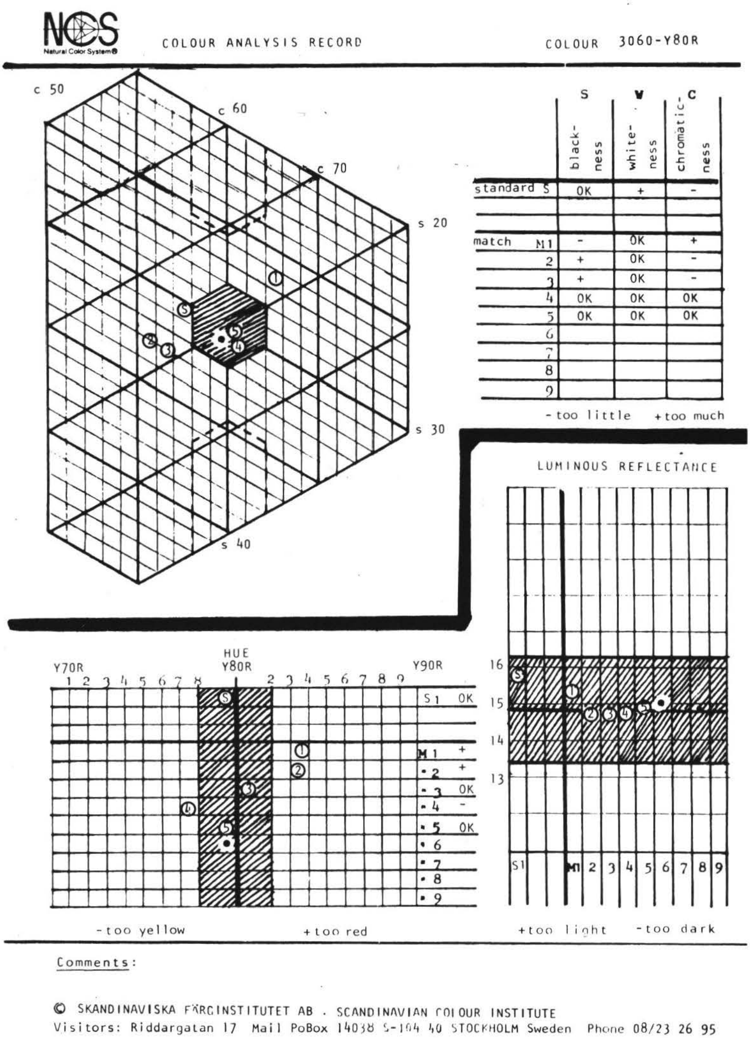

Fig Control-diagram with plotting of

Ⓢ sample sent as standard

① first mix

② second mix

etc

● control value of coating

colour-tolerance

David H. Alman and Charles G. Pfeifer, Troy (Michigan):

Use of Response Surface Techniques to Develop Empirical Models of Color Difference Perception

A Box-Behnken response surface experiment design was used to develop an empirical model of commercial color difference perception behavior as functions of CIE 1976, L*, a*, and b* variables for a light saturated blue color. The model can be viewed as a series of ellipsoided surfaces of varying rejection frequency in the L*, a*, b* space.

A l'aide de la méthode de Box-Behnken on a développé, pour un bleu clair et saturé, un modèle de l'attitude aux différences de couleurs comme fonction de l'espace des couleurs CIELAB (CIE 1976). On peut regarder ce modèle comme une série de surfaces d'ellipsoïdes dans l'espace CIELAB des couleurs.

Mit Hilfe des Box-Behnken-Verfahrens wurde ein empirisches Modell des kommerziellen Verhaltens gegen Farbunterschiede als Funktion des CIELAB-Farbenraumes (CIE 1976) für ein sattes Hellblau entwickelt. Das Modell kann als eine Reihe von Ellipsoiden-Oberflächen im CIELAB-Farbenraum aufgefaßt werden.

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RESPONSE SURFACE METHODOLOGY

In general, we are trying to develop an understanding of how a response such as frequency of color acceptance, color difference scale value, or color difference category value varies as functions of the independent color variables. For color difference experiments these color variables could be 3 dimensional color values such as X, Y, Z or color difference values from a standard like ΔX, ΔY, ΔZ or some transformation of these values. In the absence of an exact theoretical model relating the response of interest to the color variables we can develop an empirical model of the response as a function of the variables to obtain a useful local understanding of how the response behaves over the range of the experimental variables. Using CIE 1976 ΔL^*, Δa^*, Δb^* coordinates[1]:

(1) $$\text{Visual Response} = f(\Delta L^*, \Delta a^*, \Delta b^*)$$

Often a useful approximation to the true response can be found using a polynomial model. For a full quadratic polynomial this model is:

(2) $$\text{Visual Response} = C_0 + C_1 \Delta L^* + C_2 \Delta a^* + C_3 \Delta b^* + C_4 \Delta L^* \Delta a^* + C_5 \Delta L^* \Delta b^* + C_6 \Delta a^* \Delta b^* + C_7 (\Delta L^*)^2 + C_8 (\Delta a^*)^2 + C_9 (\Delta b^*)^2$$

The task is now one of designing the experiment so that the color values are chosen in a manner to provide maximum accuracy in the estimation of the coefficients with the minimum of experimental effort. A Box-Behnken[2] response surface design provides efficient fitting of the empirical model to the visual response data. The geometric relationship of the experimental variables is illustrated in Figure I. All of the points excepting the counterpoints are at the middle of the edges of a cube and are all equally distant from the center and thus lie on a spherical surface. If greater precision is needed, the design can be augmented by using additional levels of the variables on spherical surfaces concentric to the original design.

Once the color levels have been determined, the experiment proceeds by preparing samples at the specified design values, determining response values for each sample and fitting the coefficients of the polynomial model by multiple linear regression. Then for a designated value of visual response one determines the locus of color values associated with that response.

APPLICATION TO COMMERCIAL COLOR TOLERANCES

We wish to develop an understanding of how commercial color acceptability varies with color difference values for a specific color standard. In the work reported here the standard was a light saturated blue color ($L^* = 57.$, $\Delta a^* = -11.$, $\Delta b^* = -25.$) Our experience over many years with L,a,b type color difference equations has shown that they are a good first approximation to difference perception over a wide range of commercial situations. In certain cases, however, the tolerance situation for a specific color may require modification of the basic color difference relationship to individually weight the three color difference dimensions (ΔL^*, Δa^*, Δb^*) or to move the position of the center of the color tolerance specification to a point offset from the color standard. Our study was undertaken to determine how best to accomplish this empirical improvement to the color tolerance.

The samples were prepared to form three levels of ΔL^*, Δa^*, Δb^* spherical surfaces designed to be nominally 0.25, 0.50, and 0.75 color difference units from standard. Additional samples prepared from the same mixture as the standard were used to check the experimental centerpoint. It was not possible to place the samples exactly at the design point but the overall properties of balanced sampling with respect to distance and direction were maintained. Five experienced color-normal observers each made 10 judgements of commercial acceptability of the samples as matches to the standard in a MacBeth booth under daylight illumination. The observer's task was to categorize each sample as acceptable or unacceptable. The color difference from standard was determined from reflectance data on a 45/0 spectrophotometer and was integrated for Illuminant C and the 2° observer. The independent variable inputs for the modeling were the ΔL^*, Δa^*, Δb^* values.

The visual acceptability data for each sample was pooled to obtain values of frequency of rejection. All samples which were rejected universally (frequency of rejection, f = 1.0) were deleted before performing the multiple linear regression. The fit equation is:

$$\text{(3)} \qquad F = 0.43 + 0.14\,\Delta L^* - 0.06\,\Delta a^* + 0.01\,\Delta b^* + 0.11\,\Delta L^*\Delta a^* + 0.02\,\Delta L^*\Delta b^* + 0.62\,\Delta a^*\Delta b^* + 0.54\,(\Delta L^*)^2 + 1.02\,(\Delta a^*)^2 + 0.45\,(\Delta b^*)^2$$

BOX-BEHNKEN RESPONSE SURFACE DESIGN

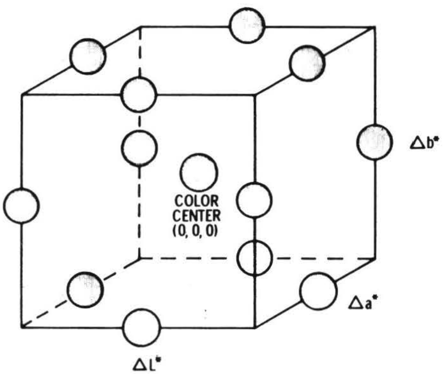

Figure I - The arrangement of the experiment points in the Box-Behnken design.

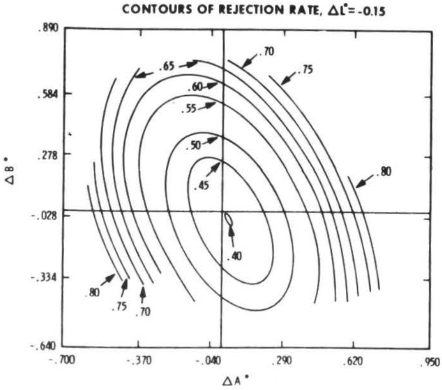

Figure II - Contour plot of the empirical model of rejection frequency as functions of Δa^* and Δb^* at $\Delta L^* = -0.15$.

The equation fit the experimental data quite well ($r^2 = 0.804$). The empirical color rejection model leads to some interesting results. Inspection of the regression coefficients for the squared terms indicates that the $(\Delta a^*)^2$ term is about twice as important as $(\Delta L^*)^2$ or $(\Delta b^*)^2$ in determining commercial acceptability for the color standard used. The crossproduct terms indicate a significant interaction between Δa^* and Δb^*. Finally taking the partial derivatives of the equation with respect to ΔL^*, Δa^*, and Δb^* and then solving the resulting system of simultaneous linear equations shows that the centroid of the color tolerance model is at:

(4) $\Delta L^* = -0.14$ $\Delta a^* = 0.05$ $\Delta b^* = 0.04$

A small offset of the color tolerance specification toward darker colors would be expected to improve acceptability. A contour plot of the model as functions of Δa^*, Δb^* at $\Delta L^* = -0.15$ is shown in Figure II. The $\Delta a^* \Delta b^*$ interaction and the greater influence of Δa^* relative to b^* are clearly indicated.

In the development of experimental knowledge one frequently is at a stage where the important variables influencing a response are known but an adequate theoretical model of the system has not been discovered. In this case, response surface techniques are an effective way of developing empirical models of a system.

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Akira Kodama, Takeshi Yano and Tetsuo Yanase, Tokyo (Japan):

A Research for Evaluation of Color of Structures Suitable for the Environment

Applying the Color Simulator, we made realistic color slides for the evaluation of the environmental impact of structures such as rolling stocks of trains, and big bridges, and made a study on the suitability of various colors with the Semantic Differential Method (SD Method). When the actual structures do not exist yet, we combine the pictures as if they do exist, then apply the Color Simulator. This method makes it possible to evaluate the environmental suitability of colors for those structures with a high degree of confidence.

A l'aide du „Color Simulator" nous avons produit des diapositives réalistes pour évaluer l'effet sur l'ambiance de structures telles que des trains en marche ou de grands ponts; avec ces diapositives nous avons étudié la validité des divers coloris en appliquant la méthode sémantique différentielle. Quand de telles structures n'existent pas encore, nous combinons des images comme si ces structures existaient et nous y avons appliqué le Color Simulator. Ce procédé rendait possible l'évaluation de la compatibilité de ces structures avec l'ambiance à un haut degré de certitude.

Mit Hilfe des „Color Simulator" haben wir realistische Lichtbilder für die Bewertung der Wirkung auf die Umgebung für Gebilde wie fahrende Eisenbahnzüge und große Brücken herstellen können, an denen wir die Eignung der verschiedenen Farbgebungen mittels der Semantischen Differential-Methode studiert haben. Wo solche Gebilde noch nicht existieren, haben wir Bilder so kombiniert, als ob diese Gebilde existierten und darauf den Color Simulator angewendet. Dieses Verfahren ermöglicht die Beurteilung der Umwelt-Verträglichkeit dieser Gebilde mit großer Zuverlässigkeit.

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1. Introduction

The Japan Color Research Institute developed the Color Simulator as an instrument to aid the process of color design.

The Color Simulator is a large slide projection system combined with a number of consecutive color light transmission projectors using the mechanism of the parallel projection method through one light path by additive color mixtures. In this system, the image is combined on the screen, and then it is possible to change the color of a part of the image freely. For example, it is able to change the color of an automobile body, while the color of the background, the unpainted part of the automobile, the luster of the painted parts, the shadow of the body color, and the reflection of the surroundings are maintained as they are.

Although we have studied many types of industrial goods, interiors, textiles, make-up, architectural structures, scenery, etc. with the application of this Color Simulator, we would like to report only the study of the evaluation system of suitable colors by the application of the Color Simulator on rolling stocks of trains, big bridges, etc. in the environment in which they operate or exist.

2. The Study of Environmentally Suitable Colors for the Rolling Stock of the Shinkansen Line.

In Japan at the present time, in addition to the Tokaido and Sanyo Shinkansen line, the Tohoku & Joetsu Shinkansenline is under construction and has reached the stage of construction of the rolling stock. In the Tohoku and Joetsu area in winter, the background is snowy most of the time, and we wanted to evaluate whether the current Shinkansen trains' ivory and blue combination would be suitable or not, or if there is any other more suitable color combination for the rolling stock in this Tohoku and Joetsu area environment.

Initially, with the Color Simulator, we made a number of various color combinations of the studied rolling stocks, and combined the pictures with the greenish scenery and snowy scenery, and then projected them on the screen with the Color Simulator. Changing the color combinations on the image (eg. red means stripe, white means body, and red-ivory means the body is ivory and the stripe is red), and taking the pictures of these combinations, we made 30 different slides. Then, we showed these slides to a survey audience, and the image research was carried out by the Semantic Differential Method.

The SD Scale Value is 10 pairs of contrasting adjectives as shown on the chart. The suitability of various color combinations for the rolling stock of the Shinkansen is thus evaluated for the proposed new environment. The survey audience was 134 students of Tohoku Institute of Technology, Iwate University, and Nagaoka Technical College located in the Tohoku and Joetsu area.

Collecting the results of the evaluation, we obtained the coefficient of correlation from the SD scale value average of the survey audiences' opinion. Then with this we did a factor analysis by the principal factor analysis method. As a result, two important factors emerged. Factor I, factor of activity was the "beautiful-desirable" factor, and as Factor II, the "gay-warm" factor emerged. With these two factors as axis, the chart was made locating each S.D. scale by factor loading. In this way, the color combination of the rolling stocks of Shinkansen trains were evaluated with two dimensions of semantic space. The factor scores of respective simulations were extracted to find out how the 30 color combination simulations were to be located in the semantic space, and the factor scores were plotted on the chart.

With this chart, it is evident that the most desirable and most appropriate color combination for the Tohoku and Joetsu area is the "cream color body and green stripe". This color combination against the scenery, is quiet, brings out the analogic harmony, and the image difference with a greenish or snowy scenery remains small.

Conspicuous color combinations of contrasting harmoney, such as the color combination of "ivory color body with red stripe" or "white body with red stripe." However, in a greenish scenery environment, the ivory body is not very conspicuous. In the simulation, there were 8 color combinations with the mark of (N) which was the body with strong colors and a stripe of white. But the evaluation revealed those color combinations were conspicuous, undesirable, and not aesthetic.

3. The Study of the Color Combination of Large Bridges

The color of large structures such as major bridges effect greatly on the environment. Using the Kanmonkyo Bridge between Shimonoseki City and Moji City as a case in point, we studied various color combinations. The bridge is a suspension bridge. Initially, 68 colors were selected and pictures were taken to make color slides. Using these as simulations, we made image surveys by the SD Method. For SD Scale, we used 25 variations of colors which we thought more suitable for a large bridge. The survey group in this case was a group of 30 university students.

By means of factor analysis, we extracted evaluation factors such as "good, desirable, harmonious" as Factor I, and negative factors such as "conspicuous, noisy" as Factor II, and reliable factors such as "clear, reliable" as Factor III.

In this semantic space, finding the location of the respective SD scale with factor loading, we came to the conclusion that there are 2 different kinds of evaluations such as 1) more evaluation with quiet and natural color and 2) conspicuous and beautiful. Also, we learned that plotting the respective colors by their factor score, the colors are plotted near their own tone of color. For example, a grayish tone is evaluated as quiet while a pale tone is evaluated as gay and beautiful.

For the bridge color simulation, there are various methods such as to combine the pictures of the location of bridge construction with a model bridge. When exactness is required, the bridge design is traced with a computer, and combined with the picture of the location. With these combined pictures, we can examine the color in advance as if the bridge is built. With these methods, we have been making evaluations of environmentally suitable color combinations.

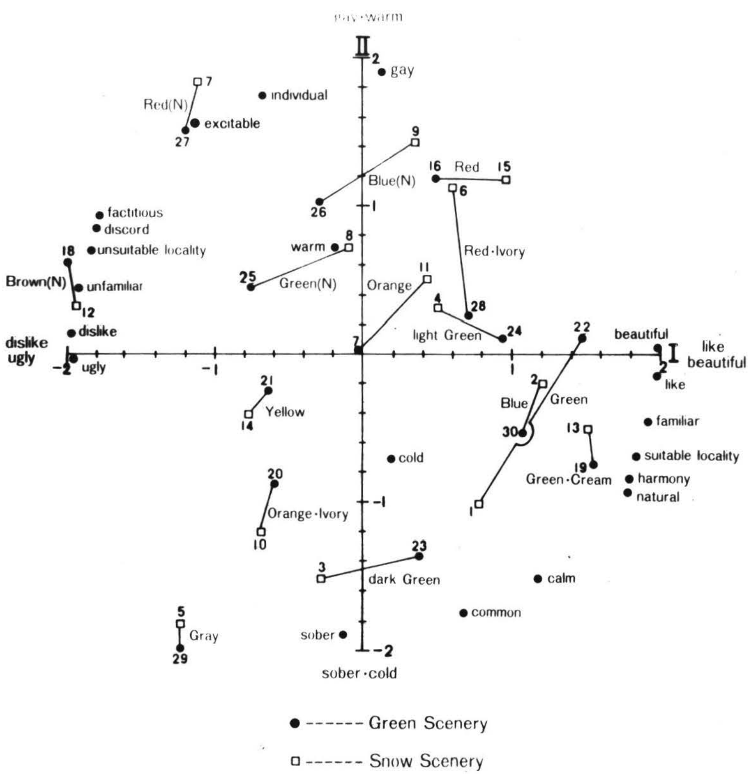

Figure: Location of SD Scale and Color Combination on the Semantic Space

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Po39

Sadao Nakamura, Osaka (Japan):

A Spectral Characteristic and Classifications of Color Arrangements

The spectral reflectance curve of the entire area of each multicolor arrangement can be characterized by the four reflectances at the wavelength ranges near the principal wavelengths of the four primary colors. From the reflectances, the characteristic spectral pattern is derived as the value which represents chromaticness of color arrangements.

La courbe spectrale de la réflexion d'une aire totale d'un arrangement multicolore peut être caractérisée par les quatre valeurs de réflexion à longueurs d'onde près de celles des quatre couleurs primaires. On peut dériver de ces réflexions la courbe spectrale comme la valeur représentant la chromatie d'un arrangement.

Die spektrale Reflexionskurve der Gesamtfläche eines vielfarbigen Musters läßt sich durch die Reflexionswerte in vier Wellenlängen-Gebieten kennzeichnen, die nahe denen der vier Grundfarben liegen. Aus diesen Reflexionswerten kann man die charakteristische spektrale Kurve ableiten als den Wert, der die Buntheit der Farbanordnung darstellt.

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Multicolor arrangements have a specific spectral characteristic. We firstly found it by measuring the entire area of each reproduction of paintings with a filter-type spectrophotometer. In the diagram, the thick curves show the spectral reflectance curves of three paintings; curve M for Leonardo's Mona Lisa, curve S for Monet's Sunflower, and curve W for Monet's Water Lily. The two thin curves show those computed for arrangements composed of four pure colors of same size; curve A for an arrangement of yellow, red, ultramarine blue, and sea green and curve B for one of red, ultramarine blue, sea green, and leaf green. These reflectance curves show that they can be characterized by reflectance at four wavelength ranges; two flat parts in the ranges of red and blue, the maximum in green range, and the minimum in yellow range. We describe the reflectances as R_B, R_G, R_Y, and R_R and corresponding wavelengths as W_B, W_G, W_Y, and W_R. Then let us consider reflectances of the four primary colors. Red show high R_R, yellow high R_R and R_Y, green high R_G, and blue high R_B. Because blue is lower in lightness than the other colors, R_R is highest, R_Y and R_G high, and R_B lowest for the four-color arrangement. Both thin curves for four-color arrangements, which include complementary colors especially of red and green, show the spectral characteristic of multicolor arrangements. Areas of light colors such as yellow are generally small in paintings and color arrangements. Curve B is made by replacing yellow of the arrangement for curve A with leaf green. The arrangement for curve B contains less amount of yellow and more amount of green than for curve A. Curve B is very close to those of the paintings.

Curve S is higher than curve M and curve W is the highest of the three thick curves. It is due to lightness difference among paintings. Then we transform the four reflectances by the equations

$$C_B= R_B/Y,\ C_G= R_G/Y,\ C_Y= R_Y/Y,\ C_R= R_R/Y,$$

where Y is the tristimulus value Y. The value Y is employed as the equivalent reflectance for the mean lightness of the entire area of each sample. The new values are called the characteristic spectral values (CSV) and may be evaluated as ones for chromaticness of color arrangements. We draw a level line, along which W_B, W_G, W_Y, and W_R are marked at equal intervals. Corresponding CSV values are plotted. Drawing the line joining the CSV values, we obtain a pattern, which is N-shaped for multicolor arrangements and is called the characteristic spectral pattern (CSP).

By analyzing the shape of CSP, we have classified colors and color arrangements. Two methods have been conducted to derive the specific parameters relating to the shape. As the first method, a regression line is computed by CSV values. Its inclination m represents the cold-warm degree. We describe the perpendicular deviations of CSV values from the line as d_B, d_G, d_Y, and d_R. For multicolor arrangements, d_B and d_Y are generally negative and d_G and d_R positive, so that we derive the modified mean deviation δ from the equation $\delta=(-d_B+d_G-d_Y+d_R)/4$, which may represents richness in color for color arrangements. In the δ, m diagram, we have classified 60 paintings of six artists whom F. Birren says as the great colorists. In the same diagram, pure colors draw a characteristic concave quadrange, close to whose vertices the four primary colors are situated.

For the second method, we modify CSP pattern. Retaining proportion of an original CSP pattern, the CSV values are modified by equalizing the lowest value to zero and the difference between the highest value and the lowest one to unity. The new pattern has approximately a same shape among same hue colors. For color arrangements the pattern may have a same shape among arrangements of same color tone. So, it is called the characteristic colortone pattern (CTP) and the modified CSV values are called the characteristic color-tone values (CTV), which are described as c_B, c_G, c_Y, and c_R. The shape of CTP is also N-shaped for multicolor arrangements. We derive the two parameters relating to the shape of CTP. They are defined by the equations $rg = c_R - c_G$, $yb = c_Y - c_B$. The value rg is the difference of the high pair of CTV values and the value yb that of the low pair. In the rg, yb diagram, which is called the color-tone diagram, we have classified pure colors and about 200 paintings of four great impressionists.

The color-tone diagram is divided radially by hue names, because single colors are situated circumferentially such as a color circle. Color tones of multicolor arrangements come close to the center of the diagram. Whether an arrangement is of a multicolor type or of small numbers divides the diagram peripherally. This division can be made by analyzing the three inclination angles of segments of CTP.

Antal Nemcsics, Budapest (Ungarn):

Farbenharmonie-Versuche

The results of our experiments have been expressed by the color specification in the Coloroid System. The most important and fundamental condition for a color harmony sensation is the specification of the colors by means of a color-sensation system. To produce a color harmony, the complementarity is not important but the luminosity and the saturation of the colors.

On a exprimé les résultats de nos expériences dans le système Coloroid. La condition la plus importante et fondamentale pour produire une sensation d'une harmonie des couleurs, c'est la spécification des couleurs dans un système des sensations des couleurs. Pour la production de la sensation d'harmonie la complémentarité ne joue aucun rôle important, mais la luminosité et la saturation des couleurs.

Die Ergebnisse unserer Versuche wurden in das Coloroid-System eingeordnet. Die wichtigste Grundbedingung für die Entstehung einer Farbharmonie-Empfindung ist die Möglichkeit einer zahlenmäßigen Einordnung der einzelnen Farben in ein empfindungsgemäßes Farbsystem. Für die Entstehung des Harmonie-Erlebnisses spielt die Gegenfarbenbeziehung keine wichtige Rolle, wohl aber die Helligkeit und Sättigung der Farben.

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Der Erlebnisinhalt der Farbenharmonie ist aus verschiedenen Komponenten aufgebaut. Diese Komponenten testehen aus den Farben der Komposition, aus der diese Farben enthaltenden Umgebung und aus dem Verhältnis des in dieser Umgebung lebenden und die Farben beobachtenden Menschen. Dieses Verhältnis ist um so allgemeiner, für je mehr Menschen eine identische Situation ein identisches Harmonieerlebnis bedeutet. Laut des Grades der Verallgemeinbarkeit des aus dem Verhältnis folgenden Harmonieinhaltes können verschiedene Niveaus des Harmonieinhaltes unterscheiden werden.

Es wurden von mir drei aufeinandergebaute Niveaus des Farbenharmonie-Inhaltes bestimmt. Das erste Niveau befindet sich an der Stufe der Wahrnehmung. Es enthält jene Zusammenhänge, die für jeden Menschen entscheidend identisch sind, die vor allem aus dem Prozess der Farbenentfindung folgend und die mit grundlegenden psychophysikalischen Geschehen zu erklären sind. Das zweite Niveau des Farbenharmonieinhaltes umfasst die Wirkung der wahrgenommenen Farbenkomposition auf das Psychikum und Physikum des wahrnehmenden Menschen.

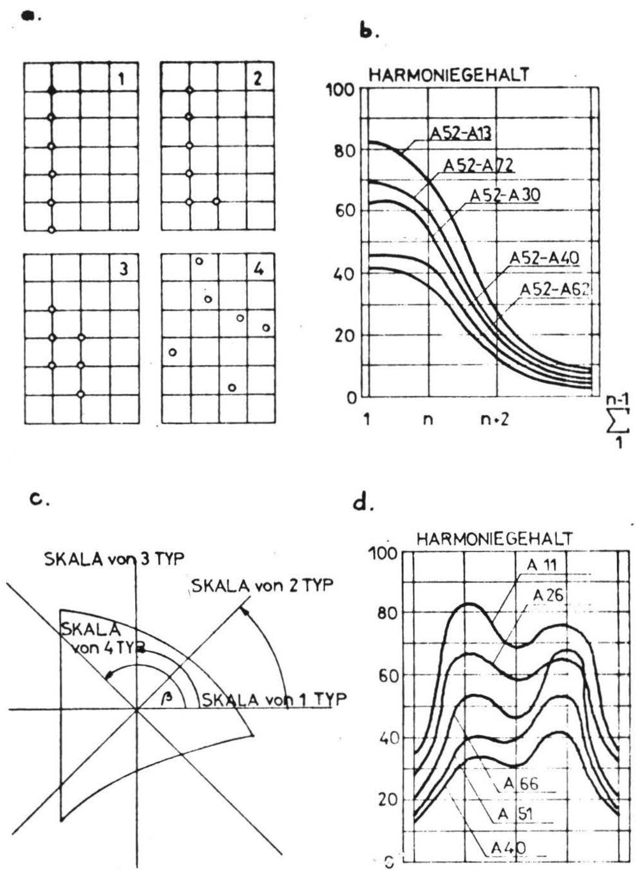
Die dritte Stufe des Farbharmoniegehaltes bringt die Wechselwirkung von Farbe - Mensch - Umwelt zum Ausdruck und bedeutet, da3 in der Ausgestaltung des Harmonieerlebnisses die räumliche Lage der Farben des Komplexes, ihr gegenseitiges Verhältnis, die Beleuchtung und die Gebrauchsfunktion der farbenträgenden Flächen eine wichtige Rolle spielen.

Farbharmonieversuche werden an der Technischen Universität seit 15 Jahren durchgeführt. Aus diesen sollen hier zwei Versuchsreihen der Untersuchungen in Verbindung mit der harmonieschaffenden Rolle der Ordnung in einer Skala beschrieben werden. Die Skalenartigkeit wurde bezüglich der auf die Harmonieintervalle des Coloroid-Farbensystems aufgebauten, ästhetisch gleichmässigen Sättigungs- und Helligkeitsskalen definiert. Eine skalenartige Harmonie wird von jener Farbenkomposition gebildet, für deren Glieder die ihre Sättigungen und Helligkeiten angebenden Coloroid-Messzahlen in arithmetische oder geometrische Reihe geordnet werden können.

Im Rahmen der ersten Versuchsreihe wurde einerseits untersucht, wie weit der Ordnungsgrad der Farben das Entstehen des Harmonieerlebnisses beeinflusst, und anderseits, wie sich die Rolle der in der vorangehenden wissenschaftlichen Literatur üver Harmonie als wichtigster harmonieschaffender Faktor beurteilten Komplementarität zur Rolle der Skalenartigkeit verhält.

Wenn der Ordnungsrad durch die Zahl der die Plätze der Farben in der COLOROID-Farbenebene verbindenden Geraden ausgedrückt, und die Zahl der in der Komposition teilnehmenden Farben mit n bezeichnet wird, dann bezeichnen die Glieder der untenfolgenden Ordnungsskala bezüglich jedes Farbtonpaares die Ordnung der Farben in der Farbebene der aus je 6 Farben bestehenden Kompositionen:

Laufnummer der Komposition:	1.	2.	3.	4.
Ordnung der Skala:	1.	n.	n+2,......	$\sum_{1}^{n-1}$



Graphische Illustration der Farbenauswahl und der Ergebnisse von Versuchen über die Bedeutung der Anordnung in einer Skala:

a. Ordnungskale der Farben der zur ersten Versuchsreiche gehörenden Kompositionen. Horizontale symbolisieren identische Helligkeiten, Vertikale identische Sättigungen, Punkte die Farben der Kompositionen.
b. Ergebnisse der ersten Versuchsreihe. Die Grösse des Harmonieinhaltes nimmt mit abnehmender Ordnung der Skalen ab.
c. Skalen von verschiedenem Typ in der zweiten Versuchsreihe in einem Axialschnitt des Coloroid-Systems.
d. Ergebnisse der zweiten Versuchsreihe. Der Harmonieinhalt ist von Typ der Skalen abhängig.

Die Aufarbeitung der Ergebnisse ergab die folgenden Zusammenhänge:

- Die geordneteste Skala erwies sich als die harmonischeste. Mit Abnahme der Ordnung nahm der harmonische Charakter der Kompositionen jäh ab.

- Die Komplementarität spielt in der Hervorrufung des Harmonieerlebnisses keine primäre, entscheidende Rolle, doch trägt sie zur Vertiefung des durch die Skalenartigkeit ausgelösten Erlebnisses bei.
- Die Komplementarität ist zur Auslösung des Harmonieerlebnisses unfähig, wenn die Helligkeiten oder Sättigungen der Farbenkomponenten nicht skalenartig geordnet sind /Abb. 1 a, b/.

In der zweiten Versuchsreihe unserer Forschungen wurde untersucht, in welchem aufeinander bezogenem Masse die Skalen von verschiedenem Charakter der Farben verschiedener Tönungen eine harmonische Wirkung auslösen.

Im Interesse einer Verallgemeinbarung wurden die Skalen auch durch die Grösse ihrer Verdrehung, , von der horizontalen Sättigungsskala um den Gewichtspunkt der COLOROID-Farbenebenen charakterisiert. /Abb. c, d/.

Nach Verarbeitung der Ergebnisse konnte folgendes festgestellt werden:
- Die COLOROID-Helligkeit spielt eine grössere Rolle in der Ausbildung der Harmonie, als die COLOROID-Sättigung.
- Jene Skalen sind die harmonischsten, in denen sich nicht nur die coloroide Helligkeit, sondern auch die coloroide Sättigung ändert.
- Skalen die aus Farben von spezifischer heller coloroiden Tönung bestehen, sind harmonischer, wenn sich ihre Helligkeit und Sättigung in der selben Richtung ändern.
- Skalen die aus Farben von spezifischer dunkler coloroiden Tönung bestehen, sind harmonischer, wenn sich ihre Helligkeit und Sättigung in entgegengesetzter Richtung ändern.

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Péter Gáborjáni, Budapest (Ungarn):

Sensation of Colouring Linked with Materials

The different materials used for surface in architecture change the physiological and psychological sensation of the colouring. The modification of the diverse surface structures in accordance with senses at the characteristic points of the colour solid was revealed in our experiments in the CIE system.

Les différents matériaux de construction, utilisés pour le traitement de surface, changent la perception physio-psychologique des couleurs. Nous avons démontré, dans le système CIE, une modification de la sensation des structures superficielles différentes dans les points caractéristiques du corps colorant.

Durch die verschiedenen baulichen Oberflächen-Gestaltungsstoffe wird die physiologisch-psychologische Perzeption der Farben geändert. In unseren Versuchen wurde im CIE-System die empfindungsgemäße Änderung der unterschiedlichen Oberflächenstrukturen in charakteristischen Punkten des Farbkörpers nachgewiesen.

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I. At Budapest Technical University an analytic test series has been begun, by decomposing architectural surfaces according to different viewpoints. Essentials of our method consisted in making life-size or reduced models of a building surface element and exposing them to light effects corresponding to those in real architectural environments. Measurements were completed by physiologic and psychologic tests. Results have been plotted in diagrams. This can be a means to improve the building products, to overcome inherent monotony of standardization, in final account to solve townscape problems.

II. Two, strictly related topics of my report are:

- Ways of use of natural colour effects of architectural surfacing materials;
- Visual effect of the surfacing material as a function of hue.

An important problem of architecture today is monotony due to standardization. Namely, up-to-date building technologies, industrial products are overwhelming against handicraft or site prefabrication.

Though, this technology cannot still produce surfaces equivalent to those of other industrial or crafts products. Besides economy, this fact has also conceptual causes. Building industrialization has opened up two ways for design, depending on the production features, i.e. those of mechanization and of automation, decisive also for trends of surfacing.

Building industry based on mechanization.

-is featured by integration, coherence of design and production. Essentials of design are related to industrial production, and the design process ends when the production starts, namely the production apparatus has created essential preconditions of standard designing, adaptation. Three consecutive phases in the building industry based on mechanization are: design - production - assembly.

Building industry based on automation.

is featured by desintegration between design and production. Essential requirements of design are related to industrial production, i.e. directly to technology,

and the design process starts together with the production, since the production apparatus created essentially the preconditions of design for variation. Thus, in a building industry based on automation, the order of three phases changes into:
production - design - assembly.

Building automation raises the design freedom to the qualitatively higher level of industry by translating it to computer language, corresponding in fact to the recognized necessity of this era.

Also as concerns the architecture, industrial revolution brought about changes in the relation between building materials industry and building industry. Automation of the building industry /in particular, for mass construction/ has much affected surfacings, namely repeated building parts have to make aesthetic effects, to express architectural ideas. Though, conditions are different. Units for mass production are to be designed at the care and scientific thought needed to meet changed but stressed aesthetic standards. Texture and colour varieties of surfacings may contribute to enforce the principle of "low number of units - high-grade variability".

Our experiments have supported the following assumptions:

1. The architect is creating the building by means of space and mass shaping true to destination. He selects the most convenient material to this work /production, design/, the entity of which produces the architectural effect. Viewed at a certain proximity, architectural surfacings are decisive because of certain physiological effects on man.

Essentials of the building are space, mass, and the structure /material/ concretizing them, but in a certain phase of perception, surface texture, colour are decisive; this phenomenon becoming prevalent at close view, even inside.

2. The visual effect of the surface referred to is related to the texture of the given surfacing material.

Via the surface texture, "natural" materials give a hint on the internal structure of the material, namely tools, machines used in processing leave imprints depending on the resistance or acommodability of the material, characteristics resulting from inherent properties depending, in turn, on molecular or atomic structure. Hence, surface textures, carriers of natural hues, result from the natural features of the material.

These features are decisive because of the return of the fashion to leave materials inaltered, but even for coloured materials, the texture carrying the colour is of importance. Coloured ceramics, fire-clay, plastics or aluminium have different visual effects.

Textural effects are those combined of the natural texture of the material, its processing, natural or coloured hue.

Light-shadow effects result from pattern, surface processing. Surface effects are also affected by the order of magnitude relations between the textural pattern and the size of the given surface.

Texture lends peculiar dynamics to colour, and vice versa, colour may enhance textural effects.

3. The final object of our experiments is to create a standard, an aid to designers and producers, likely to designate optima for various materials and surface textures as a function of illumination quality /monochromous or mixed light, spotlight or diffused light/
illumination intensity and
illumination direction /for outer surface depending on the daytime/.

Our experiments included the visual verification of the influence of colour to enhance or reduce placticity values, and on texture effects /grain, unevenness etc./

III. Conclusion: Any surfacing can be reduced to a few fundamental texture elements. Making them into models using different materials offers a visual means of testing the charecter of a given texture on a product of a given colour, or the right hue to be given to a surface in view of illumination alternatives.

Illuminations were attempted to reproduce daylight; for given materials and incidences, surfacings were observed to have dynamic or static effect depending on illumination or colouring with either high-frequency or long-wave light.

P.Gáborjáni

For surfaces of a heterogeneous material composition, determination solely by wavelength is insufficient, namely spectral energy distribution results in great many, alien reflections, in these cases the texture has to be re-determined /superposition/.

Results have been illustrated graphically, presenting at the same time the given surface texture.

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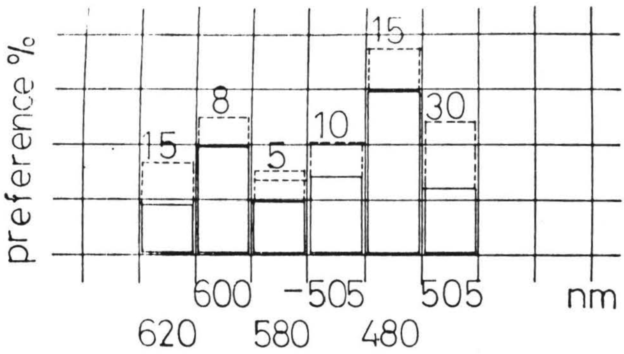
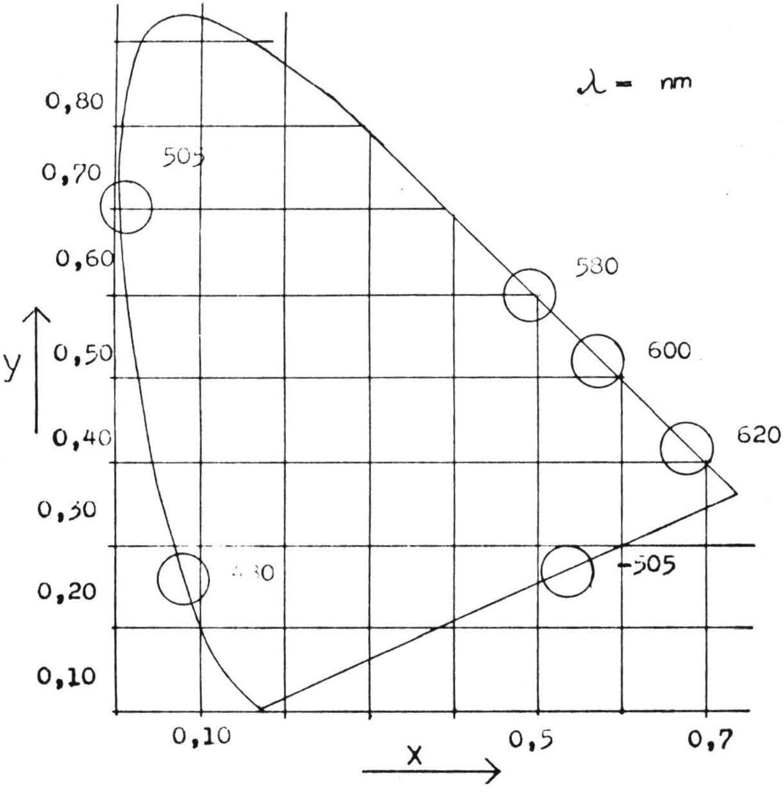


1. Modification of original surface with coloring



2. Chosen Colours in the CIE-Diagram

Per G. Rasmussen, Vancouver (Canada):

The Perceived Weight and Contrast of Colors in Pictures

Specially constructed color pictures were used to investigate commonly accepted artistic notions of "perceived weight" and „contrast". The results showed that the effects of hue were negligible, but that both value and chroma contributed significantly to the pleasingness of the perceived weight and contrast arrangement of colors.

On a examiné les notions usuelles des artistes „importance perçue" et „contraste". On a trouvé que l'effet de la tonalité est négligeable, mais que la luminosité aussi bien que le chroma contribuent significamment à l'agréabilité de l'arrangement de l'importance perçue et du contraste.

Speziell entworfene Farbbilder dienten der Untersuchung der bei den Künstlern üblichen Begriffe „Gewichtung" und „Kontrast". Dabei hat sich gezeigt, daß die Wirkungen des Farbtons vernachlässigbar sind, daß dagegen sowohl Helligkeit wie Buntheit wesentlich zum Gefallen der Gewichts- und Kontrastanordnung der Farben im Bild beitragen.

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Several artistic notions about color deal with an alleged preference for a particular type of arrangement of the dimensions of color. As examples, it is usually thought that pictures which are darker at the bottom than at the top and darker in the left half than in the right half are more pleasing than pictures with the opposite construction. The reason for this phenomenon is generally thought to be due to "apparent weight" of colors: pictures which are heavy at the bottom and in the left part are supposed to be more pleasing than pictures which are heavier at the top and in the right hand part. Alexander and Shansky [1] did a series of experiments with single colors which showed that perceived weight is a decreasing function of value and an increasing function of chroma. Hue, however, did not seem to lend itself to classification in terms of apparent weight.

Arnheim [2] notes the crucial distribution of lights and darks in pictures, but as far as chroma is concerned, no firm rules seem to exist. However, taking into account the single color study cited, it might seem reasonable to equate a picture area of intense chroma with a low (dark) value and a less intense area with a high (light) value. Thus, pictures with more intense colors at the bottom and in the left part should be more pleasing than pictures with the opposite configuration.

The color dimension of hue, in the form of the artistic notion of "color temperature", might also be included as a factor in assessing apparent weight of color components in a picture. One might adopt Itten's [3] scheme of designating colors in the YR-R region as warm, colors in the BG-B region as cool, and those in the middle GY-P region of the Munsell space as neither warm nor cool. According to this, one would expect that, since warm colors tend to advance (and to impress themselves more prominently on the viewer) and cool ones to recede, warm colors will display more apparent weight than cool colors. Thus, pictures with warm colors at the bottom and in the left part should be more pleasing than pictures of contrary construction.

The test

To test these accepted artistic notions, a series of 4 inch square pictures in the form of 32x32 matrices was constructed, with individual elements made up of glossy Munsell papers. The colors were selected in such a way that the complete series of 80 pictures had predominance in 5 hues (5YR, 5RP, 5PB, 5BG, 5GY), 2 values (light, dark), 2 chromas (strong, weak), in addition to 4 motifs (face, landscape, buildings, abstract). Each picture was assessed in terms of its top, bottom, left and right half, and averages of value, chroma and perceived temperature of the picture elements within these areas were calculated. Also, a contrast measure which took into account the numerical values of individual elements, related one element at a time to its neighboring elements, and was expressed in terms of the variance within a test area, was used. It was here termed "adjacent variance". The rationale for this measure was the fact that artists in many cases use a technique of contrasts to achieve pictorial balance, and that the measure of averages might not capture this procedure.

As part of the response measure, a dimension termed "pleasure" [4] was used. It is a composite of several polar opposite concepts (such as happy-unhappy, hopeful-despairing, etc.) and can be regarded as an affective type of preference measure in contrast to a more cognitive type of aesthetic judgement.

The presentation of the pictures was made to a group of 82 university students (41 males and 41 females ranging in age from 18 to 28 years). The illumination was daylight with a corrected color temperature of 5500°K and a magnitude of 450 lux.

Results

Both linear and quadratic step-wise regression analyses were carried out using the predictor variables of top/bottom value, chroma and temperature (T/B-V, T/B-C and T/B-T), left/right value, chroma and temperature (L/R-V, L/R-C and L/R-T), and adjacent variance value, chroma and temperature (ADV-V, ADV-C and ADV-T). The linear equation was as follows:

$$\text{Pleasure} = 1.189 \times \text{T/B-V} - 3.345 \times \text{T/B-C} - 10.646 \times \text{ADV-C} + 6.763.$$

The quadratic equation was:

$$\text{Pleasure} = 1.070 \times \text{T/B-V} - 3.649 \times \text{T/B-C} + 173.185 \times \text{L/R-C} - 85.454 \times (\text{L/R-C})^2 + 1.103 \times \text{ADV-T} - .349 \times (\text{ADV-T})^2 - 85.544.$$

Table 1 shows the partial correlations and the variance accounted for by these two equations, and figure 1 shows the results schematically (blank spaces indicate lack of significance).

	Linear		Quadratic	
Term	Partial correlation	Per cent variance	Partial correlation	Per cent variance
T/B-V	.33	11.1	.32	8.1
T/B-C	-.29	7.7	-.31	8.1
ADV-C	-.26	5.5		
L/R-C			-.03)	14.5
L/R-C^2			-.38)	
ADV-T			-.16)	7.9
ADV-T^2			-.34)	
Total		24.3		38.6

Table 1 Partial correlations and per cent variance accounted for by linear and quadratic equations.

The results showed that the top/bottom arrangement of colors is a very important one to the pleasingness of a picture, at least as far as value and chroma are concerned. The effects of hue (as assessed through perceived color temperature) is not clear. The left/right arrangement is important only insofar as chroma is concerned, whereas the contrast of both chroma and temperature elements make a marked difference to how pleasing subjects judge a picture to be.

Color component	High pleasure	Low pleasure	Variable
Value	Bottom dark	Top dark	T/B-V
			L/R-V
			ADV-V
Chroma	Bottom intense	Top intense	T/B-C
	Right intense	Left intense	L/R-C
	Low contrast	High contrast	ADV-C
Temperature			T/B-T
			L/R-T
	Low contrast	High contrast	ADV-T

Figure 1 Most and least pleasing arrangement of value, chroma and perceived temperature.

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Brigitte Jäkel-Hartenstein, Kusterdingen:

Die sogenannte „Farbenblindheit" der Haustiere

The methods for investigation of color vision of animals are considered critically. A new training method for dogs is described which enables everybody to test how his dog is seeing colors. One dog has been dressed, by this method, to discriminate chromaticities, another to lightness differences.

Les méthodes pour l'examen de la vision des couleurs des animaux sont examinées critiquement. Une méthode nouvelle de dressage des chiens est décrite, avec laquelle chacun peut examiner comment son chien aperçoit les couleurs. Avec cette méthode, un chien a été dressé à discriminer des chromaticités, un autre, à distinguer des différences de clarté.

Die Methoden der Untersuchung des Farbensehens der Tiere werden kritisch betrachtet. Eine neue Dressurmethode für Hunde wird beschrieben, mit der jeder Hundehalter prüfen kann, wie sein Hund Farben sieht. Ein Hund wurde damit auf Farbton und Sättigung dressiert, ein anderer auf Helligkeit.

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In den Massenmedien und populärwissenschaftlichen Schriften wird häufig behauptet, unsere Haustiere, insbesondere die Hunde, seien farbenblind. DieseAnsicht vertreten auch einige wissenschaftliche Arbeiten, während es zahlreiche wissenschaftliche Veröffentlichungen in den letzten 100 Jahren gegeben hat (1), in denen ein Farbensehen für Haustiere beschrieben wurde. Auf folgende Methoden stützten die Verfasser dabei ihre Untersuchungsergebnisse:

1) Bau des Auges: Stäbchen und Zapfen in der Netzhaut
2) Ableitung von Potentialen der Netzhaut
3) Optomotorische Reaktionen: Pupille und Nystagmus
4) Spontanreaktionen: Farbbevorzugung
5) Dressurmethoden.

Eine W a h r n e h m u n g von Farben, die ein Vorgang des tierischen Bewußtseins ist, kann durch die Methoden 1),2),3) weder sicher nachgewiesen noch bestritten werden. Bei positiver Reaktion nach 4) kann zwar auf ein Farbensehen geschlossen werden, bei negativer aber nicht auf dessen Fehlen.
Es bleiben als einzige schlüssige Nachweismethoden die Dressuren. Es ist selbstverständlich, daß alle olfaktorischen, haptischen, akustischen u. a. Nebenreize sicher ausgeschlossen werden müssen.
Die Dressurmethoden schaffen entweder eine künstliche Assoziation Farbe-Futter, oder sie verwenden im Tier sowieso vorhandene Triebe, z. B. den Spieltrieb. Den Tieren wurden Farbreize entweder als farbige Lichter oder als Farbpapiere dargeboten. Leider läßt die genauere farbmetrische Kennzeichnung auch bei neueren Arbeiten sehr zu wünschen übrig, bei älteren fehlt sie meistens.
Daß Farben 3 unabhängige Merkmale haben und wie sie bezeichnet werden, ist offenbar den Tierpsychologen weitgehend unbekannt. "Dieses Tier sieht keine Farben" bedeutet i. a.: "Es ist mir nicht gelungen, eine Farbton-Unterscheidung festzustellen".
Daß das gewünschte Dressurziel nicht erreicht wird, ist oft schon durch den Dressurvorgang vorprogrammiert. Als Beipiel: GERTI DÜCKER (2) dressierte Katzen zunächst auf Rot (positiv) gegen Schwarz (negativ) und behauptet, das sei eine Dressur auf den Farbton Rot. Die Katzen lernten das geforderte Verhalten schnell, nämlich den schwarzen Deckel eines Futterschälchens liegen zu lassen und den roten des daneben stehenden Schälchens abzuheben, um das darin liegende Fleischstückchen zu fressen. Später wurde der schwarze Deckel durch einen grauen ersetzt. In jeder Reihe wurde ein helleres Grau dargeboten. Insgesamt waren es 60 Stufen bis zum Weiß. Das Rot wurde beibehalten. Die Katzen, anfänglich darauf dressiert, den helleren Deckel, nämlich den roten, abzuheben, taten dies auch weiterhin und hoben zuletzt den weißen Deckel ab. Bei gewissen Graustufen wurde abwechselnd der rote und der graue Deckel abgehoben. Es folgten analoge Versuchsreihen mit Grün, Gelb und Blau, in denen die Katzen sich entsprechend verhielten. G. DÜCKER folgerte, daß die Katzen farbenblind

seien, anstatt zu erkennen, daß sie die Katzen auf Helligkeit dressiert hatte.
CHRISTIANE BUCHHOLTZ (3) ließ Katzen mit farbigen Mäuseattrappen spielen und konnte damit die Farbton-Unterscheidung der Katze sicher nachweisen. Eine anschließende Dressur auf das Merkmal Helligkeit gelang nicht, da die Katze auf das Merkmal Farbton geprägt war.
Bei D. R. MEYER, R. C. MILES und P. RATOOSH (4) ist die Dressurmethode so unzweckmäßig, daß die Katzen nicht einmal auf den gleichzeitig mit der positiven Farbe gebotenen olfaktorischen Reiz reagierten.
Bei meinen Dressurversuchen an Hunden (5) mußte ich mehrmals die Versuchsanordnung ändern, ehe die Hunde auf Farben so reagierten, wie sie sollten. Es war allerdings erstaunlich, wie schnell dann das Merkmal Farbsättigung akzeptiert wurde.

Damit jeder Hundehalter sich selbst davon überzeugen kann, daß sein Hund nicht farbenblind ist, entwickelte ich eine neue Dressurmethode, und zwar:
Zunächst muß der Dressurleiter sich selbst über die Merkmale der Farben klar sein und darüber, auf welches Merkmal er seinen Hund dressieren will. Dann sammelt er entsprechende farbige Stoffstücke - z. B. rote und blaue mit verschiedener Helligkeit und Sättigung für Rot-Blau-Unterscheidung - und zerschneidet diese in viele gleiche Teile. Der Hund wird zunächst zum Apportieren eines Stoffstückes gebracht. Tut er dies, so wirft man zwei gleichzeitig und belohnt ihn, wenn er das gewünschte Stoffstück zuerst gebracht hat. Das andere muß er dann aber auch noch bringen, sonst riecht er bald, was richtig ist!
Man kann dann auch noch zur Darbietung von mehr als zwei Farbmustern übergehen. Die Methode sollte übrigens dem Temperament des Hundes in ihren Feinheiten noch angepaßt werden. Beim Apportierverhalten darf der Hund nicht überfordert werden. So ist es wenig zweckmäßig, den ganzen Ritus, der auf dem Hundedressurplatz beim Apportieren üblich ist, vom Hund zu verlangen.

Nach dieser Methode dressierte ich zwei Mittelschnauzer-Hündinnen. Die eine war auf Farbton in folgender Art dressiert: Jeweils verschieden helle und verschieden gesättigte Farbmuster mit den Farbtönen: Rot - Blau - Grün - Gelb wurden zunächst paarweise geworfen, dabei waren jeweils die Farbtöne verschieden. Der Hund hatte eine Relativwahl so zu treffen, daß er den oben weiter links stehenden Farbton vor den anderen zuerst wählen mußte, also z. B. Rot vor Blau, Grün oder Gelb. Bei diesen Zweifachwahlen erreichte der Hund eine Dressursicherheit von etwa 80 %. Außerdem wurde ihm auch noch beigebracht, gesättigte Farben von Unbunt (Weiß bis Schwarz mit 30 Graustufen) zu unterscheiden. Dabei hatte er alle bunten Farben zuerst zu wählen. Das gelang mit einer Sicherheit von 90 %. Die Dressursicherheit war natürlich auch von äußeren Störfaktoren abhängig. Waren die bunten Farben weniger gesättigt,

häuften sich die Fehler bei den Zweifachwahlen mit Unbunt, aber auch bei denen mit zwei bunten Farben.
Der Hund war sehr freudig an diesen Farbversuchen beteiligt. So war es ohne weiteres möglich, daß er bis zum Alter von 10 Jahren in einer Versuchsreihe 100mal wählte, d. h. 200mal lief.
Als der Hund 11 Jahre alt war, änderte ich die Methode etwas: Ich legte 20 Farbmuster vor ihn hin, z. B. 10 rote und 10 blaue. Er brachte zuerst alle roten, dann alle blauen, mitunter sogar, ohne irgendeinen Fehler zu machen. Auch eine Farbtonfolge: Rot-Blau-Grün-Gelb und zuletzt Unbunt konnte er bringen, allerdings mit größerer Fehlerzahl.
Dieses Relativ-Wahl-Schema wurde sofort auf neue Stoffproben übertragen. Bei neuen Farbmustern war sogar erstaunlicherweise die Fehlerzahl geringer als sonst.
Die andere Mittelschnauzer-Hündin wurde auf Helligkeit dressiert. Zunächst wurden nur unbunte Stoffe verwendet. Später wurden bunte Farben nur gegen Weiß oder Schwarz dargeboten. Die Dressur gelang auch in diesem Fall. Der Hund kann eventuell vorgeführt werden.

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Der vollständige Text des Vortrages soll in der Zeitschrift "DIE FARBE" (Göttingen) veröffentlicht werden.

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Robert M. Boynton, Allen L. Nagy and John H. Taylor, La Jolla (Ca):

The La Jolla Analytic Colorimeter

A new instrument, capable of testing chromatic differences along critical axes in a constant-luminance chromaticity plane, singly or in combination, will be described.

On décrit un nouvel instrument avec lequel on peut mesurer des différences de couleurs le long des axes critiques d'un plan de chromaticité et de luminance constante, seul ou en combinaison.

Es wird ein Gerät beschrieben, mit dem man Farbunterschiede längs der kritischen Achsen einer Farbart-Ebene konstanter Leuchtdichte allein oder in Kombination messen kann.

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R. M. Boynton, A. L. Nagy, and J. H. Taylor

Boynton and Kambe (1980) reported experiments where chromatic discrimination steps were measured along two critical dimensions. One of these (deutan) results from an exchange of R for G cone excitation while keeping their sum, which is proportional to luminance, constant. The other dimension (tritan) relates to variable excitations of B cones, also at constant luminance. The theoretical importance of these dimensions of chromatic variation has been noted by Luther (1927), LeGrand (1949), Rodieck (1973), and MacLeod & Boynton (1979). The apparatus to be depicted in the poster display is an improvement of that of Boynton and Kambe in the following respects:

(1) It allows discriminations to be tested not only along the deutan and tritan axes, but also along oblique axes of arbitrary angle;
(2) Chromatic exchange is accomplished by a direct substitution procedure that makes calibration simple and straightforward;
(3) The rate of chromatic variation can be controlled so that, on average, the duration required can be kept constant before a step is seen, regardless of initial chromaticity or direction of color change.

These improvements are accomplished without sacrificing the desirable features of the earlier apparatus, which were:

(1) Chromatic variation occurs at automatically-controlled luminance (as in the pioneering work of MacAdam, 1942);
(2) Use of 4 monochromatic primaries minimizes individual differences and provides a large gamut of testable colors;
(3) Chromatic steps of moderate size are measured in a side-by-side discrimination using a reliable psychophysical method where each trial begins with a physical match.

The apparatus uses a principle similar to the Burnham (1952) colorimeter. In that device, a tripartite filter was moved in a beam of light; when the filtered components were mixed, chromaticity varied with filter movement. Our device uses 4 filters instead of 3. All components of the apparatus are duplicated so that each half of the stimulus field can be identically controlled. The filter plane for one field is shown in the figure.

Filters: Four pairs of interference filters, each 126 mm by 63 mm were cut into equal squares so that each half has an identical spectral transmittance. Peak wavelengths are:

639 nm -- red	492 nm -- cyan
563 nm -- green	439 nm -- violet

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Optics: Filters are mounted on precision slides, with the red and green filters adjacent on one slide and the cyan and violet filters adjacent on the other. The two slides are mounted next to one another (see figure). A homogeneous beam of collimated light passes through the filters and a square aperture slightly smaller than the filters. The chromaticity of the light depends upon the proportions passing through the 4 filters. Unmounted neutral filters are attached to the interference filters so that the luminous flux emerging from the aperture is constant for all possible filter positions. The red-green and cyan-violet exchanges are controlled remotely within an accuracy of 3 microns. The lateral position of the red-green and cyan-violet slides can also be set with high accuracy using a micrometer control and remote readout.

A ribbon filament source is used. Mixture of the filtered light is accomplished by rear projection of an enlarged image of the filament. The optical train has five lenses which produce altogether 3 images of the source and 2 of the filter plane. One of the filter-plane images is used to visualize the 4 filter components and to check alignment.

Calibration: Within reasonable error, the flux transmitted through each filter, with the others blocked, is a linear function of filter position by radiometric measure. Equilization of luminances for the 4 filters was done by the minimally-distinct border method. Assuming the Smith-Pokorny (1975) functions for cone action spectra, the exchange of light between the red and green filters causes a known exchange of R and G cone excitations. We use R as a measure of the discrimination step along that dimension. Exchange of the violet and cyan filters causes a pure change in excitation of B cones because the chromaticities of these filters lie on a tritanopic confusion line. Maximum luminance obtainable is about 120 td.

Procedure: The apparatus was developed for measuring discrimination steps by the Boynton & Kambe method. A trial begins with an isomeric match and then, after a variable foreperiod, the filters move very slowly and the chromaticity of the field changes accordingly. With the aid of a computer the rate of filter movement is varied from trial to trial so that, on average, 5 sec elapse between the time the movement begins and the subject signals that a discriminable color difference is seen. By varying the relative rates of movement of the two filter pairs, chromatic variations in arbitrary directions can be measured and referred directly to the fundamental components of chromatic variation of which they are directly composed.

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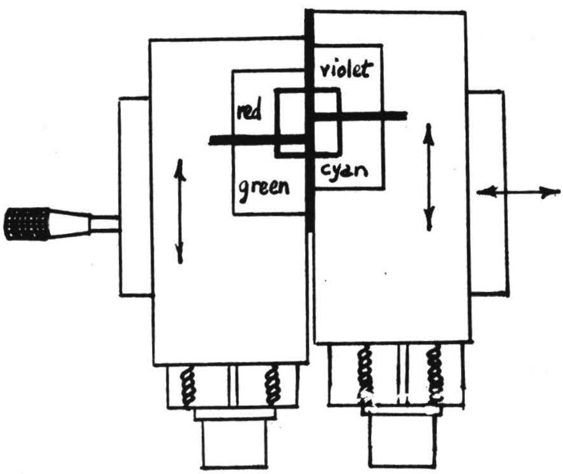

Jo Ann S. Kinney, Groton (CT):

Brightness and Luminance in Mesopic Photometry

A desirable system of photometry at mesopic light levels would provide agreement between the quantity of luminance and the visual impression of brightness. This paper lists the reasons for problems in mesopic photometry, discusses several possible solutions, and raises questions which must be answered before a final system of mesopic photometry can be obtained.

Un système désirable de la photométrie mésopique doit établir un agrément sur la connection entre luminance et impression de clarté. Ici on décrit les raisons pour les problèmes de la photométrie mésopique, on discute quelques solutions possibles, et on pose les questions à lesquelles on doit répondre avant que l'on obtienne un système définitif de la photométrie mésopique.

Ein zu schaffendes System der Photometrie für den mesopischen Bereich müßte ein Übereinkommen über den Zusammenhang zwischen Leuchtdichte und Helligkeitseindruck aufstellen. Hier werden die Gründe für die Probleme der mesopischen Photometrie aufgezählt, werden einige mögliche Lösungen besprochen und Fragen aufgeworfen, die zu beantworten wären, bevor man zu einem endgültigen System der mesopischen Photometrie gelangen kann.

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The topic, brightness and luminance, is a broad one, encompassing many different areas in vision, as we will hear in this symposium. I wish to address just one aspect - that is, a visually meaningful mesopic system of photometry. By this I mean a method or technique by which light can be measured at mesopic levels, the method to provide agreement between the quantity of luminance and the visual impression of brightness.

This concept stems from the work of Committee TC-1.4 of the CIE.[1] The committee believes that the measurement of light should be meaningfully related to its appearance; that is 20 cd/m^2, should look brighter than 10 cd/m^2 and should make seeing easier. Fortunately this is often the case, but there are also many instances in which there are sizeable discrepancies between numerical quantities of light and the visual impression. The discrepancies stem from our definition of light: radiant power evaluated by the spectral sensitivity of the human eye. More precisely, light, at photopic levels, is the integration of radiant power with the CIE luminous efficiency function or $V(\lambda)$ over the range from 360 to 830 nm. If, however, $V(\lambda)$ is inappropriate for any reason - and there are numerous possible reasons - the measurement of light will not agree with the visual impression. Since, by definition, the term mesopic covers the range of light levels at which both rods and cones are active, $V(\lambda)$ should not be used; mesopic measurement of light thus shares all of the difficulties found in photopic photometry plus a few additional ones.

Today I will first list the reasons for problems in mesopic photometry, second discuss possible solutions and finally raise several unanswered questions. For mesopic vision, the most important problem obviously is the shift in the luminous efficiency of the eye toward the shorter wavelengths. If we use a photopic, $V(\lambda)$ light meter for measurements, bluish lights will appear brighter than they are given credit for, while yellowish or red lights will be over-evaluated for their light producing capabilities. At low mesopic levels, say 0.1 cd/m^2 or below, a bluish light could have 10 or more times as much light as an ordinary tungsten source when the two measured exactly the same photopically. This problem is confounded by the fact that the spectral sensitivity of the eye at mesopic levels is dependent upon the size and position of the light in the field of view.

A second major problem for mesopic light measurement stems from the assumption underlying the formula for light - that of additivity. It is now well known that under certain conditions, light of different wavelengths can be added together and that the appearance of the total is correctly predicted from the sum of the components. Under other conditions, however, failures occur; frequently the sum looks considerably darker than it should. The crucial factor is of course how the luminous efficiency function was obtained, whether for example, by flicker photometry or by heterochromatic brightness matching. The result is that $V(\lambda)$, which was obtained by flicker photometry, will not accurately predict the appearance of colored lights. [1]

These then are the major problems to be dealt with in mesopic photometry; I wish to consider next the various methods by which we could deal with them; that is how could we measure the luminance of an unknown source at mesopic levels. First, and most obvious, we could use the appropriate mesopic luminous efficiency functions to evaluate the spectral radiant power distribution in a way completely analogous to the use of $V(\lambda)$ and $V'(\lambda)$, the scotopic luminous efficiency function. This method was discussed a number of years ago and has since been discarded. One reason is that there are not one or two mesopic luminous efficiency functions but rather many. In fact, mesopic spectral sensitivity changes progressively and somewhat erratically as the light level is lowered; [2] furthermore the specific changes involved depend dramatically upon the size and position of the light in the field of view.[3] In addition one would not know which filter to use until after the measurement was made - the old problem of which comes first, the chicken or the egg.

Another approach which has been suggested for study by TC-1.4 is to measure both the scotopic and photopic luminance. Since these two represent the limits, between which the unknown mesopic luminance must lie, a simple average of the two must necessarily provide a better estimate of its appearance than the photopic value alone.

We can do better than this however. We know that if the unknown mesopic light is close to photopic levels, its luminance should be close to its photopic value. Since the same reasoning holds at scotopic levels, we know that a nonlinear method of averaging the scotopic and photopic values would be better; the method should place primary emphasis on $V'(\lambda)$ at very low intensities and on $V(\lambda)$ at high intensities. This is essentially the technique worked out by David Palmer of England. His formula obtains L, the luminance of the unknown mesopic light, from P, the photopic luminance and S, the scotopic luminance. As P increases to high levels, its value in the formula becomes so large that S, the scotopic luminance, has no effect. Similarly, as P decreases it disappears and L reduces to S, as it should. [4]

There are two problems, however, as Dr. Palmer is the first to admit and both of these occur in normal photopic light measurement as well. First is a simple but practical problem. The formula requires that photopic luminance be measured for a large field of view, such as $\bar{Y}_{10}$ (from the CIE chromaticity values for a 10° field). Mesopic vision of course requires rods - hence the large field. There is however no way of easily measuring the photopic luminance of a large field. All light meters duplicate $V(\lambda)$, which is based upon a two degree field. To the extent that $\bar{Y}_{10}$ and $V(\lambda)$ do not agree - and they are different in the short wavelengths - there will be errors introduced.

Second is the problem of additivity that I referred to previously. This problem can be severe for the measurement of photopic luminances. For any condition for which additivity does not hold, the measured luminances will not be in agreement with the visual appearance. This is of course particularly true of colored light sources, the greater the purity or saturation of the measured light, the greater the discrepancy. Since this problem is inherent to all photopic measures, it will occur in Palmer's nonlinear averages as well, particularly at the higher intensities.

The third method by which we could measure an unknown source of mesopic intensity would be to design a new measuring technique and/or instrument based upon an adequate theory or model of how the eye works. We now believe we have such a model - based upon the research of many individuals. [5]

I am referring of course to zone theories in which color vision is mediated by three different types of cones, with their outputs combined in different ways. One combination is the linear addition of activity from the mid- and long-wavelength cones; this is the achromatic system and its spectral sensitivity is represented by $V(\lambda)$. The other two combinations are opponent color mechanisms; that is, activity generated in, say, the red system is antagonistic or subtracted from that generated in the green system; the same is true for yellow and blue. These two systems the R/G and Y/B are chromatic systems and the mechanisms by which we see hue. The spectral sensitivity of the chromatic system is a wider curve than $V(\lambda)$ with higher sensitivity at the ends of the spectrum. Furthermore, and this is most important, the perception of brightness results from activity in both the chromatic and the achromatic systems. [6]

This theory then explains why additivity sometimes succeeds and sometimes fails. If the visual task is dependent upon only the achromatic system, additivity will hold. This is apparently the case for flicker photometry and minimally-distinct borders. If the visual task involves both the chromatic and achromatic systems, as in heterochromatic brightness matching and detection thresholds, additivity failures will abound.

This theory or model has been effectively used to explain many phenomena in photopic vision, for example, hue and saturation discrimination, the Bezold-Brücke phenomenon, differences in spectral sensitivity and color defective vision. To be useful for mesopic vision, however, it must be expanded to include the rods and a variety of possible rod-cone interactions, and at this point we have a number of unanswered questions.

As a final topic today I would like to raise several of these questions - questions for which we would need answers if we were to employ the model of the visual system as a technique for mesopic photometry. For some of these, there are answers in the literature; for others, probably not. I hope these will be a starting point for discussion.

First, what is the relative contribution of the rods and the cones at different light levels? We know the general shape of the curves relating rod and cone activity to intensity level; that is, rod participation starts at a maximum and gradually decreases with the reverse being true of cone activity. However the details remain obscure. For example, what is the order in which the cones provide input as the intensity is raised? We know, for example, that they do not all become active at exactly the same intensity. This is apparent in the mesopic luminous efficiency curves; as the intensity is raised above scotopic threshold the first change to appear is heightened sensitivity to the long wavelengths - indicating activity of the long wavelength or red cone. [2] It is also indicated in the factor analysis of mesopic luminosity curves by Kokoschka; the functions relating hypothetical cone activity to intensity level differ greatly from one cone to another. [3]

An even more complex question concerns the intensity levels at which the chromatic system becomes active, for it is at this point that additivity failures will first be evident. We have no complete answers to this question but a number of investigations provide suggestions. The photopic models of Guth [6] and of Ingling [7] have intensity-dependent interactions between opponent systems. Thus, at threshold, the contribution of the blue-yellow system is much less than that of the red-green system; as intensity is increased the relative importance of the blue-yellow system increases. Whether similar interactions among opponent-color systems occur in mesopic vision is as yet unknown. Ikeda and Shimozono [8] suggest that the contribution of the chromatic or opponent channels to the heterochromatic luminous efficiency curve is the same at photopic and mesopic levels. If this proves true for all conditions it makes mesopic photometry much easier.

There are practical questions that need answers in addition such as the size and position of the field to be used in a standard measuring system. Also we must haveastandard for specifying that light level. The CIE has used a variety of standards for specifying the candela over the years, 2360K, 2042K,and now 540×10^{12} Hz or 555 nm. Should mesopic photometry be standardized on one of these?

Finally there is the important practical question of the size of the discrepancies induced from all these possible sources. I wish to return to my goal of a visually meaningful system of mesopic photometry. If we measure light sources, including color, at low intensity levels, we wish the measured quantities to agree with the visual impression of brightness. Unless our model is perfect, we will find discrepancies for various reasons. Are we talking about orders of magnitude - that is factors of 10 or more - or refinements to a measuring system which would make a barely visible difference? The present system of using $V(\lambda)$, for lack of anything else, permits enormous errors. We must decide how much precision we want and the best way to achieve it.

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Alan L. Gilchrist, Stony Brook (N.Y.):

Perception of Lightness and Illumination in an Environment of Homogeneous Reflectance

A spatially complex environment of uniform reflectance produces a non-uniform retinal pattern containing a wide variety of luminances. Although most existing theories would predict the perception of a variety of shades of gray, it was found that lightness was actually perceived as uniform while luminance variations were correctly perceived as variations in illumination levels. In addition, the surface lightness of the entire environment was approximately correctly identified, independent of absolute luminances.

Un entourage complexe dans l'espace, mais d'un degré de réflexion égale, produit un modèle sur la rétine qui montre une grande variété des luminances. Même si la plupart des théories existantes peuvent prédire la perception d'une variété des gris, on a trouvé que la clarté est en vérité perçue comme uniforme pendant que les variations de luminances sont perçues correctement comme des variations du niveau de l'illuminance. De plus, la clarté de la surface de tout l'ambiance est identifiée approximativement juste indépendant de la luminance absolue.

Eine räumlich komplexe Umgebung gleichen Reflexionsgrades erzeugt ein ungleichförmiges retinales Muster von großer Verschiedenheit der Leuchtdichten. Zwar können die meisten der bestehenden Theorien die Wahrnehmung verschiedener Grautöne voraussagen, aber es wurde gefunden, daß die Helligkeit in Wirklichkeit als gleichförmig empfunden wurde, während die Leuchtdichte-Variationen ganz richtig als Verschiedenheiten der Beleuchtungsstärke wahrgenommen wurden. Darüber hinaus wurde die Oberflächenhelligkeit der gesamten Umgebung annähernd richtig eingeschätzt, unabhängig von der absoluten Leuchtdichte.

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From the time of Helmholtz and Hering, research on lightness perception has been based on what might be called the photometer metaphor. That is, it has been assumed that fundamentally the visual system responds to the amount of light at each point in the retinal image. This basic metaphor in combination with the fact that surfaces that reflect different absolute amounts of light (luminance) often appear as the same shade of gray produced the classic problem of lightness constancy. From Hering's work until the present time the most widely favored solution to the constancy problem has been to add a contrast mechanism to the basic photometer function. In other words, the different levels of excitation, produced by the two surfaces of different luminance, are also subject to different levels of inhibition caused by luminance differences in the two regions surrounding the target surfaces. Thus the edge between the target and its surround becomes critical and this has spawned a large body of research on edge or border effects.

But it has not been generally recognized that this model only works when applied to a reflectance edge, that is, an edge in the retinal image produced by a change in the reflectance of the surface being viewed. When the model is applied to illumination edges, it not only fails, but it actually makes matters worse. Consider a shadow cast onto a white wall. The constancy problem requires that we explain how both the shadowed and non-shadowed parts of the wall can be seen as the same shade of gray despite the much higher luminance of the non-shadowed region. A contrast process operating between these two adjacent regions can only enhance the difference in neutrl activity. In no way can it reduce neural activity in the two regions to the same level.

Given this state of affairs, it seems logically required that the visual system must be capable of distinguishing illumination edges from reflectance edges. Otherwise dramatic lightness illusions would be the rule.

How successfully does the visual system discriminate illumination edges from reflectance edges? The literature on lightness perception is not very helpful here since the displays that have been used have usually been so simple as to make the distinction irrelevant. Those few more complex displays have usually involved a pattern of reflectances under uniform illumination. Alan Jacobsen and I wanted to create an illumination pattern with reflectance held uniform across the displays. To create such a pattern we built two miniature rooms, each containing a number of simple objects. One room, including all the objects within it, was painted entirely matte black (R = 4.6%); the other was painted matte white (R = 84%). In each room the illumination was provided by a simple light bulb which could not be directly seen by the observer, who looked into the room through a aperature in one wall. This display produced the kind of retinal image illustrated in Figure 1.

The critical theoretical question was whether the various surfaces in a given room, representing many different luminances, would be seen as the same or different in lightness. All of the nine observers who viewed the black room reported that the eight test surfaces, indicated in Figure 1, appeared equal in lightness. The same results were obtained for the nine observers who viewed the white room. Measurements of perceived illumination levels were obtained by having the observers adjust the level of illumination on a Munsell chart to match the perceived level of illumination level on each of the test surfaces. Those matches, which are shown in Figure 2 and Figure 3 in comparison to the actual illumination levels, show that variations in illumination levels are correctly perceived as such.

A second theoretical question emerged during this work. Given that each room is perceived as uniform in lightness, would the perceived lightness levél be correct for each room and, if so, what is the psychophysical basis for lightness perception under these conditions? In fact, the white room was correctly perceived as white (R = 79 %), but the black room was perceived as a middle gray (R = 25 %) much lighter than its actual reflectance, but much darker gray than the white room. To test whether these perceptions of lightness are based on the average luminance in each room the intensity of illumination in the white room was reduced until each point in the white room was lower in luminance than the corresponding point in the black room. Nevertheless, the white room was still perceived as almost white (R = 51 %).

Apparently, the impression of the lightness of one of these rooms is based mainly on the fact that luminance gradients are much steeper in the black room than in the white room. This difference can be seen in the luminance profiles of the rooms shown in Figure 4. Luminance gradients in the white room are relatively shallow, owing to the large amount of indirect illumination in a white environment. In the black room the shadows are very dark since very little light gets reflected into them from the neighboring black surfaces, and this results in steep gradients. Notice that the effect on the retinal image of reducing the illumination (see the profile for the dimly illuminated white room) in the white room <u>is not the same</u> as the effect of painting the room a darker shade of gray (see the profile for the black room). The fact that perceived lightness is approximately correct in these rooms is inconsistent with the photometer metaphor, with or without a contrast mechanism. Our results lend further support to the view that perception of surface reflectance and illumination is based on relationships in the pattern of light reaching the eye, largely independent of absolute levels.

This paper will be published in full in the Journal of Experimental Psychology.

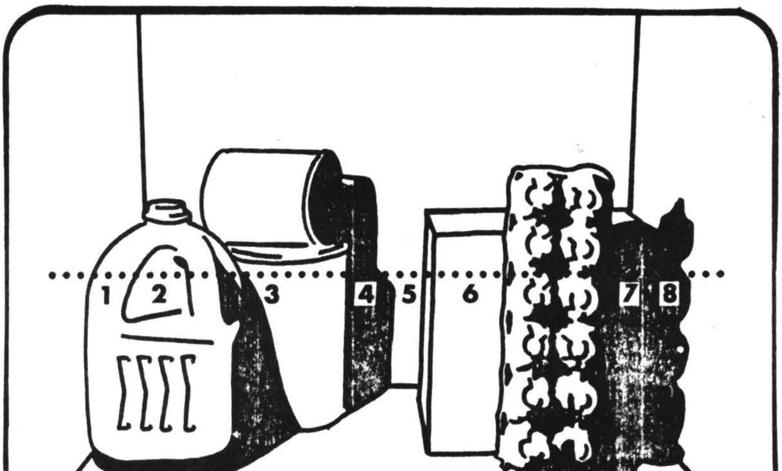

Figure 1. A line drawing of the room containing six objects - from the left to right, a plastic jug, a small paint can lying horizontally on a larger paint can, a large wooden cube, and an egg carton. The eight numbers are the eight target points that were matched for reflectance and illumination level. The dotted line is the path scanned by the photometer in producing the luminance profiles shown in Figure 4.

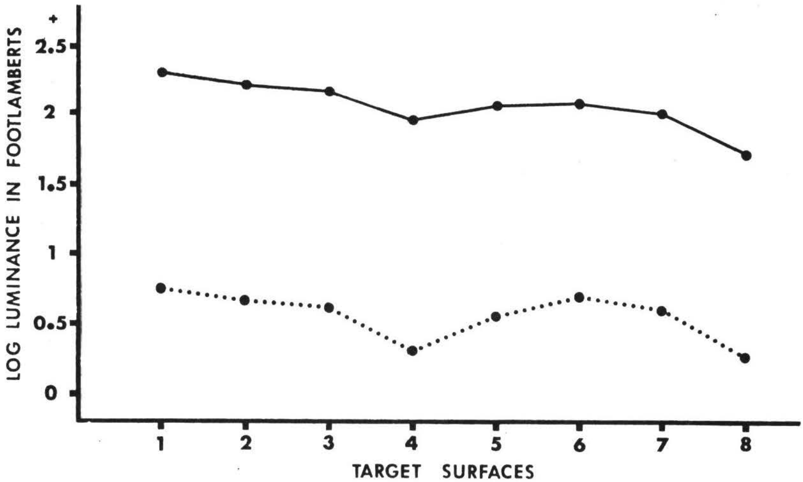

Figure 2. A comparison of actual and matching illumination levels for the brightly-illuminated white room. The solid line shows the actual luminance values of the eight target points. The dotted line shows the median values of luminance readings taken from each observer's chosen Munsell chip (in the matching apparatus) under the same observer's matching illumination level.

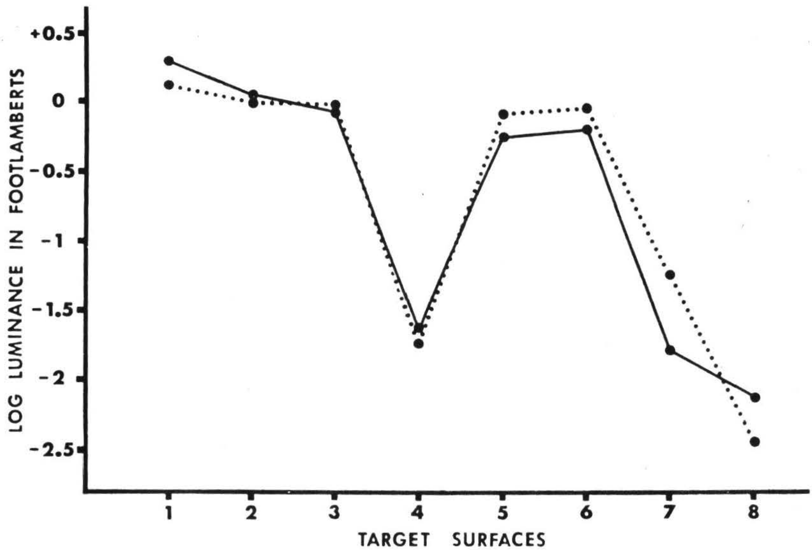

Figure 3. A comparison of actual and matching illumination levels for the brightly-illuminated black room, measured as in Figure 2.

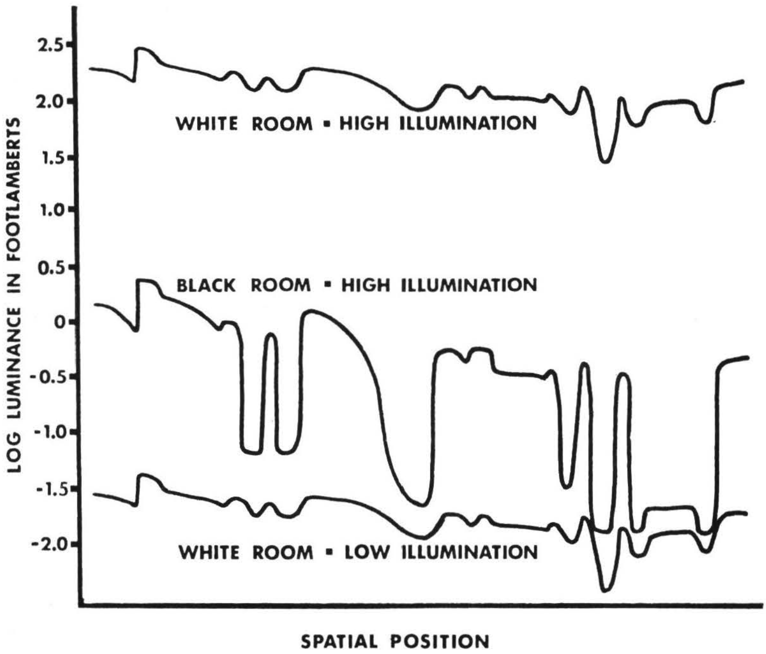

Figure 4. Luminance profiles produced by scanning across each room along the dotted line shown in Figure 1.

Robert M. Boynton, San Diego (Calif.):

The Role of a Model in Differential Colorimetry

Because one cannot test experimentally all possible color differences the use of a model helps greatly in the selection of experimental conditions and the extension of results to untested regions of the chromaticity plane. An opponent-color model serves this purpose well.

Il n'est pas possible d'examiner par expérience tous les distances de couleurs qui peuvent s'élever. C'est pourquoi un modèle est très utile à sélectionner les conditions expérimentales et à estimer l'extension des résultats aux régions non-examinées du diagramme des chromaticités. Un modèle sur la base des couleurs opposées servira bien à ce but.

Man kann unmöglich alle denkbaren Farbabstände experimentell prüfen. Deshalb ist ein Modell sehr hilfreich, um die experimentellen Bedingungen auszuwählen und die Ausdehnung der Ergebnisse auf ungeprüfte Gebiete der Farbtafel zu beurteilen. Eine Gegenfarben-Vorstellung ist hierfür gut brauchbar.

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Color differences are sufficiently important, both theoretically and commercially, that it is natural to inquire about them. It is however far easier to ask than to state the requirements for a unit difference in color perception. The experimental study of chromatic discrimination is potentially a huge undertaking because a chromatic step may be assessed with respect to any point in the chromaticity plane, in any direction from every point, at many luminance levels.

MacAdam (1942) reduced the problem to managable size by making measurements at only 25 chromaticities, testing discriminability along a limited number of axes for each, and doing so at a constant luminance. Although obtained 40 years ago with only a single subject, the resulting body of experimental data forms the basis of a system still used today to gauge the discriminability of colors (Wyszecki and Stiles, 1967, p. 532). One reason why subsequent progress has been slow is that, upon extending the work to additional observers, individual differences appeared that have never been satisfactorily explained (Brown and MacAdam, 1957). A second problem relates to MacAdam's decision to abandon his original method (where luminance was automatically held constant as the subject adjusted chromaticity using a single knob) for a method of trichromatic color matching from which it was hoped that constant-luminance cross sections of ellipsoids in trichromatic space would yield the required information. The newer method did not in fact seem to work as well as the original one (see Wyszecki and Fielder, 1971 and Boynton, 1979, Ch. 8).

Differential colorimetry provides an excellent example of a problem area that cannot profitably be examined in the absence of some kind of model. From a theoretical standpoint, a model is needed so that the problem can be analyzed in terms of managable components and their interactions. From a practical viewpoint, given a necessarily limited data set, a model is needed to allow rational interpolations on a continuous basis. Our model* can be regarded as an extension of concepts originally proposed by LeGrand (1949) in

*I have been assisted in this work by Naotake Kambe, Allen L. Nagy, and John J. Wisowaty.

an important paper that seems to have received less attention than it deserves.* LeGrand reanalyzed MacAdam's results along two theoretical dimensions. On the assumptions that (1) blue-sensitive (B) cones do not contribute to luminance and (2) chromatic discriminations should be tested (as they were by MacAdam) at constant luminance, it follows that the excitation of B cones can vary while the activity levels of both kinds of long-wavelength-sensitive (R and G) cones are held constant. Although LeGrand was not then thinking in terms of opponent-color concepts, it is a short and useful step to incorporate them. When the red-green opponent system is balanced, the resulting sensations are related to the degree of B-cone excitation (blue or yellow, of any saturation, including white). As the red-green system becomes progressively more unbalanced, the resulting sensations are at first tinged, and eventually dominated, by the appearance of red or green.

The second dimension that LeGrand analyzed was that of red-green exchange. If one assumes that luminance depends upon the total amount of R and G cone excitation, whatever their proportional contributions, then the concept of chromatic differences based upon unique changes of excitation of R (or G) cones becomes meaningless because luminance must also vary and pure chromatic discriminations will no longer be tested; instead, as the excitation of one class of these cones is increased, that of the other must be similarly decreased, and a discrimination step can be measured in terms of the change of excitation of either one.

Before illustrating how an opponent-color model has proved useful as a guide for our research, a few remarks are in order concerning our experimental procedure. From MacAdam's original method we take the idea of working along only one line of the chromaticity plane at an automatically controlled luminance. But MacAdam used a method of repeated matches which introduces three difficulties: (1) Any experimental method

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*One reason for this, perhaps, is that the paper was published in French. However, the key ideas are available in extremely compact form starting on page 486 of <u>Light, Colour, and Vision</u> (LeGrand, 1968).

is extremely time consuming if it depends upon the variance of data as a prime datum; (2) it produces discrimination steps that cannot in fact be discriminated; and (3) it implies a symmetrical relation of discrimination steps with respect to the match point, whereas MacAdam's own data, taken in the large, prove that this cannot be so.

With our procedure, we begin with a match. After an unpredicatable foreperiod, one side of a split field begins to change very slowly in one of two possible directions. The subject responds only when he can correctly identify the direction of change. The resulting steps are roughly a dozen times larger than MacAdam's. Our method utilizes experimental conditions that allow LeGrand's two dimensions of chromatic variation to be examined in isolation, with the other treated as a parameter and held at various constant levels. This is easy to accomplish for the red-green axis by exchanging long-wavelength stimuli, neither of which significantly excites B cones. To vary the excitation of B cones alone, we employ tritanopic metamers, first used by Boynton, Hayhoe, and MacLeod (1977).

Our results to date have largely confirmed LeGrand's analysis, while yielding at least two new insights: (1) a high steady level of B-cone excitation has deleterious effects upon red-green discrimination, although a weak excitation--equivalent to that required to turn yellow into white--is beneficial (see also Polden and Mollon, 1980); (2) B-cone-mediated discrimination is independent of the balance of the red-green system.

The foregoing findings have been published (Boynton and Kambe, 1980). We are currently retooling to extend this work to a systematic examination of what happens for simultaneous differences in ΔR and ΔB. If there were no interactions between the two dimensions of chromatic difference, then it would be predicted that the major and minor axes of MacAdam's ellipses should fall along lines radiating from the tritanopic copunctal point, or along confusion lines for a fusion deuteranope. (In the CIE chart, the latter radiate from (1,0) and include the long-wavelength portion of the spectrum locus.) The ellipses do not do this. Figure 1 illustrates this for MacAdam's ellipse No. 6. In this figure, the arrow T

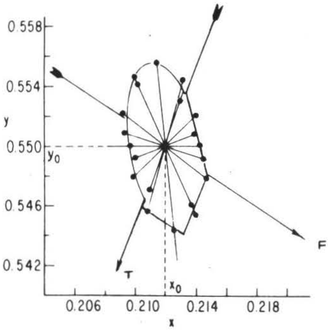

Fig. 1

points toward the tritanopic copunctal point and F toward the point (1,0). The data are MacAdam's, with a half-ellipse drawn at the upper left.

A hypothesis that we wish to test is represented by the three straight lines fitted at the lower right. The longest of the three lines describes a rule of linear summation: a discrimination step is reached when the sum of excitations caused by simultaneous differences in the two opponent-color systems reaches the threshold of either one alone. The bottom sector is fit instead by two lines parallel to the reference lines pointing toward T or F. These describe the other extrme possibility that a discrimination step is achieved only when the more sensitive opponent system reaches it, there being no coooperation between them.

From the standpoint of the underlying model, the previously incomprehensible individual differences could result from between-subject variations along either the T or F axis, or in interactions that may occur when chromaticity is varied simultaneously along both. By testing substantial numbers of subjects with abridged procedures designed to assess these three sources of variability, we hope to come to a fuller understanding of the nature of individual differences in chromatic discrimination.

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The ATD Vector Model: Its History and Limitations

The development of the ATD vector model is traced from its origins in heterochromatic additivity data to its most recently refined version. Special attention is paid to the fact that the important questions regarding mechanisms of color vision cannot be answered by tests of the model that involve color discriminations and thresholds.

On suit le développement du modèle ATD vectoriel dès son origine des dates de l'additivité hétérochromatique à la version récemment améliorée. Particulièrement on attire l'attention sur le fait que les questions importantes du mécanisme de la vision colorée ne peuvent pas être répondues par des expériences qui sont basées sur la discrimination et les seuils des couleurs.

Die Entwicklung des ATD-Vektor-Modells wird von seinem Ursprung der heterochromen Additivität bis zu der neuesten verfeinerten Version verfolgt. Besondere Aufmerksamkeit wird auf die Tatsache gelenkt, daß die wichtigen Fragen über den Mechanismus des Farbensehens nicht durch Versuche über Farbunterscheidungsvermögen und Farbschwellen beantwortet werden können.

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Many years ago, we completed experiments in which we determined the relative radiances required both for the detectabilities of monochromatic lights and for the relative radiances of those monochromatic lights when they were components of just-visible bichromatic mixtures. The radiances of each component in threshold-level mixtures were expressed relative to the radiances required to bring each component, alone, to threshold; that is, we expressed the amount of each component in threshold units. According to an additivity law, the threshold units for the components in a just-visible mixture should sum to unity. This approach had previously been used by Boynton, Ikeda and Stiles (1964).

We found that the additivity law was not valid. Rather, the sums of the threshold units for just-visible mixtures tended to be greater than unity (Guth, 1965; Guth, et al, 1967; 1968, 1969, 1972, 1973).

To describe our results, we used an idea originally suggested by Swets (1960). The idea was to use vector addition as a metric to summarize additivity data. For example, if a just-visible (one threshold unit) red plus a just-visible green were added together to yield a just-visible mixture (also one threshold unit), then it was as if the red and green were vectors separated by 120°. That is, the vector resultant of two unit-length vectors separated by 120° is itself unity. Given the threshold units of each component required to yield a just-visible (unit resultant) mixture, it was always possible to calculate the angle (or its cosine) that described the degree of additivity between any two wavelengths. We did this not only for our own data, but also for related additivity data that had previously been obtained by others. (E.g., Boynton, Ikeda and Stiles, 1964).

Data from our own experiments provided angles between the 45 possible two-component mixtures that could be made from ten wavelengths. We subsequently found that, (i) the ten wavelengths could be represented as unit-length vectors in a Euclidian three-dimensional space such that the angles between pairs of vectors corresponded to the angles derived from our experimental data, and (ii) the three-dimensional vector space was a linear transformation of color-matching data similar to those that form the basis of the CIE chromaticity space.

We then realized that the axes of the space could be rotated so that the projections of the vectors (scaled from unit-length to equal-radiance lengths) on the axes represented equal-radiance responses from opponent-colors mechanisms. Early in the development of the model, we adopted opponent colors theory and speculated that both threshold responses and brightness judgments are mediated by the combined outputs of the opponent and nonopponent systems. We did not then realize that Jameson and Hurvich (1953) had anticipated this view in a consideration of their data concerning the effects of chromatic adaptation on retinal sensitivity. We also reasoned that our nonadditive effects were due to neural cancellations within opponent mechanisms and that flicker photometry tapped only the achromatic system (Guth, et al, 1969). This explained why flicker photometry yielded additive data and why flicker-based sensitivity functions were narrower than detection-based sensitivity curves (Guth and Lodge, 1973). The same idea implied what we later made explicit--that, since modern photometry is based mainly upon flicker data, it is really a photometry of the achromatic system, and that the quantity we define as luminance relates only to the whiteness of a light (Guth and Lodge, 1973).

The initial quantitative version of the vector model (Guth, 1972; Guth and Lodge, 1973) was improved upon when the opponent colors mechanisms were defined in terms of the three cone receptors (Guth, Massof and Benzschawel, 1980). This, most recent, version of the model is schemetized in Figure 1.

The receptors are those derived by Smith and Pokorny (1972, 1975). The post-receptor mechanisms are the achromatic, the red-green (R/G) and the blue-yellow (B/Y) systems, which are identified as A, T and D in accordance with the idea first proposed by Walraven (1962) that normal vision is made up of tritanopic and deuteranopic components. Note that B feeds neither A nor T, and that G does not feed D. I shall return to these issues later.

Figure 2 shows the equal radiance response functions of the three mechanisms as defined by the equations,

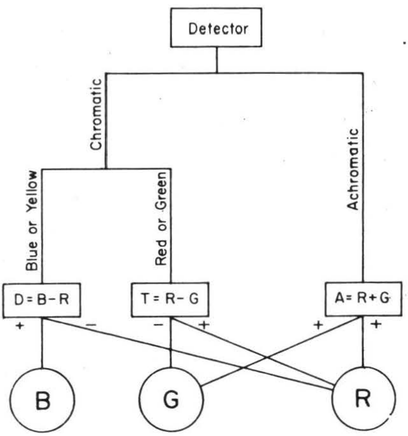

Fig.1: Schematic diagram of the ATD vector model

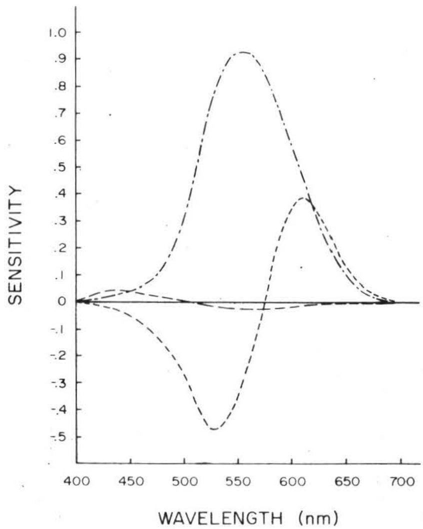

Fig.2: Threshold-level, equal-radiance response functions for A, the achromatic system (dots and dashes) T, the tritanoptic system (short dashes) and D, the deuteranoptic system (long dashes).

$$A = 1.0\ (0.5967\ R + 0.3654\ G), \qquad (1a)$$
$$T = 1.0\ (0.9553\ R - 1.2836\ G), \qquad (1b)$$
$$D = 1.0\ (-0.0248\ R + 0.0483\ B). \qquad (1c)$$

The unit multipliers in each equation are "dark" threshold weightings which are used whenever the model is applied to color discriminations or thresholds in the dark-adapted state. As stimulus intensity or size or duration change, the multipliers typically vary. Similarly, conditions of chromatic adaptation cause the receptor coefficients, within the parentheses, to vary in accordance with Vón Kries principles.

To apply the model, it is first necessary to estimate the appropriate values for the unit multipliers and the receptor coefficients. Second, it is necessary to use the equations to determine how a light stimulates the $\underline{A}$, $\underline{T}$ and $\underline{D}$ mechanisms. Given the spectral distribution of the light, this is a simple matter, since the absorptions of the three receptors are known. Finally, the model assumes that the information from $\underline{A}$, $\underline{T}$ and $\underline{D}$ is combined in a vector fashion, such that the total information available to the detector is given as $(\underline{A}^2+\underline{T}^2+\underline{D}^2)^{1/2}$. The ability of the model to account for spectral sensitivity functions obtained under a wide variety of adaptation conditions can be appreciated by referring to Guth, et al, (1980).

Clues that the square root of the sum of the squares of opponent mechanisms would be a useful quantity were available as early as 1949, when Judd used the metric to predict chromatic thresholds within his interpretation of the Müller theory. According to Massof and Starr (1980) the metric follows from modern signal detection theory which suggests that the optimal way to combine noise-limited signals from independent channels is to take the vector sum of the information available in each channel. Massof (personal communication) also points out that his paper was anticipated in Swets' 1960 report. That report has a discussion section that I had forgotten because I did not see it as relevant 15 years ago, but which was obviously highly relevant when read by Massof after the Massof and Starr paper was published.

To account for color discriminations within the model, we use the traditional line element approach and assume that a just noticeable color difference can be represented by a distance in the $\underline{A}$, $\underline{T}$, $\underline{D}$ vector space. Friele (1961, 1971) was the first to use an opponent-colors model as the basis for a line-element space, but the development of our model leads to new insights regarding the color difference problem.

Consider MacAdam-like observations where color discriminations are studied under conditions of constant luminance. Within ATD vector space such discriminations are made in a plane of equal luminance, or constant $\underline{A}$. But, the model incorporates the generally-accepted idea that the relative weights for $\underline{A}$, $\underline{T}$ and $\underline{D}$ change as adaptation level changes. (It is well-known that light adaptation increases apparent saturation, presumably because of a relative fatigue of the $\underline{A}$ system, and that increases in intensity result in a Bezold-Brücke decrease in the relative weight of the T system.) This implies that the constant $\underline{A}$, or $\underline{t_A}$ vs $\underline{d_A}$, chromaticity plane of the ATD vector space changes with adaptation level.

For example, a chromaticity diagram appropriate for foveal observations made under conditions of dark adaptation can be constructed by first using equations (1) to determine $\underline{A}$, $\underline{T}$ and $\underline{D}$ for spectral lights. For each wavelength, we then divide $\underline{A}$, $\underline{T}$ and $\underline{D}$ by $\underline{A}$--a procedure that projects each spectral vector to the unit $\underline{A}$ plane. We can then plot $\underline{t}_A$ ($\underline{T}/\underline{A}$) and $\underline{d}_A$ ($\underline{D}/\underline{A}$) for the spectral lights. However, if adaptation level is raised, the model must be adjusted to account for the adaptation of $\underline{A}$ and the adaptation of $\underline{T}$ relative to $\underline{D}$. This is accomplished by adjusting the values of the unit multipliers. (The relative values of these multipliers are identified with the lower-case letters, $\underline{a}$, $\underline{t}$ and $\underline{d}$.)

Figure 3 shows chromaticity diagrams for three different adaptation levels. The usefulness of these diagrams as uniform chromaticity spaces can be evaluated by referring to the 1980 article. It is especially important to understand the implication that there is no single uniform chromaticity space. Rather, any practical color metric must take into account the long-accepted ideas that mechanisms of color vision change their relative contributions as adaptation conditions (and stimulus sizes or durations) vary.

In regard to Figure 1, we noted earlier that the $\underline{B}$ receptor feeds neither $\underline{A}$ nor $\underline{T}$, and that $\underline{G}$ does not feed the $\underline{D}$ mechanism. That is, the "wiring-diagram" differs from the Hering-Hurvich and Jameson model as well as from the Walraven-Vos model. The precise form of the correct wiring diagram remains a question to be answered, but I should like to point out that there exist an infinity of possible wiring diagrams that are consistent with the thresholds and color-discriminations predicted by the vector model. In reference to Figure 3, any rotation of the $\underline{t}_A$ and $\underline{d}_A$ axes about their origins will not affect any of the predicted color discriminations, but a rotation will imply a different wiring diagram. For example, in the high brightness space of Figure 3, the $\underline{t}$ axis cuts the spectrum locus at about 502 nm. This reflects the fact that $\underline{d}$ is zero at that wavelength, because our receptor inputs to $\underline{D}$ were made to cancel, or "cross" at a value around unique green. Similarly, $\underline{d}$ is zero near a yellow of 575 nm because the receptor inputs to $\underline{T}$ cancel at that wavelength. As the axes are pictured, there is no unique blue, which, within the Hering-Hurvich and Jameson model, is a second cross-point in the $\underline{T}$ system caused by an input from the $\underline{B}$ receptor. However, if the axes are rotated approximately 45° counterclockwise, then the $\underline{d}$ axis will cut the spectrum locus at around 582 and 475 nm, which implies that T is zero at those lengths, as is approximately true for the Hering-Hurvich and Jameson model. Such a rotation places unique green in the wrong place, and implies that the unique hues vary with intensity, especially unique blue which would shift to very short wavelengths as adaptation level decreases (where $\underline{d}$ cuts the spectrum locus in the low brightness diagram). Therefore, the rotation raises as many problems as it solves.

In conclusion, it appears that vector models provide a powerful metric for predicting a wide variety of visual discriminations. However, even a theoretically complete and perfect set of discrimination

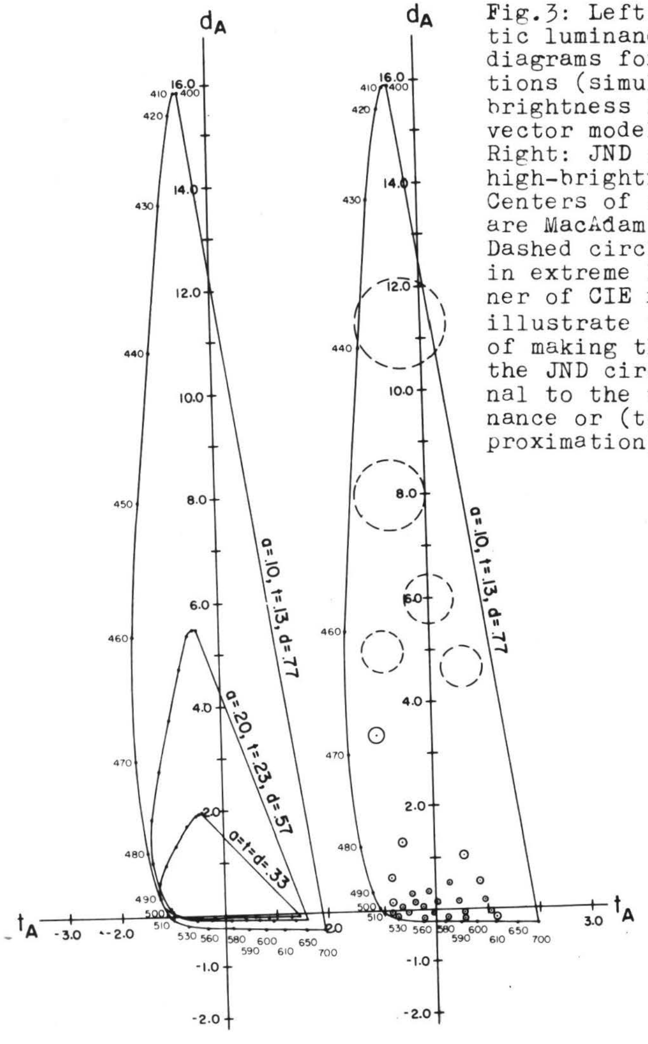

Fig.3: Left: unit achromatic luminance chromaticity diagrams for three variations (simulating three brightness levels) of the vector model.
Right: JND circles in the high-brightness diagram. Centers of closed circles are MacAdam's centers. Dashed circles would fall in extreme lower left corner of CIE x, y space and illustrate the consequence of making the radius of the JND circle proportional to the vector luminance or (to a first approximation) brightness.

and threshold data will only precisely define the <u>relative</u> positions of color vectors in three-dimensional spaces. The correct positioning of a given set of vectors relative to the axes of its three-space can only be accomplished through experiments that concern other-than visual discriminations.

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Carl R. Ingling jr. and Eugenio Martinez, Columbus (Ohio):

Opponent Theory: Revision to Include the X-cell Achromatic Channel

The primate visual system is organized into two parallel sub-channels, the tonic and phasic or X-cell and Y-cell channels. For the primate, the X-cells are color-opponent and signal information about wavelength differences. Analysis of X-cells shows that for high spatial frequencies these cells lose their color-opponency and function as an achromatic or summing channel.

Le système visuel des primates est organisé à deux canaux parallèles: le canal tonique (ou des cellules X) et la canal phasique (ou des cellules Y). Chez les primates les cellules X sont opposées en couleurs, et les informations des signaux correspondent aux différences des longueurs d'onde. Une analyse des cellules X montre que ces cellules perdent leur opposition et elles travaillent comme un canal achromatique ou accumulatif.

Das Seh-System der Primaten ist in zwei parallelen Kanälen organisiert, den tonischen (oder X-Zellen-)Kanal und den phasischen (oder Y-Zellen-)Kanal. Bei den Primaten sind die X-Zellen gegenfarbig und die Signal-Information entspricht Wellenlängen-Unterschieden. Eine Analyse der X-Zellen zeigt, daß diese Zellen für große räumliche Frequenzen ihre Gegenfarbigkeit verlieren und wie ein achromatischer oder summierender Kanal arbeiten.

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Recent zone theories of color vision transform the signals from three kinds of cone to sum and difference signals. That the general principle of taking sums and differences is correct has been confirmed by electrophysiological recordings from many species, including primate. Zone models built upon this principle are successful in accounting for many discrimination functions. Examples of successful zone theories are Guth, Massof and Benzschawel's (1980) optimization of the parameters of Guth's vector model, and Vos's account (at this meeting) of the Vos and Walraven model. The basic form of these models is currently thought to be correct. The task now seems to be to tidy up the details which are the heart of the models, and extend them to explain other phenomena.

We disagree with the assessment that current zone theories are basically correct. It has been our view for some time that major obstacles lie in the way of reconciling current zone theories with the results from electrophysiology, particularly primate electrophysiology. The aim of this paper is to show that a substantial revision of zone theory is necessary.

A typical zone theory transforms the outputs from three kinds of cone (R G B) into three channel sensitivities, r-g, y-b and V_λ. (Fig. 1). The general view of, say, the r-g channel is that it computes the transformation from (primarily) R and G cones to r-g by, say, subtracting the signal produced by quantum absorptions in G cones from those in R cones. This calculation is implemented by the simple-opponent receptive field described in electrophysiological studies; e.g., a circularly symmetric receptive field with say an excitatory center of R cones surrounded by an inhibitory annulus of G cones (Wiesel and Hubel (1966) Type I cells, Gouras's (1968) tonic cells).

The general view of the transformations summarized in Fig. 1 is that the opponent or difference signals carry (primarily)

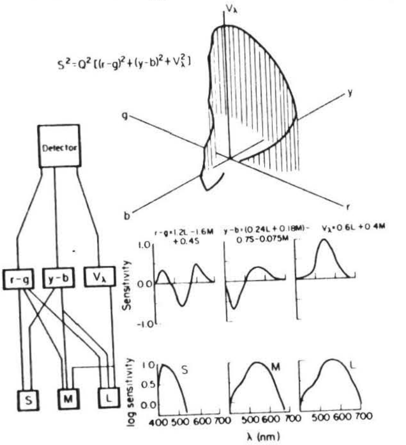


Fig.1.Left:The receptor,differencing and summing, and detector stages. Right: The spectral sensitivity of the channels at each stage.

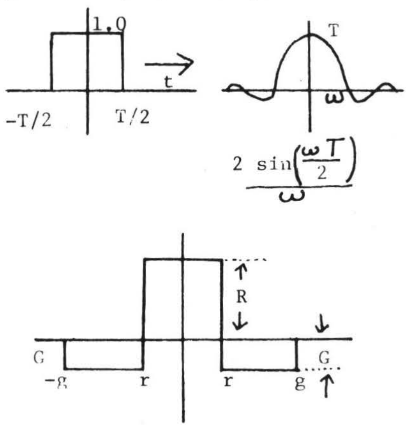


Fig. 2. Top: the sinc function transform for a gate pulse. Bottom: An idealized r-g receptive field.

information about hue (wavelength differences) while the V_λ channel carries information about intensity (luminance, whiteness, etc.) The explanatory power of the zone models derives from quantitative treatment of transformed channel signals similar to those shown in Fig. 1. In particular, the sum signal originates in a channel which adds cone outputs; the opponent signals originate in channels which difference cone outputs.

We have argued elsewhere (Ingling, 1978) that this picture is difficult to mesh with the structure of the visual pathway delineated by electrophysiology. The recent electrophysiological literature indicates a structure for the primate visual system which is composed of two parallel systems: "... (i) a fast system which responds to stimuli phasically, i.e., with transients at on or off, subserved by large neurons having large receptive fields and large axons with short conduction times, preferentially sensitive to low spatial frequencies, and predominantly color-blind; and (ii) a slow system which responds tonically with sustained responses, subserved largely by the midget system of the retina and having the smallest receptive fields recorded, showing long conduction times to higher centers, preferentially sensitive to high spatial frequencies, and whose receptive fields give color-opponent responses." (Ingling, 1978). Lennie's recent review (1980) confirms this description.

The problem in reconciling the X-Y channel structure with Fig. 1 arises when asking the question "which channel mediates detection of high spatial frequencies?" The conventional psychophysical answer is the achromatic channel of Fig. 1. The evidence is (i) spectral sensitivity with an acuity criterion resembles the spectral sensitivity measured with a flicker criterion, and (ii), even more convincingly, mixtures of different lights are additive when an acuity criterion is used. One-half unit of a red grating added to 1/2 unit of a green grating produces one unit of the mixture (Myers, Ingling and Drum, 1973). Substituting a uniform field for the grating yields a subadditive result. The quantitative explanation of this subadditivity is of course one of the triumphs of the opponent models (Guth et al, 1980). From such models derives the dictum that detection by chromatic channels must be tagged by subadditivity.

To summarize, the problem is this: Electrophysiology indicates that the acuity system of the retina is subserved by small, tonic X-cells which comprise some 90% (Lennie, 1980) of foveal cells. Psychophysical tests, on the other hand, exclude this system as the acuity system because X-cells are color-opponent and any task mediated by such cells cannot be photmetrically additive, as acuity tasks are.

Ingling and Drum (1973) and Ingling (1978) resolved this contradiction by proposing that the r-g cells could send two kinds of signal; both a difference signal in response to hue and a sum signal in response to contrasts. Essentially, this hypothesis states that the major <u>achromatic</u> signal arises from the r-g <u>chromatic</u> channel. The remainder of the paper demonstrates the correctness of this proposal.

We wish to prove the following proposition: For low spatial frequencies (simple detection) the spectral sensitivity of the r-g channel is (R-G,) i.e., the conventional opponent spectral sensitivity curve (see Fig. 1). For high spatial frequencies (acuity tasks) the spectral sensitivity is (R + G), i.e., similar to V_λ .

The proof requires knowledge of the Fourier transform for a gate pulse: see Fig. 2 (top). The transform of a rectangular gate pulse is the sinc function, $\frac{\sin \omega}{\omega}$. The curve in frequency space shows the amplitude of the harmonics present in the gate pulse. Given this transform, write the transform for an idealized r-g opponent cell which we represent as shown in Fig. 2 (bottom).

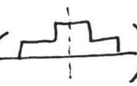
The transform for this receptive field is the sum of the transforms for the center and the surround. The transform for the surround is the difference of two sinc functions. The annulus may be visualized as a rectangular pulse of width g minus a rectangular pulse of the same height, G, with width R. Setting the unit height for G to be one-half the unit height for R (the normalization is explained below) the transform for the receptive field of Fig. 3 is

$$f(\omega) = \frac{2R}{\omega} \sin\left(\frac{\omega r}{2}\right) - \frac{G}{\omega} \sin\left(\frac{\omega g}{2}\right) + \frac{G}{\omega} \sin\left(\frac{\omega r}{2}\right) \quad \text{(Eq.1)}$$

To factor this expression substitute the identities $R = \frac{1}{2}(R + G) + \frac{1}{2}(R - G)$ and $G = \frac{1}{2}(R + G) - \frac{1}{2}(R - G)$ for R and G respectively. Gathering terms then gives (Eq. 2)

$$\left(\frac{R+G}{\omega}\right)\left[\frac{3}{2} \sin\left(\frac{\omega r}{2}\right) - \frac{1}{2} \sin\left(\frac{\omega g}{2}\right)\right] + \left(\frac{R-G}{\omega}\right)\left[\frac{1}{2} \sin\left(\frac{\omega g}{2}\right) + \frac{1}{2} \sin\left(\frac{\omega r}{2}\right)\right]$$

Inverse transform this back to the x-domain from the ω domain by inspection:

$f(\omega) = \left(\frac{R+G}{2}\right)$ () + $\frac{R-G}{2}$ () (Eq.3)

Normalizing the original receptive field (Fig. 2 bottom) to have zero area at 580 nm (center area = surround area) constrains the (R + G) filter to have zero area.

This exercise of transforming to the frequency domain, factoring and inverse transforming to the spatial domain shows that the r-g "opponent" receptive field can be represented as the sum of two receptive fields. The band-pass or tuned field has (R + G) spectral sensitivity, and the low-pass or dc field has (R - G) or opponent sensitivity. Eq. 3 shows the achromatic and chromatic filters in X-space as receptive fields. Fig. 3 shows the same filters in ω space. These curves are simply plots of the (R - G) and (R + G) coefficients. They are spatial weighting functions for the two different "opponent" channel spectral sensitivities. They show that for low frequencies the spectral sensitivity is (R - G), and for high it is (R + G). The spectral sensitivity of the channel is a function of the spatial frequency of the stimulus.

In conclusion, we have shown that the color-opponent cells of the retina, classically viewed as encoding and transmitting only information about hue as a difference signal, actually form the major achromatic pathway of the primate visual system. Our view is that the principal characteristics of primate foveal vision - the ability to see high spatial frequencies in careful fixations - have their origin in a photometrically additive signal originating in small, tonic receptive fields of the r-g opponent cell pathway. We have shown that the r-g differencing channel is also an (R + G) summing channel.

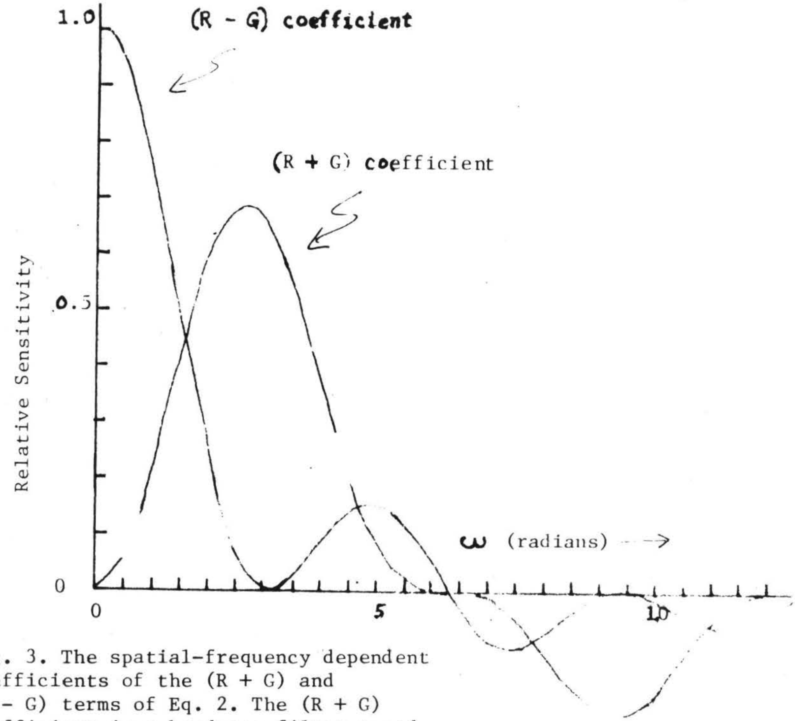


Fig. 3. The spatial-frequency dependent coefficients of the (R + G) and (R - G) terms of Eq. 2. The (R + G) coefficient is a bandpass filter tuned to high spatial frequencies. The (R - G) coefficient is a low-pass filter.

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Theoretical Aspects of Center-surround Subtractions in Retinal Color Coding

The connexion between the three-component and the opponent color theory has been derived with the aid of a randomly distributed receptor mosaic. Non-opponency of simple green and simple red may be explained by receptor compression, the Bezold-Brücke phenomenon by antagonism of red and green cones within the receptive field surround of red-green units. The quality of the fundamental colors is discussed.

On a dérivé la connexité entre les théories de la vision colorée à trois composantes et des couleurs opposées, sur la base d'un mosaïques des récepteurs distribués par hasard. On explique, par une compression des récepteurs, le fait que le rouge simple et le vert simple ne sont pas opposés; le phénomène de Bezold-Brücke s'explique par l'antagonisme des cônes rouges et verts dans le champ réceptif autour des unités rouge-vert. La qualité des couleurs fondamentales est discutée.

Ein wahllos angeordnetes Rezeptor-Mosaik ermöglicht es, die Verbindung zwischen der Dreikomponenten-Theorie und der Gegenfarben-Theorie abzuleiten. Die Nichtopponenz von einfachem Rot und einfachem Grün kann durch Rezeptor-Kompression erklärt werden, der Bezold-Brücke-Effekt durch den Antagonismus der roten und grünen Zapfen, die im rezeptiven Feld die Rot-Grün-Einheiten umgeben. Die Qualität der Grundfarben wird diskutiert.

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Introduction

A quantitative derivation of opponent colour coding based on center-surround subtractions within the Walraven (1974) cone mosaic has been demonstrated (Paulus and Kröger-Paulus, 1980). A local excitation E(C) as estimation of the receptive field surround subtracted from each cone signal C resulted in the colour opponent response H:

$$(1) \qquad H = k \cdot C - E(C)$$

The positive constant k is assumed to relate to the higher receptive field center sensitivity in comparison with the sensitivity of the receptive field surround (RFS). The structure of the RFS and its formation out of three different types of cone within a more or less rigid cone mosaic play an essential part in the foregoing considerations.

The model

The structure of the model may be seen in Fig. 1. The receptor mosaic at the top merely assumes a relative receptor distribution with slightly more green than red cones and relatively few blue cones (according to Marc and Sperling, 1977, 1-2^{o} eccentricity).

Four selected receptor clusters demonstrate the, almost inevitable, outcome of colour opponent channels.
A constant k of k=6 is well suited to counterbalance the influence of the receptive field surround, which in this simplified form is assumed to consist of only the six cones in the immediate surround. Thus in the first example equation 1 reads:

$$(2) \qquad H = 6 \cdot G - 5 \cdot R - 1 \cdot B$$

A predomination of this type of unit against red-center and blue-green surround units may well account for the perception of violet: the blue cone in the surround mediates a red effect at short wavelengths by inhibition of the green receptive field center. The equations of the other three examples are:

$$(3) \qquad H = 6 \cdot B - 3 \cdot G - 3 \cdot R$$
$$(4) \qquad H = 3 \cdot G - 3 \cdot R$$
$$(5) \qquad H = 4 \cdot R - 4 \cdot G$$

Equation (3) is one of seven similar blue-yellow units with any relation between six green cones and no red cone, and six red cones and no green cone, in the receptive field surround. These two extremes may well explain the differences in the neural zones of deuteranopes and protanopes (Paulus and Kröger-Paulus, 1980). The maximal shift of the zero-crossing of the blue-yellow opponent curves of deuteranopes and protanopes, and consequently the maximal possible shift in normal individuals, did not exceed 8 nm.

Similar uniformity is evident in the red-green channels if no blue cone intrusion is present. Equations (4) and (5), as well as any other receptor cluster excluding blue cones, result in an equal amount of red to be subtracted from green or vice versa.

Thus blue cone intrusion or destruction of the regularity of the mosaic in the periphery of the retina causes a disturbance in this relationship as evidenced by equation (2). The convolution array at the bottom of Fig.1 characterizes red-green opponent units by blank areas and blue-yellow units by triangles.

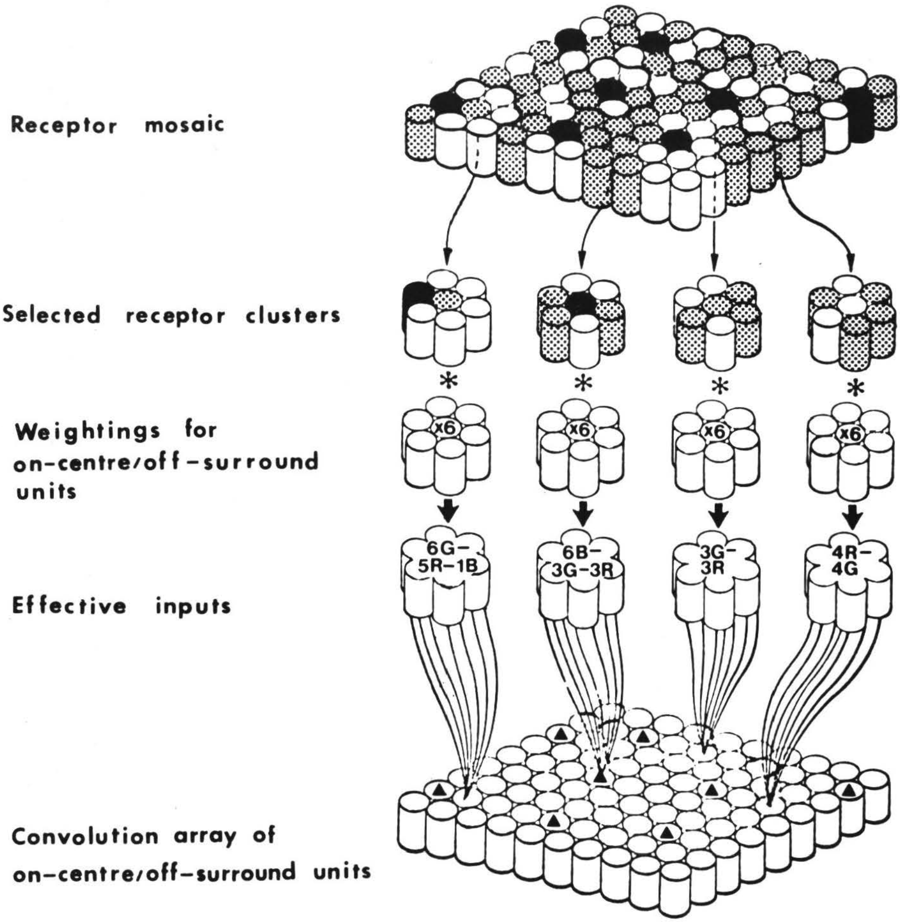

Fig.1. Transformation of three cone inputs R(blank), G(dotted), B(black) into colour-opponent units (convolution array: red-green units blank, blue-yellow units marked by triangles). (Modification of Frisby's figure (1979) with kind permission of author and publisher).

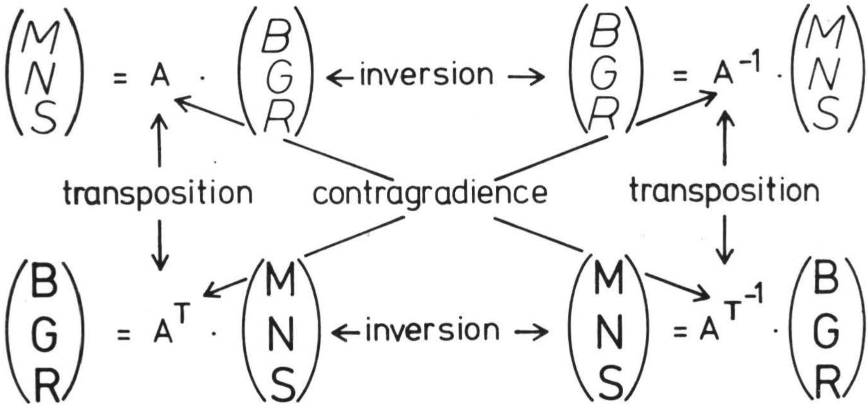

Fig.2. Mathematical relationship between $\vec{R},\vec{G},\vec{B}$ system and $\vec{N},\vec{M},\vec{S}$ system as well as between scalars and vectors (bold face letters). Matrix A may be transposed or inverted.

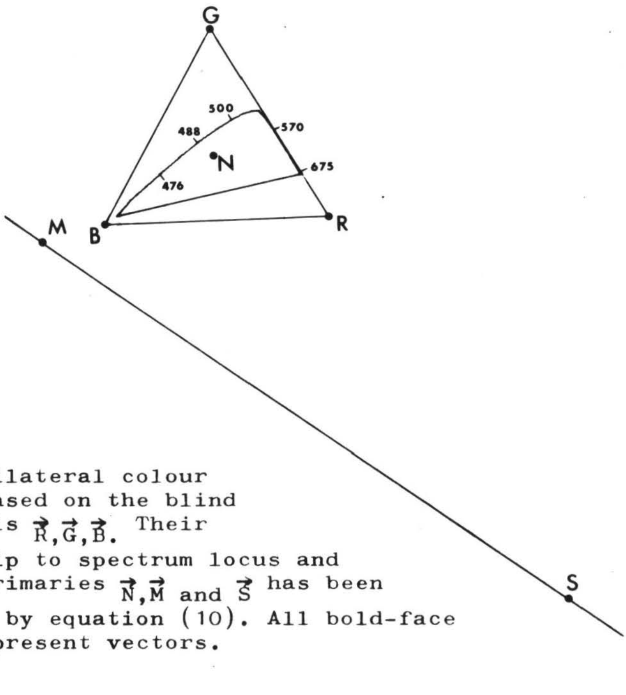

Fig.3. **Equilateral colour triangle based on the blind fundamentals** $\vec{R},\vec{G},\vec{B}$. Their **relationship to spectrum locus and opponent primaries** $\vec{N},\vec{M}$ **and** $\vec{S}$ has been **calculated by equation (10).** All bold-face **letters represent** vectors.

Cone distribution and opponent channels

The assumed cone relationship is quite contradictory to the Walraven mosaic. A recent review by Estevez concerning the incompatibility of colorimetric and photometric data may well explain the overestimation of red cone contribution to $V(\lambda)$ in CIE 1931 Standard Observer based transformations (Vos and Walraven: 1-16-32 for blue to green to red cones). They converted the CIE data into a new system based on the blind fundamentals of the three types of dichromat, transforming the CIE luminosity coefficients 0,1,0 into 1,1,1 for the new system. Marc and Sperling, however, estimated the percentage of red cones in the fovea at 30 to 40%, with the relation of blue cones varying between 3 and 20%. Thus the average distribution is assumed to add in the achromatic channel N to:

$$N = 0.6 \cdot B + 3.24 \cdot G + 2.16 \cdot R \tag{6}$$

with a relationship of 1:1,5 of red to green cones and 10% blue cones of the whole population. B,G,R always refer to signals of red, green and blue cones within an equation in scalar units. The relative numbers of R,B,G add up to 6 in respect to the 6 cones in the receptive field surround.

A blue-yellow channel M is defined as follows: the blue cones will be surrounded on average by 3.6 green and 2.4 red cones, hence:

$$M = 6 \cdot B - 3.6 \cdot G - 2.4 \cdot R \tag{7}$$

In the case of the red-green channels some difficulties arise. As confirmed by equations (4) and (5) the receptive field center and surround relationship remains constant, but the absolute excitation will vary depending on the composition of the receptive field surround. In the extreme cases where, for example, one central green cone is surrounded by six green cones, the unit should act as black-white cell and only detect borders across its receptive field. This type of cell should give almost no response to coloured homogeneous stimuli, while a cell with one central green and six surrounding red cones should give the strongest possible response to coloured light. Therefore the channels should on average have values for R and G midway between 6 and 0, namely:

$$S = -0.6 \cdot B + 3 \cdot G - 2.7\ R \tag{8}$$

Thus the transformation matrix between the three-component and the opponent colour theories derived from a random receptor mosaic reads:

$$\begin{aligned} N &= 0.6 \cdot B + 3.24 \cdot G + 2.16 \cdot R \\ M &= 6 \cdot B - 3.6 \cdot G + 2.4 \cdot R \\ S &= -0.6 \cdot B + 3 \cdot G - 2.7 \cdot R \end{aligned} \tag{9}$$

In order to calculate colour opponent primaries (Paulus and Kröger-Paulus, 1980) the matrix of equation (9) must be transposed and inverted as shown in Fig.2:

$$\begin{aligned} \vec{N} &= 0.1666\ \vec{B} + 0,1666\ \vec{G} + 0.1666\ \vec{R} \\ \vec{M} &= 0.15\ \vec{B} - 0.00957\vec{G} - 0.0273\ \vec{R} \\ \vec{S} &= 0\ \vec{B} + 0.14184\vec{G} - 0.21276\vec{R} \end{aligned} \tag{10}$$

Fig.3 demonstrates the colour loci of these opponent primaries, and hence the relationship between Young-Helmholtz' and Hering's theories by means of trichromatic and opponent primaries within an equilateral colour triangle probably first used by Maxwell (1857).

<u>Receptor compression and the non-opponency of simple red and simple green</u>

Opponent colours are usually defined as colours which combine to white in an additive mixture. However experiments dating back at least to Westphal (1909) result in a slightly yellowish hue, if simple red (on the purple line) and simple green (colours which are neither bluish nor yellowish) are added.

Fig.4 suggests that this deviation is at least partly due to the receptor compression in the cones, for which Boynton (1979) suggested the following equation:

$$(11) \qquad R_4 = \beta \cdot (L \cdot A \cdot p)^{0.7} \;/\; (L \cdot A \cdot p)^{0.7} + 631$$

A = diameter of the pupil, p = fraction of bleached pigment, R_4 = Lum in cd/m^2, β = a scaling constant.

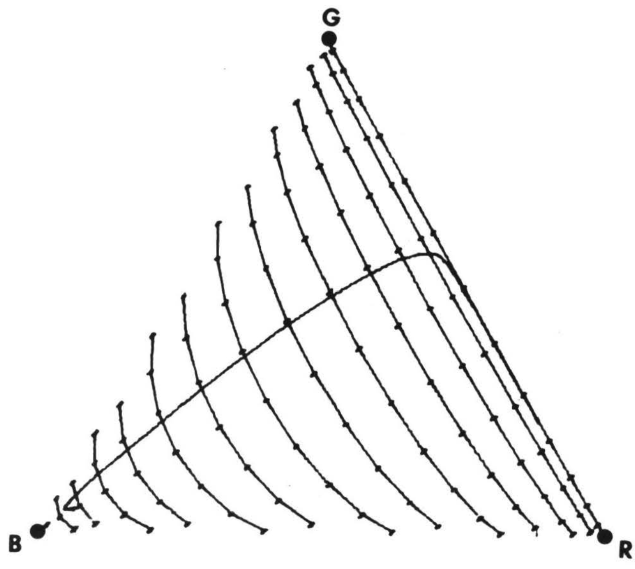

Fig.4. Colour triangle with spectrum locus as in the previous figure. Each line has been calculated by changing the relative amount of receptor output of red and green in such a way that the level of excitation is kept constant. The different lines have been calculated by variation of equal steps of changing blue receptor signal.

The inversion of this equation reads as follows:

$$(12) \quad L = e^{\ln (0.7\, R \cdot 631) \,/\, (\text{ß}-R_4)(\lambda \cdot p)^{0.7}}$$

In comparing the effect of different colours a constant luminance level should be maintained. In this case a constant level of the sum of the receptor output has been assumed:

$$(13) \qquad R_4 \cdot B + R_4 \cdot G + R_4 \cdot R = 100$$

Alteration by constant steps in equation (13) in the relative contributions of red, green and blue cones and calculation of the required luminance values (eq. 12) resulted in lines connecting the triangle sides $\vec{B}$-$\vec{G}$ and $\vec{B}$-$\vec{R}$ with increasing contortion. In Fig. 4 only colours with no blue cone excitation mix to colours with the same amount of yellow or blueness (line $\vec{R}$-$\vec{G}$). Thus with the exception of colours with no blue cone excitation (line $\vec{R}$-$\vec{G}$) any mixture of two colours with a certain yellow-blue level will increase the yellowness of the new colour. The effect may be easily explained by the higher ascent in function (11) for lower luminances which is the case if all three pigments contribute to luminance. If one or two pigments decrease their luminance contribution, the remaining pigment required overproportional stimulation to keep the receptor output constant, and causes a deviation towards its primary.

The Bezold-Brücke Effect

The Bezold Brücke effect accounts for the shifts in the spectral colours due to luminance alterations with predominance of blue-yellow colours at high levels in comparison to red-green predominance at low luminance levels. This effect may be demonstrated as follows: the spectral values of Estevez have first been transformed into R_4 values and then into the opponent stage according to eq. (10). Retransformation has been performed into R_4 values with the aid of inversion of matrix (9) (cf. Fig. 2), each time increasing only the achromatic channel N by a constant amount, followed by transformation according to eq. (12) to get the luminance values.

Fig. 5 demonstrates the contraction of the whole spectrum, accentuated for the red-green direction more than for the blue-yellow direction. This effect is assumed to be strongly related to the antagonism within the receptive field surround of red-green units as mentioned above, and should be exaggerated in high luminances where the receptor compression affects the red-green units much more than the blue-yellow units (eq. 10).

This is in good agreement with the predictions of Hurvich and Jameson (e.g. Hurvich 1977), which assume a higher red-green sensitivity at low luminance levels and a different saturation function for both opponent systems.

Fundamental Colours

The so-called fundamental colours red, green and blue, which may be perceived by stimulation of just one class of the three visual cone pigments, were first suggested by Aristoteles (MacAdam 1975) on a purely phenomenological basis. The blue cones probably mediate a red contribution to the red-green opponent channel, thus the first fundamental colour is assumed by many authors to be violet. Very few doubts arise in case of the red and green primaries. However, as may be seen from Fig.4 the fundamental red and green colours are probably not simple colours (neither yellowish nor bluish). The line representing simple red, green and white in the middle of Fig.4 separates bluish and yellowish colours. Thus fundamental red and fundamental green should be some kind of super-saturated yellow-green and yellow-red.

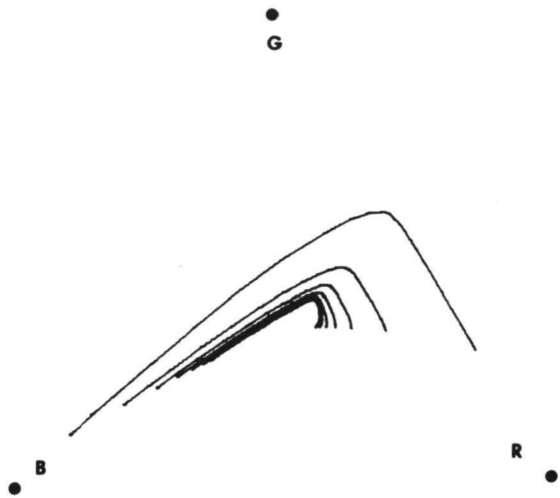

Fig.5. Spectral values have been recalculated from N,M,S values by increasing N by the same amount each time, and keeping M and S constant. The contraction is much more evident in the red-green than in the blue-yellow direction.

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This paper will be submitted in full to Vision Research.

Joel Pokorny, Co-authors of this paper are Vivianne C. Smith, Stephen A. Burns, Ann Elsner and Qasim Zaidi. Drs. Burns and Elsner are currently at the Eye and Ear Hospital, 230 Lothrop St., Pittsburgh, PA 15213, Chicago (IL):

Modeling Blue-Yellow Opponency**

Linear models of yellow-blue opponency are easily constructed but data suggest non-linearities. Some requirements which a non-linear model should fulfill are discussed and published models are evaluated. It is noted that it is inappropriate to model the valence curve with a non-linear combination of pigment sensitivities.

Il n'est pas difficile de construire un modèle linéaire de l'opposition jaune-bleu, mais les résultats souhaitent un modèle non-linéaire. On discute quelques exigences d'un tel modèle qui doivent être accomplies et on regarde des modèles déjà publiés. On a trouvé, qu'il n'est pas approprié de présenter la courbe des valences par une combination non-linéaire des sensibilités des pigments.

Lineare Modelle für den Gelb-Blau-Gegensatz lassen sich leicht konstruieren, aber die Versuchsergebnisse legen eine Nicht-Linearität nahe. Es werden hier einige Erfordernisse besprochen, die ein nicht-lineares Modell erfüllen muß, und schon veröffentlichte Modelle werden kritisch untersucht. Dabei zeigt sich, daß es unangebracht ist, die Valenzkurven durch eine nicht-lineare Kombination der Pigmentempfindlichkeiten darzustellen.

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Many modern color theories postulate that signals arising from cone excitation in three cone types are reorganized in the nervous system to two opponent color channels and one additive luminance channel. Some theories, those postulated for example by Hurvich and Jameson (1955), by Judd and Yonemura (1969) and by Guth, Massof and Benzschawel (1980) use linear modeling. The chromatic component is assumed to reflect a linear combination of cone sensitivities. For this paper we use estimates of the cone sensitivities (Smith and Pokorny, 1975) expressed in terms of a set of CIE (Judd, 1951) revised color matching functions:

$$\text{SWS:}\quad S_\lambda = \bar{z}_\lambda \tag{1}$$

$$\text{MWS:}\quad M_\lambda = -0.15514\bar{x}_\lambda + 0.45684\bar{y}_\lambda + 0.03286\bar{z}_\lambda \tag{2}$$

$$\text{LWS:}\quad L_\lambda = 0.15514\bar{x}_\lambda + 0.54314\bar{y}_\lambda - 0.03286\bar{z} \tag{3}$$

The blue-yellow opponent is then derived by linear subtraction of a "blueness" component given by the SWS curve with a "yellowness" component; for linear models $(y,b)_\lambda$ valence curves are directly expressed in equations involving CIE color matching functions. According to the precise theoretical standpoint, the "yellowness" component may be represented as a sum of MWS and LWS (equation 4, e.g. Hurvich and Jameson (1955); MWS (equation 5, e.g. Judd and Yonemura, 1969); or LWS (equation 6, e.g. Guth, Massof and Benzschawel, 1980). Since "white" is perceived by young observers for spectral distributions near equal energy (Priest, 1921; Hurvich and Jameson, 1951; Valberg, 1971, Burns et al, 1979), we constrain all linear models to have zero $(y,b)_w$ valence at equal energy white ($\bar{x} = \bar{y} = \bar{z}$); to accomplish this, we adjust the coefficient of $\bar{z}$ so that the sum of coefficients is zero. The maximal heights of the valence curves are arbitrary and depend on the exact nature of the model. By convention, the blue valence is negative, For ease of comparison, in equations (4) - (6) constant multipliers are used so that the blue-valence is 0.4089 at 470 nm.

$$(y,b)_\lambda = 0.4\ (\bar{y}_\lambda - \bar{z}_\lambda) \tag{4}$$

$$(y,b)_\lambda = 1.27\ (-.15514\bar{x}_\lambda + .45684\bar{y}_\lambda - .3017\bar{z}_\lambda) \tag{5}$$

$$(y,b)_\lambda = 0.583\ (.15514\bar{x}_\lambda + 0.54314\bar{y} - 0.69828\bar{z}_\lambda) \tag{6}$$

When the output of the (y,b) channel is set to zero, a set of null coordinates for the yellow-blue opponent may be derived and plotted in the CIE (Judd, 1951) x, y diagram. For this purpose, equations (4) - (6) may be rewritten as functions of x and y:

$$y = 0.5 - .5x \tag{4a}$$

$$y = .3977 - .1932x \tag{5a}$$

$$y = .5625 - .6875x \tag{6a}$$

In the CIE x, y diagram, linear models predict a line passing through the equal energy white, intersecting the spectrum locus at or near 500 nm, the locus of equilibrium green for each theory. Each line also intersects the locus of extra-spectral purples predicting that some short wavelength light must be added to long wavelength lights to give the appearance of equilibrium red. According to linear models, equilibrium red is complementary to equilibrium green.

Linear models have two important properties: First the valence of a mixture of two lights equals the sums of their valences:

$$(y,b)_{\lambda_1 + \lambda_2} = (y,b)_{\lambda_1} + (y,b)_{\lambda_2} \tag{7}$$

Second, the null coordinates are luminance invariant. In a linear model, it is usual to give valence curves for an equal energy spectrum. A change in radiance level changes the heights of the valence curves but does not change the position of the null coordinates in the CIE diagram. For example, suppose there is a ten-fold increase in radiance, the $(y,b)_\lambda$ valence curves (equations 4-6) are multiplied by 10; this factor of course drops out in (4a) - (6a). It is irrelevant whether the x,y coordinates are calculated for equal luminance or equal radiance spectra, the null coordinates will be identical. It follows from these properties that $|(y,b)_{\lambda_1}|$ units of λ_2 will cancel $|(y,b)_{\lambda_2}|$ units of λ_1 if the valences for λ_1 and λ_2 are of opposite sign; therefore a linear chromatic valence function is independent of the choice of cancellation of light except for changes of unit. This discussion applies equally to chromatic response functions expressed in terms of cone sensitivities. Both properties will also hold for those non-linear functions which can be treated as linear at equilibrium i.e. for the set of null coordinates.

Although linear models are attractive for their simplicity there are accumulating data indicating that the blue-yellow opponent is not linear. For example (1), unique red is not complementary to unique green (Dimmick and Hubbard, 1939). (2), Valberg (1971) showed that the loci of null points for blue-yellow perception are not collinear. We (Burns et al, 1979) have extensive data confirming Valberg (1971) for a larger region of chromaticity space. In these two studies, null coordinates for blue-yellow perception were determined for various color mixtures and plotted in the CIE diagram. There is a kink near equal energy white and data points connect from unique green to the equal energy white and then turn toward the red corner of the diagram. (3), Ikeda and Ayama (1980) have observed additivity failures of the yellowness component of mixtures or orange and yellow-green lights, a result which implies that two cone types contribute to yellowness and the responses of those cone types do not add linearly to produce the yellow section. (4), Larimer, Krantz and Cicerone (1975) have presented evidence that yellow-blue equilibria are not luminance invariant for a 100-fold change in luminance. They measured changes in unique green and unique red. They derived the following non-linear model from their data:

$$\phi_\lambda = - S_\lambda + k_1 M_\lambda \mp k_2 \,|[L_\lambda - M_\lambda]|^n \tag{8}$$

In equation (8), S_λ, and M_λ, and L_λ are pigment sensitivities such as those given in equations (1) - (3); k_1 and k_2 are weighting constants; and n allows compression of the L-M cone difference signal.

The sign of the non-linear portion is positive when $L_\lambda > M_\lambda$ (above 500 nm for the normalization they used) and negative otherwise. Larimer, Krantz and Cicerone (1975) do not explicitly associate equation (8) with a valence, but they do imply that positive values of ϕ_λ will be associated with "yellow" percepts and negative values of ϕ_λ with "blue" percepts. (5), Werner and Wooten (1979) measured hue cancellation curves for an equal luminance spectrum, referring the data to the conventional equal radiance form. They then modeled the equal radiance valence curves, using an equation of the form:

$$(y,b)_\lambda = - k_1 S_\lambda + |[k_3 L_\lambda - k_2 M_\lambda|^n \tag{9}$$

In considering methods of deriving non-linear models, we are faced with certain restrictions. In a cancellation experiment, the relative heights of the y and b lobes are determined by postulating that when two spectral stimuli, λ_1 and λ_2, are mixed to give an equilibrium percept (that is neither yellow nor blue) then the "yellowness" E_{λ_1} $(y,b)_{\lambda_1}$ of λ_1 is equal to the "blueness" E_{λ_2} $(y,b)_{\lambda_2}$ of λ_2. The amount of "yellowness" at λ_1 and "blueness" at λ_2 needed to cancel each other can be used as units of the "blueness" and "yellowness" This postulate depends on the assumption that the set of equilibria is closed under additive mixture and for radiance changes (Krantz, 1975). It is inappropriate to fit a non-linear model to a valence curve because the non-linearity contradicts this postulate underlying the normalization of heights. Therefore, two lights which will cancel in the proportions predicted by the empirical valence curve, will not add to equilibrium in the non-linear model which is fit to the valence curve.

The use of exponents greater than unity leads to conflicts with data when radiance change is introduced. Consider a ten-fold increase in radiance in the Werner & Wooten model, where the empirically fitted exponent, n, varied from 3.04-3.90. The yellowness component, $|10\ (L_\lambda - M_\lambda)|^3$, will grow one-hundred fold relative to the "blueness" component, $10S_\lambda$. Similarly with a ten-fold decrease in radiance the yellowness component will decrease 100-fold relative to the blueness component. Equilibrium green would have a 70 nm range and the achromatic point would change its chromaticity coordinates from near the usual spectral yellow to near the usual spectral blue.

The Larimer, Krantz & Cicerone model also has shortcomings since it was optimized for a restricted data set; if values of the Vos and Walraven (1970) spectral sensitivity functions are substituted in the model, two out of four observers show a "yellow" percept at very short wavelengths. Their equations do not produce chromaticity coordinates which intersect the "white" region of the diagram.

Non-linearities can also be introduced in other ways than expansion or compression. For example, consider the possibility that the blue-yellow opponent signal is affected by the red-green signal according to equation 10:

$$(y,b)_\lambda = .4\ (L_\lambda + M_\lambda - S_\lambda) - k\ |(L_\lambda - 1.99M_\lambda)| \tag{10}$$

where S_λ, M_λ, L_λ are from equations 1-3, and k is a constant. The first term gives a conventional linear $(y,b)_\lambda$ channel identical to equation 4; the second term gives a linear $(r,g)_\lambda$ opponent similar to that defined by Guth, Massof and Benzschawel (1980). The effect of equation 10 is that the absolute value of the $(r,g)_\lambda$ opponent is subtracted from the (y,b) opponent. This type of equation will give null coordinates that pass through equal energy white and that are not affected by changes in radiance. A luminance dependent or observer-dependent function may be obtained by varying k. An increase in k from 0.1 to 0.5 results in a 4 nm shift to longer wavelengths for unique green, while the yellowness component of long wavelength reds is reduced. Increasing k with luminance increase yields predictions which are consistent with data reported by Larimer, Krantz, and Cicerone (1975) that at higher luminance, less blue cancelling stimulus is necessary to cancel the yellowness content of long wavelength lights. The absolute value function will not be linear for all mixtures of lights. The non-linearity results from the inequality:

$$|(r,g)_{\lambda_1}| + |(r,g)_{\lambda_2}| \geq |(r,g)_{\lambda_1} + (r,g)_{\lambda_2}| \tag{11}$$

Non-linearity occurs for mixture wavelengths of opposite red-green valence (i.e. $\lambda_1 > 570$ nm, $\lambda_2 < 570$ nm). The mixture color will appear yellower than predicted by a linear model. This type of finding was noted by Ikeda and Ayama (1980). The absolute value function provides a restricted type of non-linearity and maintains linear properties for many other conditions.

In summary, we have pointed out that many theorists have concluded that the (y,b) chromatic valence is non-linear. Some non-linear models using exponents have been proposed and optimized on restricted data sets. However, at least one model's derivation violates basic assumptions concerning the nature of equal energy valence curves. Other types of non-linearity may avoid some difficulties associated with the use of exponents. As an example we have used an absolute value function to introduce a non-linearity, but other types of non-linearity could presumably be used. The consequences of the non-linearity must be reviewed both for its effect on the chromaticity coordinates and for its effect under scalar multiplication and mixture additivity. We emphasize that non-linear models may be expressed in chromaticity space but it is inappropriate to model a valence curve using non-linear combinations of pigment sensitivities.

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J. Opt. Soc. Am. 69: 422-434, 1979

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The Zone-Fluctuation Model of Color Vision – A Heuristic Experiment

The introduction of the concept of a photon-noise limited detection accuracy in a zone color vision model has proven a fertile basis for exploring the color vision domain. Successive adjustments to physiological reality could account for an ever growing body of experimental data. Emphasis in this short review is on the heuristic value of the model, rather than on detailed results.

L'introduction de l'idée d'une détectabilité d'exactitude limitée par le bruissement des photons, cette idée se trouvait être très fertile pour l'explication de la vision colorée. L'assimilation successive aux réalités physiologiques a mené à une accumulation augmentée de données expérimentales. Ici on veut souligner la valeur heuristique du modèle, plus que présenter des résultats spécifiques.

Die Einführung des Begriffes der durch das Photonenrauschen begrenzten Genauigkeit der Nachweisbarkeit in das Zonen-Modell des Farbensehens hat sich als fruchtbare Grundlage für die Erklärung des Farbensehens erwiesen. Schrittweise Angleichungen an physiologische Tatsachen haben zu einem stetig wachsenden Bestand an experimentellen Daten geführt. In dieser Übersicht liegt die Betonung mehr auf dem heuristischen Wert des Modells als auf experimentellen Einzelergebnissen.

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1. Introduction

The zone fluction model of color vision, as developed by P.L. Walraven in the sixties, rest basically on two premises:

- o R, G and B receptor signals are recoded in terms of opponent hue signals. This zonal aspect goes back to thoughts, already expressed by Donders (1881) and Von Kries (1929), among others.
- o Signal accuracy is primarily limited by the inherent noise in the photon input. This fluctuation aspect goes back to thoughts developed by Rose (1942) and De Vries (1943), mainly.

The quantitative combination of these two aspects led to the basic wiring diagram of Fig. 1,*l* which essentially boils down to a Cartesian to Polar recoding in ($\sqrt{R}$, $\sqrt{G}$, $\sqrt{B}$) space (Fig. 1,*r*). The attractive thing of this type of recoding is that this square root space is Euclidean (since the fluctuation determined uncertainty domains are spheres of constant size), and thus that the Cartesian to Polar conversion is a neatly orthogonal transformation.

Since its conception, the basic premises have become firmly established through direct electrophysiological confirmation. Opponent color signals could be picked up at the ganglion and geniculate level and quantum bumps were shown to occur in neural signals indeed. On the other hand, it became quickly clear that the scheme of Fig. 1 could only serve as a starting point for adjustment to physiological reality. The foremost merit of the model lies in its adaptability. So far it proved always possible to make such adjustments without touching the basic elements, and so to explain a manifold of color vision phenomena. The present paper will sketch, in broad outline, these successive adjustments and refinements. For details and for justifications in terms of the accuracy of the experimental description, we cannot but refer the reader to the original publications.

2. Non-linearity

Almost from the onset, deviations from linear data transmission at higher intensities were included in the basic scheme. This was necessary to account for the changes in hue with increasing light level,

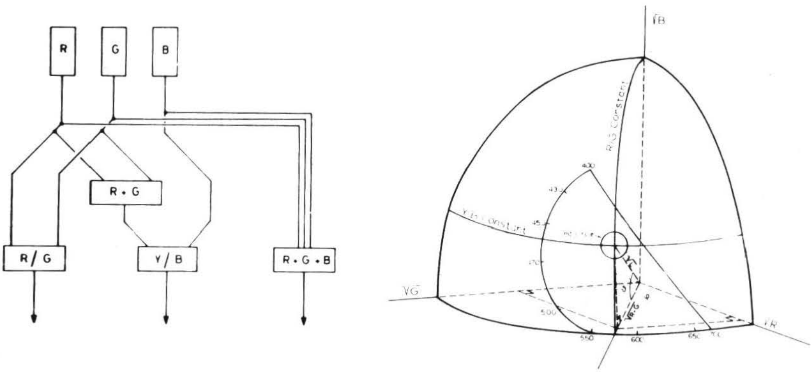

Fig. 1 Zonal processing
Left: Basic wiring diagram. Right: Cartesian to Polar recoding in the Euclidean square root color space.

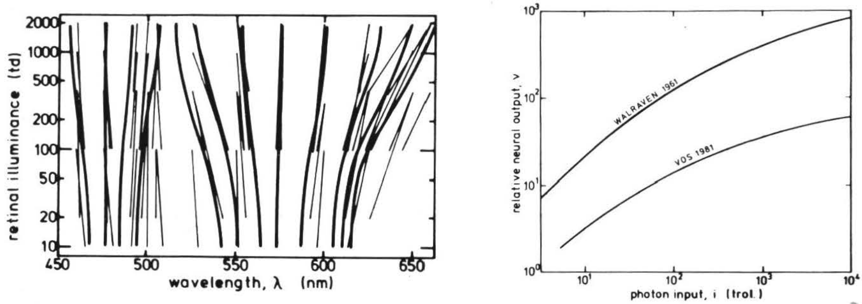

Fig. 2 The Bezold-Brücke effect
Left: Experimental (thin lines; Purdy, 1937) and theoretical (thick lines; Walraven, 1961) courses of constant hue. Right: Two neural transmission characteristics, equally well describing the experimental hue shift. Upper: gradully diverging from linear (Walraven, 1961); Lower: semi-theoretical course going from square-root scaling to logarithmic data transmission (Vos, 1981).

known as the Bezold-Brücke effect (Fig. 2,*l*). With ν_R/ν_G (instead of R/G) and ν_{R+G}/ν_B (instead of $\frac{R+G}{B}$) as determinants of hue the quantitative description of the hue changes proved to be rather successful (Walraven, 1961). This lineartiy also served to describe the deviations from ideal detector behavior (jnd's proportional to $1/\sqrt{L}$) at Weber levels (constant jnd's) (Bouman, Vos and Walraven, 1963). In departure from the original concept, based on linearity at low levels and passive saturation at higher levels, we later explored more sophisticated gain control mechanisms (Fig. 2,*r*) with square root scaling ($\nu \sim \sqrt{L}$) and gradual conversion to logarithmic data transmission ($\nu \sim \log L$) which are more in accordance with physiology and better able to explain the large dynamic range over which the eye can operate (Vos, 1978[1]). Pilot reconnaissances have shown that such an active gain control may well fit with color contrast phenomena (J. Walraven, 1981).

3. Reception densities

To explain the experimental location of the blue hue stable wavelength of the Bezold-Brücke effect (at 476 nm), Walraven had to postulate that the spectral sensitivity of the B-system was much - 16 times, according to the last estimate - higher in its color than in its luminance contribution. Only by that assumption he could move the cross-over point of B_λ and $R_\lambda+G_\lambda$ to 476 nm (Fig. 3,*l*).

It was a rather natural step, then (Vos and Walraven, 1971), to ascribe this "color valence factor" to a relatively low receptor density of the B-system, such in accordance, by the way, with general views on other, anatomical and physiological, grounds. By reckoning with a luminance contribution on the basis of the system output (i.e. sum of the receptor outputs) and with a color contribution on the basis of receptor outputs, one can, indeed, easily understand this color valence effect.

An interesting implication of this concept is, that the gain control, introduced in §2, should seize on the B-system at considerably lower luminance levels than on the R- and G-systems. As a consequence (Fig. 4)

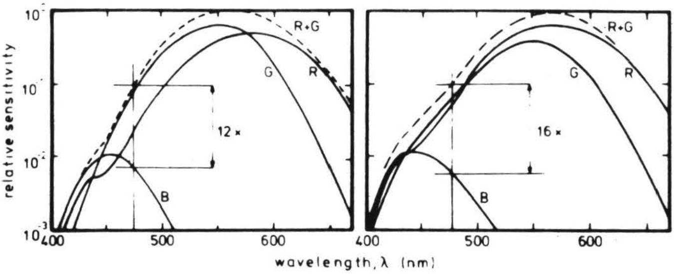

Fig. 3 Action spectra for the three cone systems
Left: Those of Pitt (1944), used by Walraven. Right: Last version, compatible with the present model (Vos, 1978[2]).

the branching of Weber's constancy law from De Vries-Rose's ideal detection law should occur at a 16× lower luminance for the B-system, resulting in a $\sqrt{16}$, thus 4× higher Weber fraction for the B-system - almost exactly the value experimentally found by Stiles (1946). Confident by this agreement, we reversed the reasoning and converted the 40% difference between the R- and G-Weber fraction according to Stiles, to a factor $1{,}4^2 = 2$ ratio between the R- and G-receptor densities. The conclusion of all this is summarized in the formula:

$$N_B : N_G : N_R = \frac{B}{\text{jnd } B} : \frac{G}{\text{jnd } G} : \frac{R}{\text{jnd } R} = 1 : 16 : 32$$

and in the new set of foveal cone system primaries (Vos, 1978[2]) as sketched in Fig. 3,*r*.

4. Locus of gain control

The alinearity in the neural signal transmission was originally located by Walraven in the hue channels, after the luminance-hue bifurcation. This choice was made to comply the alinearity requirements for the Bezold-Brücke effect with the linearity requirement for luminance, known as Abney's law.

Now this law is only true to some extent, and in view of electrophysiological evidence for gain control already at the receptor level,

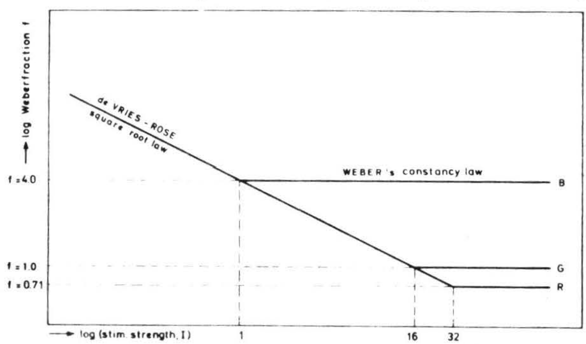

Fig. 4 De Vries-Rose to Weber deflection in jnd I vs. I diagram, based on $N_R:N_G:N_B$ = 32:16:1.

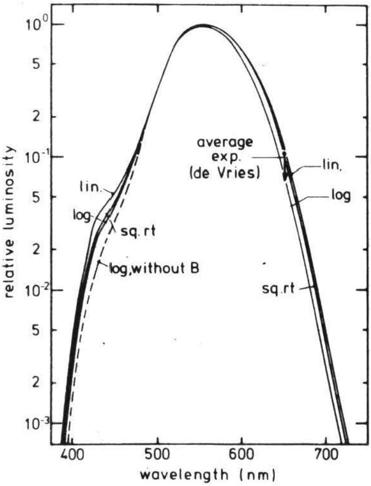

Fig. 5 The near-validity of Abney's law. Lines indicate theoretical courses based on various types of neural transmission characteristics (cf. Fig. 2). Arrow indicates experimental data, taken from De Vries (1948).

the consequences of such a peripheral location upon the model predictions were investigated (Vos, 1978¹). The result was that Walraven's precaution proved not only to be unnecessary, but even disadvantageous to some extent, as a location at the receptor level turned out to be better consistent with the *near* validity of Abney's law (Fig. 5). The thus adjusted model (Fig. 6) moreover produces a change with luminance in the mathematical form of the V_λ-description,

from $\quad V_\lambda = R_\lambda + G_\lambda + B_\lambda \quad$ to $\quad V = R_\lambda^{0.65}\, G_\lambda^{0.33}\, B_\lambda^{0.02}$

which is fully in line with considerations on orthogonality, as expressed by Stiles (1946).

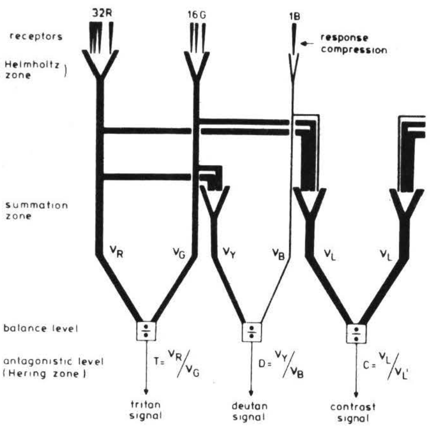

Fig. 6 Improved version of the wiring diagram of Fig. 1,*l*.

5. The B-system

The occurrence of deterioration effects in wavelength discrimination at higher light levels made us to postulate an even stronger gain control than corresponding to a logarithmic input/output characteristic (Vos and Walraven, 1972). A further analysis, triggered by electrophysiological findings on anomalous behavior of the B-system (Gouras, 1970; Van Norren and Padmos, 1973), revealed that the deterioration effects observed could be fully understood on the assumption that the B-system alone should show "over-Weber-behavior" and that it was not necessary to attribute a ceiling effect to the other cone systems. The deviant behavior of the B-system may also serve to settle a so far unresolved dispute on the contribution to luminance of the B-system. Walraven (1974) showed that the locus of the tritanopic confusion point in the (x,y) chromaticity diagram is *just above* the alychne, which points at a small, but significant, contribution. On the other hand, Smith and Pokorny (1975) and, recently, Eisner and MacLeod (1980) claim that the B-system feeds only into the color mediating channels and does not contribute to luminance. The above postulated deviant behavior of the B-system opens a road to reconcile the two views, as the ceiling effect should cause a complete suppression of the luminance share of the B-system. This suppression effect (Fig. 5, dotted line) should take place somewhere between 1 and 10 td.

6. Further extension

The main merit of models is that they serve to substantiate questions by quantifying predictions. That means that the zone fluctuation model can be no finished concept, but should be considered as a line of thinking with a few basic starting points, permanently open to adjustments to physiological reality.

One interesting field for exploration and extension is its dependence on spatiotemporal conditions. The dependence of wavelength discrimination on field size (MacCree, 1960) and the differences in luminance and chromatic flicker frequencies only indicate the importance of spatiotemporal parameters. Walraven and Bouman (1966) showed that the influence of field size could be described in terms of weighting factors for the R/G and Y/B opponent channels. Recently, Noorlander et al. (1980) systematically explored the influence of spectral and temporal frequency on the shape of jnd ellipses and also found that their locus of impact should be sought at the balance level (Fig. 6).

Another area for further research we touched upon already, is the extension of the gain control concept to situations were test and conditioning stimulus are separate. Here we enter a field that is commonly described in terms of π-mechanisms, a concept that so far seems to escape a description in terms of a real model. Preliminary reconnaissances have shown that definite posibilities exist to build a bridge between the two ways of thinking.

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Colour Reproduction: Problems Associated with its Assessment

Colour reproduction is described in two areas, one of which concerns assessment of illuminants used in colour reproduction processes and the other concerns colour fidelity between original and reproduction. Some of the difficulties involved in making the relevant comparisons are described as an introduction to the three contributed papers (Taylor, Pointer, Hunt) to the mini-seminar on Colour Reproduction.

Si l'on parle de la reproduction de la couleur, il peut s'agir de l'évaluation des illuminants que l'on utilise dans les processus de reproduction colorée, ou de la fidélité entre l'original et sa reproduction. Ici on décrit quelques difficultés qui se présentent dans ces comparaisons; cela veut introduire dans les trois contributions suivantes (Taylor, Pointer, Hunt).

Wenn man von Farbwiedergabe spricht, kann es sich einerseits um die Bewertung der Lichtarten handeln, die bei Farbreproduktions-Prozessen benutzt werden, oder um die Farbtreue zwischen Original und Wiedergabe. Hier werden einige der Schwierigkeiten beschrieben, die bei solchen Vergleichen auftreten; dies soll in die nachfolgenden drei Beiträge (Taylor, Pointer, Hunt) einführen.

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An abridged schematic of the comparisons involved in assessing colour reproduction is shown in fig. 1. The discussion can be divided into two main areas:-

I the specialised field now being considered by CIE sub-committee SC-3.2 (Illuminants for Colour Reproduction) where a 'horizontal' comparison (fig.1) between two reproductions is under consideration

II the more general question, involving a 'vertical' comparison of the original with one (or more) reproductions(s).

The objective of SC-3.2 is to develop and recommend methods for assessing new illuminants for use in colour photography, colour television and colour printing i.e. to determine their suitability for replacing the well-tried and frequently used illuminants such as P3000 for studio lighting or alternatives to daylight (e.g. D_{65}) for illuminating sports stadia at night. There are strong economic incentives behind this study: modern illuminants using sources such as metal halide arc lamps have a much higher efficacy than tungsten filament lamps but their spectral power distributions can be very discontinuous with some spectral regions almost completely lacking. The CIE Colour Rendering Technical Committee (TC-3.2) is concerned with the appearance of colours viewed and illuminated in these more modern illuminants. The "Illuminants for Colour Reproduction" sub-committee is engaged in a parallel study of new illuminants for use in photography, television and printing and is attempting to establish methods whereby the colour reproduction obtained using new illuminants can be compared, using a suitable colour metric (e.g. CIELUV), with that obtained using more conventional and well-tried illuminants. The progress of this work in the field of colour television will be described in a paper by E. W. Taylor.

On the more general question (II) we are concerned with how to assess what may be broadly termed "fidelity of reproduction". The assessment poses a number of problems that can be summarised briefly as follows:-

(1) the original is usually three-dimensional and sometimes large; the reproduction is two-dimensional (stereoscopic reproduction apart) and often of limited size with the exceptions of cine projection and theatre television.

(2) The illumination of the original and that of the reproduction or white balance point in the case of television is often different in two respects

(a) chromatic change, for example D_{65} to P3000 or vice-versa

(b) illumination levels.

Dr. M. R. Pointer will contribute a paper on these two aspects.

(3) Apart from size differences, the surround of the reproduction may be of such a nature as to modify the appearance e.g. a dim or dark surround in television, slide or cine projection. In television the effect is such that a gamma of approximately 1.2 is

needed to compensate for loss of colour due to a dim surround and in colour film slide projection in a darkened room, a gamma of approximately 1.4 is required.

(4) With rare exceptions the reproduction is a metameric match to the original rather than a spectral match. This is true for television particularly since rare-earth activated red phosphors have been used; thus observer metamerism may be relevent. It is also a pertinent factor in colour photography.

The purpose of a colour reproduction can vary according to the application. For scientific or medical photography one may be aiming at 'accurate' reproduction (although the definition of 'accurate' is complicated by the factors listed above and generally implies similarity of appearance in as far as this is possible under very different viewing conditions). For other purposes one may be aiming at a 'pleasing' reproduction that is fairly truthful but permits (or even encourages) some distortions that enhance colours in a manner generally liked by the public.

The simple concept of identical chromaticity coordinates for original and reproduction (in the special case where viewing and taking illuminants are the same) together with the same luminance factors relative to white may be a useful first aim-point but there are circumstances where it is inadequate. Hunt has analysed the general situation and has described six types of colour reproduction. His detailed analysis is presented as the third accompanying paper for this mini-seminar on colour reproduction.

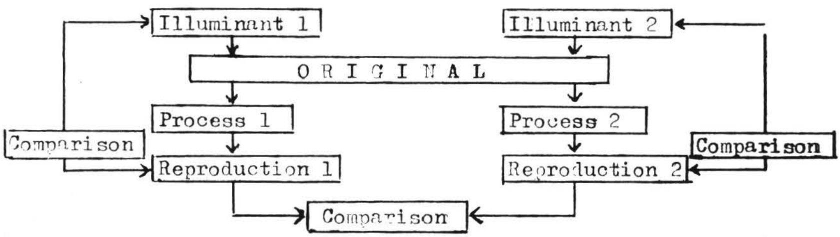

Figure 1 showing block schematic: the horizontal comparison applies to assessment of illuminants. The vertical comparisons assess the fidelity of reproduction for either process or illuminant. The illuminant required for viewing a photographic reproduction is not shown (television requires no illuminant for display as most displays are self-luminous).

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Colour Reproduction Objectives

Six different objectives for colour reproductions are defined: spectral (equality of relative spectral power distributions); colorimetric (equality of chromaticities and relative luminances); exact (equality of chromaticities and absolute luminances); equivalent (equality of appearance); corresponding (equality of appearance with the scene when lit at the same level of illumination); and preferred (departure from equal appearance to achieve a more pleasing result). The objective can be any one of the six, according to the application considered.

Ici on définit six différentes propriétés dans le domaine de la reproduction des couleurs: spectral (égalité de la distribution relative du rayonnenent spectral c.-à-d., égalité des stimulis); colorimétrique (égalité des chromaticités et des luminances relatives); exact (égalité des chromaticités et des luminances absulues); équivalent (égalité de la perception); correspondant (égalité de la perception avec la scène si elle est illuminée au même niveau d'illumination); et préféré (déviation de la perception égale pour produire une impression plus agréable). Chacune de ces six notions peut être appliquée selon la situation considérée.

Sechs verschiedene Begriffe aus der Farbreproduktion werden hier definiert: spektral (Gleichheit der relativen spektralen Strahlungsverteilung, d.h. Gleichheit der Farbreize); valenzmetrisch (Gleichheit der Farbvalenzen); exakt (Gleichheit der Farbarten und der Leuchtdichten); gleichwertig (Gleichheit der Farbempfindungen); entsprechend (Gleichheit der Farberscheinung mit der Szene, wenn diese mit demselben Beleuchtungsniveau beleuchtet ist); und bevorzugt (Abweichung von der Gleichheit der Farbempfindung um ein angenehmeres Ergebnis zu erzielen). Jede dieser sechs Definitionen kann zutreffen, je nachdem, welche Anwendung betrachtet wird.

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Introduction

Colour pictures are used for various purposes: as records of memorable events; as mementos of people; for entertainment and pleasure; as aids to scientific investigations; for instruction; for advertising; for decoration; and for various other purposes. The objectives are not the same in all these cases. It is useful to distinguish six different objectives for colour reproduction: spectral, colorimetric, exact, equivalent, corresponding, and preferred; in different applications the objective could be any one of these six (Hunt, 1970).

Spectral Colour Reproduction

If a colour reproduction system is being used for the production of a mail-order catalogue, for example, then it is desirable that the colours of the goods displayed in the catalogue appear the same as those of the actual goods themselves; it is further desirable that this equality of appearance be maintained when the illuminant colour is changed. For instance, if a prospective purchaser is looking at the catalogue in daylight, then the colours should match those of the goods in daylight; but, in addition, if the catalogue and the goods are both taken into electric tungsten filament lighting then the match should still hold good; if the appearance of the goods has changed, that of the catalogue should have done so equally. And the same should be true for all other common illuminants, such as fluorescent lamps.

This requirement (colour-matching independent of the illuminant) can only be met if the spectral reflectance curves of the original and reproduced colours are identical; this is called <u>spectral colour reproduction</u>. In colour television, the concept of spectral colour reproduction is also useful, but, in this case, since the picture is self-luminous, it has to be defined as equality of relative spectral power distribution. An important feature of equality of spectral reflectance curves, or of relative spectral power distributions, is that it would ensure that the colours matched for all observers (assuming identical viewing conditions), whatever the nature of their colour vision.

In photography, sets of cyan, magenta, and yellow dyes are used and these cannot achieve spectral colour reproduction except for a few special colours; in printing, much the same is true, although the use of a black ink, in addition to the cyan, magenta, and yellow inks, can provide some help, as can the use of additional coloured inks; in colour television, the spectral emission curves of the phosphors are such that the relative spectral power distributions of the displayed colours are usually markedly different from those of the original colours.

There is, moreover, a sense in which modern systems are becoming worse as far as spectral reproduction is concerned. In order to enlarge the gamut of reproducible colours and improve colour reproduction generally, the dyes used in colour photography are tending to become more spectrally selective, and this means that the more prevalent pale and dull colours will be reproduced with poorer spectral colour reproduction. In colour television, spectral colour reproduction has also become worse in recent years with the introduction of the rare-earth red phosphors.

With all the current practicable methods of colour reproduction, whether by photography, by television, or by printing, it is usually impossible to achieve spectral colour reproduction; the only exception is the duplication of an original which itself consists of mixtures of the reproduction dyes, inks, or phosphors. The concept of spectral colour reproduction is, nevertheless, useful, in that it defines the requirement for independence of illuminant colour and of observers' colour vision; and the extent to which any colour reproduction system is sensitive to these factors can be assessed by considering the effects of specified changes in illuminant or observer.

Colorimetric Colour Reproduction

Observer metamerism cannot be eliminated in practical situations, but it has been found that, if computations are made with the C.I.E. Standard (2^{o}) Observer data, the results usually accord well with assessments made by (non-colour-defective) real observers. It then becomes possible to define colorimetrically the particular metamer in the reproduction that would match any colour in the original. Such metameric matches are usually characterized by the original and the reproduction colour having the same C.I.E. chromaticities and relative luminance: this is called <u>colorimetric colour reproduction</u>. (In the case of reflection prints this would normally imply that the original and reproduction illuminants had the same chromaticities; but their spectral power distributions could be different.) The colorimetry is usually carried out relative to a well-lit reference white in the original and relative to its reproduction in the picture. This procedure makes the relative luminances independent of changes in the intensity of either the original or the reproduction illuminant (or, in television, the luminance of the screen). This is a simplification that has some limitations, which we shall discuss later, but it enables the usual type of colour difference formula to be used. Thus, for daylight viewing of reflection reproductions of scenes lit by daylight, the colorimetric evaluations could be made using a daylight-type Standard Illuminant and departures from colorimetric colour reproduction (Pitt, 1967) could be calculated using the colour difference formula currently recommended by the C.I.E. However, it must be remembered that, in pictures, the colours of some objects (such as skin, blue sky, grass, foliage, and greys) are more important than others, and errors in some directions (such as hue) are more serious than in others: a distinction therefore has to be made between the perceptibility and the acceptability of colour differences.

If the appearance of colours were independent of illuminant intensity, then the concept of colorimetric colour reproduction might be applicable to all cases where the original and reproduction illuminants had the same colour (chromaticity co-ordinates); but the appearance of colours certainly is affected, sometimes quite markedly, by the illuminant intensity (which can vary very widely), and hence the achievement of colorimetric colour reproduction does not necessarily imply equality of appearance of colours in the original and in the picture. Moreover, other factors affecting the appearance of colours are also important, as will be discussed later. However, colorimetric reproduction is a useful criterion for reflection prints.

Exact Colour Reproduction

If, in addition to the chromaticities and relative luminances being equal, the absolute luminances of the colours in the original and in the picture are also equal, we have a situation in which differences in illuminant intensity (or screen luminance in the case of television) have been eliminated: this is called exact colour reproduction. Hence the reproduction of a colour in a picture is exact if its chromaticity, its relative luminance, and its absolute luminance, are the same as those in the original scene. This would result in equality of appearance of the reproduced and original colours provided that the state of adaptation of the eye were the same when viewing the original scene; factors that can have an important effect on the adaptation of the eye include the luminance and colour of the surround, the angular subtense, and glare, and only if all these viewing conditions are similar will the adaptation be the same.

Thus, if the reproduction of a certain colour is exact, the observer will only see the same colour as he would have done when looking at the original scene, if a number of important conditions are simultaneously met. In general, there would be a difference in colour appearance: if the viewing conditions were not the same for the original object and for the reproduction; or if the observer differed appreciably from the C.I.E. 2° standard observer; and, in practice, it is frequently the case that the spectral power distributions of the illuminants are not quite identical to those assumed for calculating the chromaticities and relative luminances (so that colorimetric errors may be present).

Equivalent Colour Reproduction

There are many situations where colorimetric and exact colour reproduction are known to be erroneous objectives. For instance, if a scene lit by tungsten light is reproduced in a viewing situation in which the ambient lighting is daylight, then colorimetric and exact colour reproduction would both produce results that were too yellow. This situation commonly occurs in colour television: a studio scene lit by tungsten light, if reproduced on a colour receiver with colorimetric or exact colour reproduction, would look too yellow when viewed in ambient daylighting; this is because the eye would be adapted mainly to the daylight, as a result of its larger area, whereas, in the case of the original the eye would have been adapted to tungsten light and hence would have had its blue sensitivity increased, and its red sensitivity decreased, relative to its green sensitivity.

Because of the effects of the viewing conditions, such as those just described, it is necessary to define a fourth type of objective, equivalent colour reproduction: this is defined as reproduction in which the chromaticities, relative luminances, and absolute luminances of the colours are such that, when seen in the picture-viewing conditions, they have the same appearance as the colours in the original scene.

There are at least three types of effect that are of practical importance in this connection: the effects of differences in colour between the original-illuminant and the reproduction-illuminant; the effects of differences in intensity between the two illuminants; and the effects of differences in the surround of the original and of the reproduction.

Corresponding Colour Reproduction

A problem that arises with equivalent colour reproduction is that, if saturated colours are viewed in sunlight, the sensations they produce are more colourful than those any stimuli (even including spectral stimuli) can produce under typical levels of artificial lighting (Hunt, 1953). To conclude that it must be impossible to produce satisfactory colour reproductions of sunlight scenes for viewing in artifical light is contrary to experience. To overcome this difficulty we need the concept of corresponding colour reproduction, which is defined as reproduction in which the chromaticities and relative luminances of the colours are such that, when seen in the picture-viewing conditions, they have the same appearance as the colours in the original would have had if they had been illuminated to produce the same average absolute luminance level as that of the reproduction. By eliminating any differences in absolute luminance levels between the original and the reproduction we avoid, as in the case of colorimetric colour reproduction, unrealistic conclusions that pictures of brightly-lit scenes cannot be reproduced for viewing at lower levels of illumination, but by requiring equality of appearance in other respects we can allow for the effects of differences in surround and illuminant colour.

The way in which the above definition enables allowance to be made for the effect of the surround on the reproduction of white, grey, and black, colours is illustrated in Fig. 1. The reproduction density required in order to achieve corresponding colour reproduction is plotted as ordinate, and the logarithm of the exposure of the original scene relative to white (Bartleson and Breneman, 1967) is plotted as abcissa (Hunt, 1969). The requirements for three different surround conditions are shown: average surround, such as occurs with reflection prints; dim surround, as for television viewing or viewing sheet transparencies on illuminated opals; and dark surround, as for films projected in a dark room. The gamma has to be raised to about 1.2 and 1.4 respectively for the latter two cases because the dim and dark surrounds reduce the apparent gamma. (Ambient lighting in television viewing situations is usually variable, but it has been found that, if the television display has a gamma of about 1.4 in dark surround conditions, then, as the ambient lighting is increased to typical levels, the amount of viewing flare added usually reduces the gamma to about 1.2 as required (Novick, 1969).

Raising gamma in colour reproduction systems usually results in increases in reproduced purity, but this is slightly offset by saturation being decreased as a result of dim or dark surrounds (Hunt, 1950; Rowe, 1972; Hunt, 1973; Pitt and Winter, 1974; Breneman, 1977).

The concept of corresponding colour reproduction is probably the most appropriate to use generally in colour reproduction problems. It has the same advantage over equivalent colour reproduction as colorimetric colour reproduction has over exact colour reproduction: by relating the colours both in the original and in the reproduction to a reference white, allowance is made for the fact that observers tend to perceive, not in isolation, but with reference to a framework provided by the environment.

For example, when a sunlit scene is projected by tungsten-light with a dark surround, equivalent colour reproduction would call for colours of very high purity in order to produce the sensations of high colourfulness experienced in bright sunlight; but the observer knows that, in the somewhat dimmer conditions provided by the projector, all colour sensations are lower in colourfulness, and the picture will look more natural if this is taken into account. More research is required to quantify these effects, and it is important not to forget that (just as with the concept of colorimetric colour reproduction) the picture will tend to look more like the original if the illumination level is adjusted to be closer to that for the original scene. For example, it is well known that raising the screen luminance of a projected colour transparency raises the quality of a picture of a sunlit scene (Bartleson, 1965); and reflection prints of brightly lit scenes are usually much improved if viewed under strong lighting. Similar effects also occur in television: when the green sulphide phosphor was introduced there was an appreciable reduction in colour purity, and colorimetric colour reproduction deteriorated; but, because the green sulphide phosphor enables pictures of higher absolute luminance to be produced, the loss of purity was offset by a gain in the apparent colourfulness of the colours, and the final effect was that the pictures were improved (Matthews, 1963); in this case, corresponding colour reproduction was made worse, but equivalent colour reproduction was made better.

Preferred Colour Reproduction

There is a considerable body of evidence that for Caucasian skin colour the above concepts must be supplemented to allow for the fact that a sun-tanned appearance is generally preferred to average real skin colour (MacAdam, 1951; Bartleson and Bray, 1962). There may also be other colours where similar considerations apply: for instance, blue sky and blue water are usually preferred in real life to grey sky and grey water; most colour films have some sensitivity to ultra-violet radiation and hence tend to increase the blueness of sky and water relative to the saturation of the other reproduced colours, but such a tendency, if not over-done, may well be preferred to a more consistent reproduction. It may also be desirable to introduce other distortions of colour rendering to create mood or atmosphere in a picture. These factors may be very important in practice, but it is felt that the concepts of spectral, colorimetric, exact, equivalent, and corresponding colour reproduction, provide a framework which is a necessary preliminary to any discussion of deliberate distortions of colour reproduction. In this context, <u>preferred colour reproduction</u> is defined as reproduction in which the colours depart from equality of appearance to those in the original, either absolutely or relative to white, in order to give a more pleasing result. The nature of the preferences will probably be influenced by the nature of the reproduction system used, and it also seems likely that they will be influenced by the particular form of the viewing conditions, and by cultural, ethnic, and psychological features of the observers.

Degree of Metamerism

In the case of colorimetric or exact colour reproduction, the degree of metamerism can be assessed by a direct comparison of the spectral reflectance (or relative power distribution) of the original and reproduction. But in the cases of equivalent, corresponding, and preferred colour reproduction, the colours in the reproduction must, in general, be physically different from those in the original: hence there must always be some metamerism. However, some reproduction colorants will tend to produce corresponding colours with greater degrees of metamerism than others, and some means of assessing this would be desirable. For this purpose it would probably be good enough to assess the degree of metamerism for an appropriate colorimetric colour reproduction situation, and to regard the results as indicative of the degree of metamerism for the other cases. Thus, for a picture of a sun-lit outdoor scene projected with a dark surround by tungsten light, the degree of metamerism could be assessed by comparing the spectral reflectance curves of various original colours with those of dye-concentration combinations in the film that are metameric matches to them for tungsten light.

Conclusions

Spectral colour reproduction (equality of spectral reflectances or of relative spectral power distributions), though not attainable in most situations, provides a useful basis for determining the degree of metamerism of reproduction systems.

Colorimetric colour reproduction (equality of chromaticities and relative luminances) is a useful criterion when the original and reproduction have the same viewing conditions and use illuminants of the same colour; this is often roughly true for reflection prints.

Exact colour reproduction (equality of chromaticities, relative luminances, and absolute luminances) ensures equality of appearance for original and reproduction if the viewing conditions are the same for both.

R.W.G. Hunt

Equivalent colour reproduction (chromaticities, relative luminances, and absolute luminances such as to ensure equality of appearance) can allow for all effects of viewing conditions, but may be an unrealistic criterion if there is an appreciable difference in luminance level between original and reproduction.

Corresponding colour reproduction (chromaticities and relative luminances such as to ensure equality of appearance when the original and reproduction luminance levels are the same) allows for all effects of viewing conditions except absolute luminance levels, and provides a realistic criterion for most situations.

However, for some objects, whose colours are well-known, preferred colour reproduction may be required, wherein departures from equality of appearance (whether at equal or at different absolute luminance levels) may be required in order to achieve a more pleasing result.

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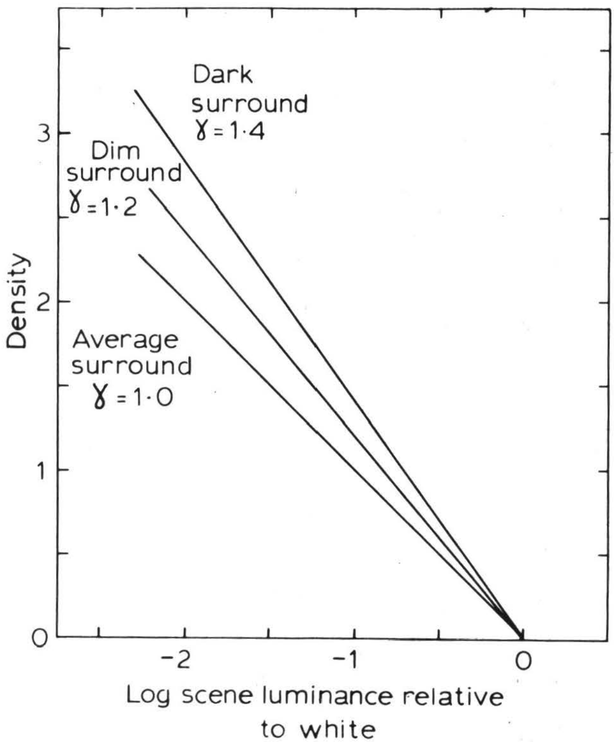

Fig. 1 The density required to achieve corresponding colour reproduction for whites, greys, and blacks, is shown for three different surround conditions: average surround, as is common for reflection prints; dim surround, for television and for the viewing of sheet-films on illuminated opals; and dark surround, for pictures projected in dark rooms.

Michael R. Pointer, Harrow (England):

Colour Scaling and the Projected Transparency

The technique of colour scaling has been used to derive a grid of lines that can be used for predicting the appearance of colours when they are viewed with a dark surround, as is the case when viewing projected transparencies.

On a appliqué la méthode d'échelles des couleurs pour dériver un réseau de lignes que l'on peut utiliser à prédire la perception des couleurs dans l'ambiance noir comme on les voit en cas de la projection des diapositives.

Um ein Liniengitter abzuleiten, das sich für die Voraussage der Farberscheinung bei dunklem Umfeld eignet, wie es bei der Projektion von Diapositiven auftritt, wurde die Technik der Farbskalierung verwendet.

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Traditionally the reproduction of a coloured original scene can be assessed in two ways. First, the colours in the reproduction can be compared with those in the original scene. This can be either a side-by-side comparison or, more usually, the reproduction is compared with what we remember the original scene to look like. This use of memory colour introduces inevitable distortions, or preferences, into our judgment of the quality of the reproduction. A more accurate method of assessment would use colorimetry; the measured chromaticities and luminance factors of the original scene are compared with measurements made of the corresponding colours in the reproduction. Even this approach is not straightforward because allowance must be made in the comparison for the fact that the exposing illuminant and viewing illuminant may be different, the levels of illumination may be different, and the reproduction may have a dark, or dim, surround. Hunt has shown that the use of colorimetry cannot account for all these effects in a satisfactory manner (Hunt, 1979). These differences between the original exposing conditions and the reproduction viewing conditions are still important if a third technique of analysis is used, that of colour scaling or magnitude estimation. This technique is now well established as a method of assessing the appearance of colours and defining grids, or loci, of constant hue and colourfulness, in chromaticity space (See, for example, Bartleson, 1979, and Pointer, 1980).

This technique of colour scaling has now been used to derive a grid of lines that can be used for predicting the appearance of colours when they are viewed with a dark surround, as is the case when viewing projected transparencies.

Experiment

A transparency was projected onto a white screen to provide an adaptation of approximately 60° angular subtense. The test colours were projected from the back of the screen, through an aperture in the screen, such that they subtended an angle of 1° at the observing position. The area, in the transparency, surrounding the aperture was neutral; it was made up of the background of the scene. The transparency itself contained a model and several coloured objects and test colours. The luminance of the scene white was 32 cd/m^2 and relative to it the test colours all had a luminance factor of 0.2. Thus, although they were projected filters, they appeared as surface colours because their luminance was lower than that of their surround. Three observers scaled the hue and colourfulness (as defined in Pointer, 1980) of the 36 test colours 3 times each. A separate experiment was conducted to find the neutral point corresponding to the transparency adaptation condition.

Results

The data were analysed using the method outlined by Pointer (1980) and the resulting grid is shown in Fig. 1. The loci of constant hue are drawn to coincide at the neutral point which had a chromaticity corresponding to a colour temperature of approximately 3600 K. It is seen that this point does not lie in the centre of the lowest colourfulness contour, but is displaced well towards the blue part of the chromaticity diagram.

It is of interest to try to predict this grid using a set of chromatic adaptation transformation equations. The equations derived empirically by Bartleson have been used to transform the author's experimental grid obtained using illuminant D_{65} to an equivalent grid for an illuminant corresponding to 3600 K. A correction had to be made to allow for the fact that the illuminance levels were different in the two experiments. Bartleson has shown that this correction need only be applied to the colourfulness data; the position of the hue loci is independent of the illuminance level (Bartleson, 1979).

The lines drawn on Fig. 1 represent the differences between the experimental 'transparency' grid and that obtained by transforming the illuminant D_{65} grid. It is seen that the hue is predicted very well in the red, yellow/red, yellow, green/yellow, and blue directions but not quite so well in the other directions. Considering the nature of the experiment the overall agreement is quite encouraging. That the colourfulness values are different is explained by the fact that no account has been taken, in the transformation, of the effect of the surround to the projected transparency; the original D_{65} data were derived using a white surround. Thus, the difference between the two sets of data is a measure of the effect of the surround on the values of colourfulness. It is seen that the values of colourfulness are higher for the experimental projected transparency than for the predicted data, implying that a higher colourfulness is needed with the projected transparency surround to match the same colour as seen with a light surround. This agrees with the effect previously reported by Pitt and Winter (1974) and Breneman (1977). The relative size of the effect is less than that found by Pitt and Winter where large areas of test colour were used, and greater than that found by Breneman where small test colours were used.

Thus a grid has been derived experimentally that enables the hue and colourfulness of colours, as seen in projected transparencies, to be predicted. The hue lines of the grid have been satisfactorily predicted from experimental daylight, D_{65}, data using the Bartleson adaptation transformation equations.

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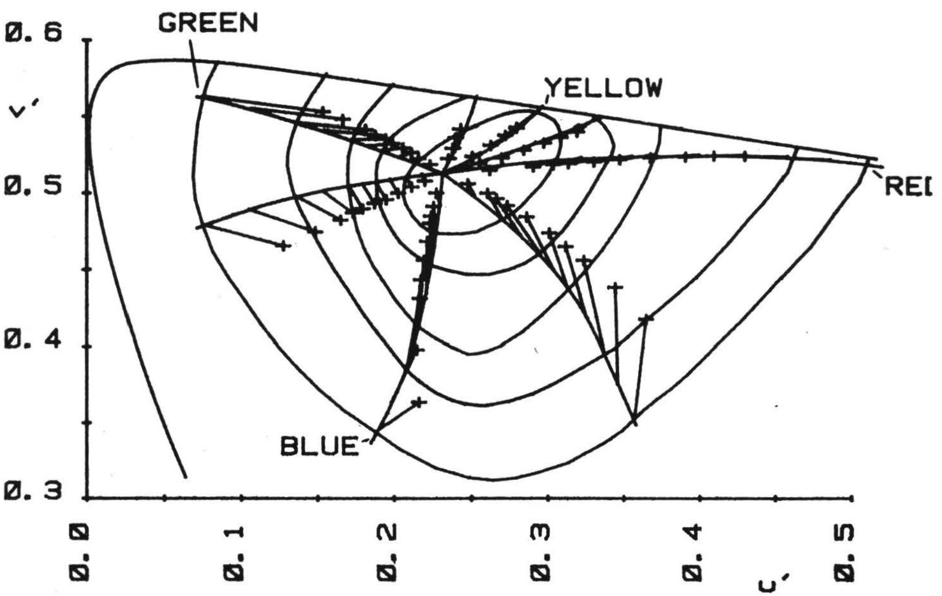

Fig. 1. The 'transparency' grid; loci of constant hue and colourfulness in u', v' chromaticity space. + represents equivalent points predicted from illuminant D_{65} data without allowance being made for the effect of the dark surround.

This paper will be published in full in Color Research and application.

S12

E. William Taylor, Engineering Research Department, British Broadcasting Corporation, Tadworth (England):

The Television Consistency Index: Formulation and Preliminary Tests

The Consistency Index method of assessing lamps for colour television scene lighting is described. A preliminary qualitative assessment is made of the extent to which such an index is representative of lamp performance, while being independent of colour television camera analysis characteristics. The work which is discussed has been carried out under the auspices of the CIE Sub-committee on Colour Reproduction, S.C.-3.2.

On décrit la méthode de l'Indice de Consistance pour l'évaluation de sources lumineuses qui sont utilisées à l'illumination de scènes dans la prise pour la télévision en couleurs. On a estimé l'étendue dans laquelle un tel indice caractérise une lampe, indépendant des propriétés de la caméra. Le travail ici discuté a été fait en connection avec le CIE Sous-comité SC-3.2 Reproduction des Couleurs.

Die Konsistenz-Index-Methode zur Bewertung von Lichtquellen wird beschrieben, die zur Beleuchtung von Szenen bei Aufnahmen für das Buntfernsehen dienen. Der Umfang, in dem ein solcher Index charakteristisch für eine Lampenanordnung ist, wurde versuchsweise abgeschätzt, der von den Eigenschaften der Buntfernseh-Kamera unabhängig ist. Die hier besprochene Arbeit wurde im Zusammenhang mit dem CIE-Subkomitee SC-3.2 für Farbreproduktion durchgeführt.

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1. Introduction

The Television Consistency Index (1) is intended to fulfil the same function in the field of colour reproduction by a television system as that of the CIE Colour Rendering Index in the field of the direct visual observation of colours. It should provide a simple "yardstick" or figure of merit to both lamp manufacturers and lamp users when considering lamps as light sources for television scene illumination.

2. Formulation of the Television Consistency Index

In the calculation of the Television Consistency Index, a set of test colours is assumed to be reproduced by a television system under two conditions : first with the test colours illuminated by the lamp under test as shown on the right of Fig. 1, and then with the colours illuminated by a reference illuminant as shown on the left of the Figure. In each case the television system is balanced (i.e. the relative gains of the colour separation channels are adjusted) so that achromatic scene objects are reproduced with the chromaticity of the display white point. The results of the two conditions of reproduction are compared, colour by colour using a suitable colour difference formula, in the same way as is specified for the Colour Rendering Index. Because the calculation of reproduced test colour chromaticity involves the parameters of the television system both when using the reference illuminant and when using the spectral power distribution of the lamp under test, the television system performance does not enter directly into the value of the Consistency Index obtained. Nevertheless, the index value is to some extent affected by the choice of the television system parameters (see Section 3).

In the forseeable future, tungsten lighting will continue to be used very frequently in studio applications, and it is obvious that daylight will be the normal illumination for outside events. The purpose of the Television Consistency Index therefore becomes the assessment of lamps for lighting television scenes that will most likely be intercut with (or at least be viewed very shortly before or after) other scenes which have been illuminated with either a tungsten source or with daylight. Two reference illuminants have therefore been selected : P_{3000} (a full radiator at a temperature of 3000K) to represent studio working using tungsten illumination, and RD_{65} (Reconstituted Daylight having a correlated colour temperature of 6500K) to represent outside broadcast operations. Consistency index calculations are carried out using each reference illuminant in turn, and the lamp is assessed as "studio compatible for television" or "daylight compatible for television", depending upon which reference illuminant gives the highest index value. This assessment is intended to replace the use of correlated colour temperature as a description of lamp colorimetric performance in television scene lighting applications, since "colour temperature" can be an unreliable guide in this field, particularly when the spectral power distribution of the lamp differs considerably from that of a full or "black-body" radiator.

Following the procedure used in deriving the CIE Colour Rendering Index, an average index value is taken over a number of test colours representing the complete gamut of scene colours that can be reproduced by the television system. Because of the particular importance attached to the correct reproduction of skin tones, a second average is taken over a number of skin-tone test colours to give a "skin-tone" index. Furthermore, because the presence of one inconsistently reproduced colour in an otherwise consistently reproduced scene would have an adverse subjective effect much greater than the overall average index would suggest, the "worst" (i.e. numerically lowest) index value out of the indices obtained for the individual test colours is also quoted, together with the identifying number of the particular test colour concerned. Thus the Television Consistency Index is expressed as four numbers:-

(1) Overall index
(2) Skin-tone index
(3) Worst index
(4) Number of the test colour giving the worst index.

The set of test colours to be recommended for the calculation of the index has not at the time of writing this paper been determined. Work has so far been carried out using an "overall" index taken over 25 test colours which include the eight "BBC" desaturated test colours, the eight "BBC" skin tones, the eight "CIE" desaturated colours and the "CIE" skin tone.

The television system parameters used in the calculation of index values represent, as far as possible, current European practice. It is intended to use the CIELUV 76 colour-difference formula in the calculations, but for comparison purposes the 1964 U* V* W* formula has also been used. The CIELUV 76 formula was used in the work described in Section 3.

3. Tests of the Consistency Index.

3.1 Purpose of the Tests

The fact that the value of the Television Consistency Index is to some extent affected by the choice of the television system parameters used in its calculation is of considerable importance, particularly in respect of the effect on index value of the colour camera analysis characteristics used in the calculation. This is because a large degree of dependence of the calculated index value on the camera analysis characteristics would imply a corresponding practical dependence of lampperformance on the particular type of camera in use in the studio or outside broadcast location. To be of the greatest use, the Consistency Index should be a measure only of lamp performance and should be independent of such factors as the camera analysis characteristics. The index cannot however be taken as representing only lamp performance if it is found that the behaviour of a lamp is strongly dependent on the actual camera in use. Considerable effort is therefore being directed to assessing this aspect of Consistency Index behaviour : a summary of the work which has so far been carried out is given in Sections 3.2 - 3.5 of this paper.

3.2 Method of carrying out the tests

The method of carrying out the tests on the Television Consistency Index has been to calculate index values under a large number of different conditions, and apply statistical analysis to the values obtained in this way to examine the effect of the use of different camera analysis characteristics. A total of fourteen different camera analysis characteristics has been used, twelve being the measured characteristics of different cameras of broadcast standard, and two being "reference camera analyses". The latter analyses have been derived for use in calculating the Consistency Indices, so that a standard method of calculation could be used without reference to any practical camera. The two reference analyses are intended to represent the "narrow-red" category of colour television camera in which the response of the red colour-separation channel is restricted to below about 650 nm by the characteristics of some lead-oxide camera tubes, and the "extended-red" category of camera which is not subject to this restriction. Part of the purpose of the tests on the consistency index is to examine the extent to which these reference analyses are in fact representative of camera analysis characteristics as a whole, and in particular to examine how the differences in index value obtained when using first a reference analysis and then each of the various practical camera characteristics in the calculations compare with the cases in which index values obtained using two practical cameras are compared.

Index values, calculated using each set of camera analysis characteristics in turn, have been obtained using a total of 63 "hypothetical" lamp spectral power distributions. J.J. Opstelten has derived these spectral power distributions by combining the distributions of various phosphors in the case of fluorescent lamps or additives in the case of high-intensity discharge lamps, without however constructing the lamps physically. The 63 lamps are arranged in groups or "lamp families". Each family consists of seven members having different chromaticities. The chromaticities of four members of each family correspond to full (black-body) radiatiors at temeratures of 2600K, 3000K, 3500K and 4200K, while the chromaticities of the other three members correspond to reconstituted daylight with correlated colour temperatures of 5000K, 6500K and 8000K. There are nine families in all designated by the letters A - I inclusive. In any one family (with the exception of Family A) the constituents of the lamp (i.e. the phosphors or additives within it) are the same, but the proportions of these constituents are varied from lamp to lamp to give the required chromaticities. Lamp Family A is exceptional in not representing either a fluorescent or a high-intensity discharge lamp, but consisting of the actual full-radiator or reconstituted daylight spectral power distributions themselves.

3.3 Variation of index value with lamp chromaticity.

For each lamp family and for each camera analysis characteristic, the index value obtained for each member of the family may be plotted against the chromaticity of that member, expressed as colour temperature or correlated colour temperature. Fig. 2 shows examples of such plots using two lamp families (B and G), "overall" index values (see Section 2) and nine "extended-red" camera analysis characteristics. Of those cameras, those coded D, E and I to N inclusive refer to practical cameras, white Camera R is the extended-red reference characteristic. In the case of lamp family B (Fig. 2a) the trend of the relationship between index value and lamp colour temperature is similar for all eameras, and in fact the actual index value obtained for each colour temperature is very similar for the majority of cameras, including the reference analysis. In this case it may reasonably be deduced that the effect of using one camera analysis characteristic rather than another in calculating consistency index values is quite small, and furthermore that the reference analysis quite reasonably represents the majority of practical cameras. In the case of lamp family G, on the other hand (Fig. 2b), the differences between index values obtained for any one colour temperature, using different camera analysis characteristics, are much greater, and the trends in the relationships between index value and colour temperature are much less similar, as compared with those shown in Fig. 2a. In this case the influence of camera analysis characteristic on index value is quite pronounced, and the reference analysis is a rather poor representation of the practical cameras.

3.4 Regression Analysis of Index Values obtained using Pairs of Camera Analysis Characteristics.

Regression analysis of pairs of index values, obtained using two different camera analysis characteristics but with other conditions of calculation otherwise unchanged, provides a convenient method of expressing the influence of the camera analysis on the index value in numerical terms. For each pair of camera analyses examined, the result of such analysis is a "best fit" straight line giving the average relationship between the index values obtained using one camera analysis and the corresponding index values obtained using the other analysis. The "goodness of fit" of the straight line relationship, or in other words the "scatter" in the results obtained under the two conditions of calculation, are expressed by the value of the "correlation coefficient" : a value of unity indicates perfect correlation between the two sets of index values while values less than unity indicate the degree of scatter involved. Regression analysis also gives a "standard error of estimate", which can be used to express a confidence limit around the average result indicated by the best fit straight line. Thus, using regression analysis, index values which would be obtained using one camera analysis can be predicted from the values that are actually obtained using another camera analysis. The prediction takes the form of a "most likely" average value, and upper and lower limits around this average value within which the value will fall with a certain degree of probability. It is customary to adopt a 95% confidence limit, which means that there is a 19 in 20 chance that the index value prediction will fall between the stated limits, and only a 1 in 20 chance that it will fall outside this limit.

Regression analysis carried out by Powell and J.J. Opstelten leads to the conclusion that the confidence limit mentioned above must be considered when comparing consistency index values. Two indices whose difference is smaller than a certain value, derived from the confidence limit, should for practical purposes be considered as being the same : in other words, the lamps that these two indices represent may be considered as being identical in terms of their suitability for television scene lighting. This uncertainty or lack of precision in specifying an index value reflects the fact that different cameras do in fact give different index values for the same lamp spectral power distribution.

3.5 Rank Order Analysis of Index Values obtained using Pairs of Camera Analysis Characteristics.

One of the principal uses of the Television Consistency Index will be to determine which of a number of lamps is most suitable for use as a light source for television scene illumination. The index will be used to "rank" the light sources first, second, third and so on in order of merit in this particular application. It is therefore important to determine the influence of the particular camera analysis characteristic used in the calculation of index value on the order of merit or "rank order" conferred on a set of lamps by their index values. The consistency index will have little value, and may indeed prove to be misleading, if in practice the order of merit of a number of lamps, in terms of their suitability as television light sources, is markedly dependent on the particular camera in use.

The work on rank order analysis has involved the consideration of pairs of rank orders. The two sets of index values which make up the two rank orders in this pair are calculated using two sets of camera analysis characteristics, other conditions remaining the same. A statistical method (2) enables the two rank orders under comparison to be assessed as "significantly different" or "not significantly different".

Differences in rank order obtained using nine extended-red camera analysis characteristics have been assessed. Taking "overall" Consistency Index values obtained using the CIELUV 76 colour-difference formula, rank orders over all 63 "hypothetical" lamp spectral power distributions have been derived, without regard to the "lamp family" structure of these spectral power distributions, and rank orders within each lamp family have also been considered. As far as the ranks over the 63 lamps were concerned, no significant differences in rank order were found, irrespective of the pair of camera analysis characteristics that were involved. The results obtained when rank orders over individual lamp families were taken showed significant rank order differences in the case of a few combintations of lamp family and reference illuminant, but no such significant differences in the majority of cases. The reason for this behaviour has not yet been analysed. No significant differences of rank order were obtained, however, when rank orders were compared over groups of lamps having the same chromaticity but different spectral power distributions.

4. Conclusions and outline of further work.

The results of regression analysis and rank order analysis obtained so far suggest that it may be feasible to index lamps in terms of their performance as light sources in television scene lighting. Any index so obtained should not be taken as a rigidly defined value, but as a centre value subject to upper and lower confidence limits. Two lamps having indices whose difference is less than a certain value, derived from these confidence limits, should be regarded as identical as far as their performance as television light sources are concerned.

In general, the rank order of a number of lamps, in terms of their index values, does not change significantly when different camera analysis characteristics are used. Some combinations of lamp type and reference illuminant do however appear to involve significant differences in this respect and these require further investigation.

The results discussed in this paper must be regarded as tentative since they are based on "hypothetical" lamp spectral power distributions which may or may not be realisable in practice. J.J. Opstelten has measured the spectral power distributions of 66 practical fluorescent and high-intensity discharge lamps and further tests are being carried out using this new spectral power distribution set. It is also intended to carry out practical comparative tests in which some lamps will be assessed in terms of their suitability as light sources for television scenes and an actual studio scene : the results of these tests will be compared with the corresponding "theoretical" assessments of the lamps using the Television Consistency Index.

5. Acknowledgements.

The work described in this paper has been carried out under the auspices of the CIE Sub-Committee on Colour Reproduction, SC-3.2. The author wishes to acknowledge the activities of the members of the SC-3.2 Television Working Party, particularly Dr. J.J. Opstelten (Philips, Netherlands) and Mr. B. Powell (Australian Broadcasting Commission). He also thanks the Director of Engineering, British Broadcasting Corporation, for permission to present this paper.

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It is hoped that this work will be published in Lighting Research and Technology (UK) and the SMPTE Journal (USA).

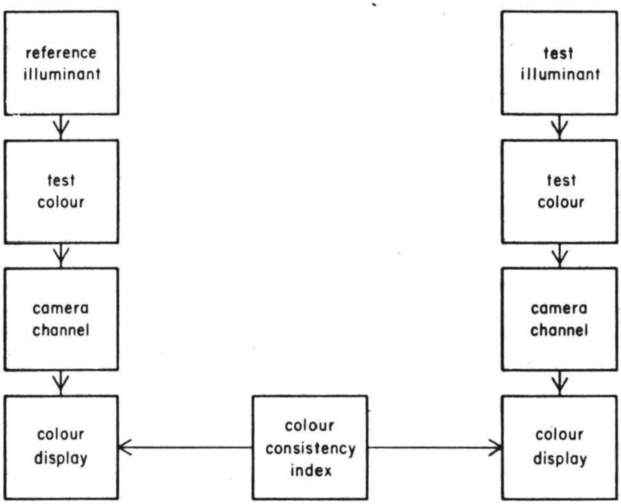

Fig. 1. Method of formulating the Television Consistency Index.

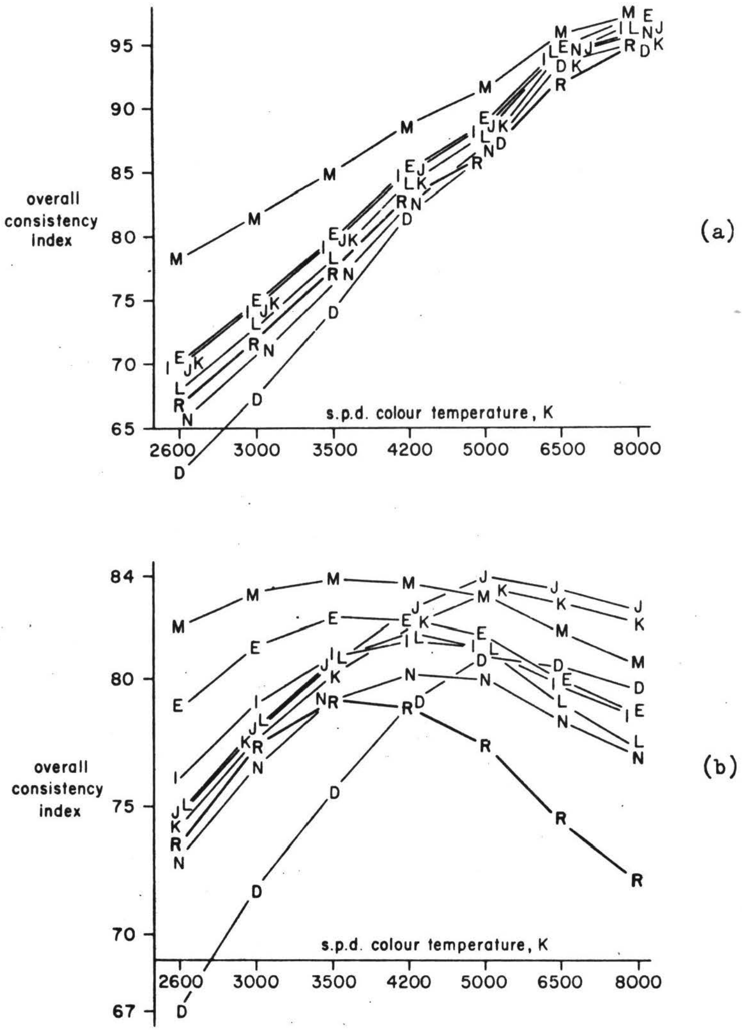

Fig. 2 Examples of relationships between index value and lamp chromaticity.

(a) lamp family B

(b) lamp family G

Letters used as plot points refer to individual cameras.

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