PROCEEDINGS

COLOUR & LIGHT 91

25 · 28 JUNE

INTERNATIONAL COLOUR CONFERENCE

- Visual Arts
- Industry
- Science

Organised on behalf of the

ASSOCIATION INTERNATIONALE DE LA COULEUR (AIC) by:

THE COLOUR SOCIETY OF AUSTRALIA (New South Wales Division)

AIC

POWERHOUSE MUSEUM • SYDNEY • AUSTRALIA

COLOUR AND LIGHT '91

25th - 28th June 1991

Sydney, Australia

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School of Optometry, University of NSW

APPOINTMENTS

Qantas
Jetabout
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Delegates to Colour and Light 91 enjoyed a visit to the Sydney Opera House

CONFERENCE PROGRAMME

Wednesday 26th June

8.30 - 9.00 Registration & Information - Coles Theatre, Level 2, Powerhouse Museum

9.00 Introductions

SESSION 1

9.20 **LIGHTING FOR COLOUR ASSESSMENT & REPRODUCTION**
Keynote Speaker
Colour Assessment in Industry
McGinley P

9.50 The Draft Australian Standard: Colour-Lighting Booth for Visual Colour Assessment. Standards Australia Committee CH/3/9
Bolton J, Dain SJ, Luescher M, Maxwell A, McGinley P, Parsons R, Powell B, Wright RC*

10.10 Methods of Selecting Light Sources for Colour Assessment and Reproduction
Powell B

10.30 Colour Matching using Fluorescent Lamps and the Judgement of the Whiteness of Papers.
Schultz UE

10.50 BREAK

11.10 Lighting for Colour Vision Examination - an Outline of the Problem
Dain SJ

11.30 Quality of Daylight Simulators
Terstiege H

11.50 Simulating Surface Colors on CRT Displays: The Importance of Cognitive Clues.
Berns RS, Gorzynski ME*

12.10 Thresholds and Scaling of Light and Colour by an Opponent Model of Vision
Richter K

12.30 LUNCH

SESSION 2

2.00 **COLOUR IN THE VISUAL ARTS AND ARCHITECTURE : PART A**
Keynote speaker
Light and Colour in Environment Design
Spillmann W

2.30 Colour and Architecture. The Colouring of the Crystal Palace for the Great Exhibition of 1851 in London
Brino G

2.50 So What is New About Colour? Interior Design Colour Schemes in 1870 and 1970.
Denne D

3.10 Colour and Light: The Visual Reality of Architectural Space.
Styne A

3.30 BREAK

3.50 Impact of Colour and Light on the office Environment - A Breakthrough Study.
Kwallek N, Lewis CM, Dilling J*

4.10 Hong Kong Housing Harmony Chromatic Chart
Cler M

4.30 Colour & Light: A Post-occupancy Evaluation of a Student Health Centre.
Burton CM, Anderson CC*

4.50 Entropy and Colour
Light W

5.10 Light and Colours in Chinese Architecture and Architectural Paintings.
Yang C

CONFERENCE PROGRAMME

Thursday 27th June

8.30 - 9.00 Registration & Information - Coles Theatre, Level 2, Powerhouse Museum

SESSION 3

9.00 COLOUR EDUCATION
Keynote Speaker
Color Science Education in the 1990's
Berns RS

9.30 Creative Colour Communication
Fay E, Leith P**

9.50 Nordic Interest in Colour Research and Education
Sivik L

10.10 The Teaching of Light and Colour in Schools of Architecture
de Mattiello MLF

10.30 Colour Navigation
Maxwell-Smith E

10.50 BREAK

11.10 Localised Environmental Colour Palette
Day PW

SESSION 4

11.30 Colour in the visual arts and architecture - Part B
The Relationship of Light-and-Shade to Colour in European Painting
Osborne R

11.50 Colour in the Fourth Dimension
Green-Armytage P

12.10 On the Subjective Colours of Stained Glasses.
*Ronchi LR, Schanda J**

12.30 LUNCH

SESSION 5

2.00 INSTRUMENTATION FOR COLOUR MEASUREMENT
Keynote speaker
Making Meaningful Colo(u)r Measurements
Simon FT

2.30 The Sensitivity of various Instruments in the Measurement of Small Colour Differences: A Comparison
Raggi A, Barbiroli G*

2.50 A Modular Design Smart Colorimeter.
Dobrentei L, Reti I, Schanda J

3.10 Parameterising Colour-Difference Evaluation.
Witt K

3.30 Colour Uniformity as a Food Quality Factor
Barbiroli G, Raggi A, Mazzaracchio P*

3.50 BREAK

SESSION 6

3.50 - 5.00 POSTER SESSION

CONFERENCE PROGRAME

Friday 28th June

8.30 - 9.00 Registration & Information - Coles Theatre, Level 2, Powerhouse Museum

SESSION 7

9.00 **Invited speaker**
Colour of the Stars
Malin D

9.30 Goethe's Theory of Colours
Merz B

9.50 The Gem of a Thousand Lights
Costello M, Costello J, Weber R**

10.10 Ideal primary Colours: Theory and Relations with other Functions
Pridmore RW

10.30 Ergonomic Aspects of Colour Monitors
Tonnquist G

10.50 BREAK

SESSION 8

11.10 **Special lecture on the occasion of the acceptance of the Deane B. Judd AIC Award**
Back to Helmholtz
Voss JJ, Walraven PL

SESSION 9

11.40 COLOUR IN THE VISUAL ARTS AND ARCHITECTURE: PART C
Colour in Marketing: Is there any Reliability in the Anticipation of the Colours to Come?
Oberascher L

12.00 NCS, a Method for Determining Perceived Colours of Object in Environment Observed Under Various External Conditions
Hård *A, Hård T**

12.20 Comparison Between Aperture and Surface Colours.
Indow T

12.40 LUNCH

SESSION 9 **continued**

2.00 Cross-cultural Studies of Color Meaning
Sivik L, Taft C*

2.20 Colour Appearance and the Effect of Simultaneous Contrast.
*Scrivener SAR, Luo MR, Clarke AA, MacDonald LW**

2.40 Coloured Transparency Over an Undulating Surface
da Pos O, Pietrella M

3.00 The orchestration of Colour and Light in Nature and Art.
Bull D-M

3.20 BREAK

3.40 Colour and Interior Design
Fernandez BM

4.10 Color and Physiological Arousal
Mikellides B

4.30 Color and Physiological and Physiological Effect of Colour Light.
Shimagami K, Hihara M*

4.50 Textural Properties of the Traditional Materials and the Possibilities of Using these Materials Today
Aytug A, Evci F

5.10 CLOSING SESSION

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* *Speaker*

Colour Education

Instrumentation for Colour Measurement

* *Speaker*

* *Speaker*

FOREWORD

This is a collection of most of the papers presented at the interim meeting of the Association Internationale de la Couleur (AIC) held in Sydney in June 1991. This conference was organised by the New South Wales Division of the Colour Society of Australia and was the Society's third national conference.

The theme of the conference was Colour and Light with presentations organised into the following sessions: Lighting for Colour Assessment, Colour in the Visual Arts and Architecture, Colour Education, Instrumentation for Colour Measurement, and Miscellaneous, a session for general interest papers not fitting into the preceding categories.

In an attempt to provide consistency in presentation, the convenor of the Papers Committee, Dr Stephen Dain, had asked authors to provide their manuscripts as camera ready in a specified format or as a text file on a floppy disc. Only two papers were received on disk and the remainder supplied using a variety of type faces, character size and formats. It was therefore decided that all papers should be converted to text files using a scanner and optical character recognition software thereby enabling all papers to be published in a common style.

The task of scanning the papers has fallen to me and I must accept responsibility for any mistakes that may have crept in. I would like to thank Carol Arthur and Loris Isabel for their help in designing the format and for their patience in checking each paper.

Finally, and most importantly, I would like to thank the authors who have contributed by making their papers available for publication in these proceedings.

Bryan Powell
Chairman Organising Committee.

Lighting for Colour Assessment

ABSTRACT ONLY

KEYNOTE ADDRESS:

COLOUR ASSESSMENT IN INDUSTRY

Peter McGinley

Dulux Australia Pty Ltd, PO Box 60, Clayton, Victoria 3168, Australia

The attainment of a colour approval by a customer in an industrial situation has required patience, colour matching skills, negotiation power and some luck. The ideal of the exact colour match sought by many demanding customers can neither be achieved by the supplier nor afforded by the customer. The ability to judge the customer acceptability of a match became the colour matcher's greatest asset.

Much progress has been made toward formalising this process with improved control over viewing conditions, application of instrumental methods of colour assessment and statistical approaches to the analysis of data. The specification of the required quality of colour match has however remained an area of uncertainty.

The recent adoption of supplier quality assurance techniques requires the responsibility of the colour match to be passed back to the manufacturer as it has been for some time with many other physical and chemical properties. The problem of specification now becomes one of fitness for use and is the responsibility of the manufacturer.

ABSTRACT ONLY

THE DRAFT AUSTRALIAN STANDARD: COLOUR-LIGHTING BOOTH FOR VISUAL COLOUR ASSESSMENT

Bolton, J.,* Dain, S.J., Luescher, M., Maxwell, A.
McGinley, P., Parsons R., Powell, B., Wright, R.C.
Standards Australia Committee CH/3/9 - Methods of Colour Measurement

Standards Australia Committee CH/3/9 is responsible for, *inter alia,* the revision of Australian Standard 1580.601.1 Colour - Visual Comparison. In revising the procedures of this standard the Committee has found it necessary and expedient to draft a product standard for a lighting booth for visual colour assessment. The draft standard will shortly be issued for public comment and the requirements of the standard will be discussed here along with some of the considerations which went into the writing of the requirements. Whilst the CH/3 set of committees is mainly concerned with the visual assessment of the colours of paints, CH/3/9 see a role for this product standard in other areas where colour assessments are made. A copy of the latest draft of the standard will be made available in the satchels given to you at the time of registration. Discussion and comments both after the presentation and outside the session would be appreciated by the Committee.

METHODS OF SELECTING LIGHT SOURCES FOR COLOUR ASSESSMENT AND REPRODUCTION

Bryan Powell

Federal TV Technical Services
Australian Broadcasting Corporation
GPO Box 9994, Sydney, NSW 2001, Australia

ABSTRACT

Since the advent of the electric light source, lamp manufacturers have been searching for ways to produce more light, more efficiently, and from smaller sources. A wide range of sources is now available having colour temperatures ranging from the warm colour of an incandescent lamp to the cool blue of daylight but often at the expense of their colour rendering properties.

Different types of light sources have different spectral characteristics and it is these characteristics that primarily determine the colour rendering properties of the source. Other factors include the spectral reflectance characteristics of the test colours, the spectral characteristics of the observer and the state of chromatic adaptation. When selecting light sources for use in colour assessment and reproduction it is essential to consider all the above factors.

INTRODUCTION

There are many different types of light source available today. These sources can be broadly classified as tungsten filament, quartz halogen, tubular fluorescent, or gas discharge.

The spectral power distribution of an incandescent or quartz halogen lamp is smooth and continuous throughout the visible spectrum and is influenced only by the temperature of the filament. Increasing the lamp current increases the temperature causing the emitted light to become more blue until the filament finally evaporates. Such lamps may be specified in terms of their colour temperature or more correctly, their distribution temperature.

The spectral power distribution of tubular fluorescent and gas discharge lamps is not smooth throughout the visible spectrum and is dependent upon the type of gas used and the type of phosphors or metals added. These types of lamps can produce a wide range of spectral power distributions and, consequently, appear in many colours.

This paper provides a brief description of three different methods for selecting light sources suitable for use in areas where colour matching or colour reproduction is critical.

COLOUR RENDERING INDEX

In 1971 the International Commission on Illumination (C.I.E.) published a method of specifying the colour rendering properties of light sources[1]. This method, known as the test colour method, is based on the resultant colour differences obtained when an observer views a given set of test colours illuminated first by the light source under test and then by a suitable reference illuminant. In practice, however, these comparisons are made by calculation using the spectral characteristics of the light source under consideration, a suitable reference illuminant, the CIE standard colorimetric observer, and a set of test colours.

The general Colour Rendering Index (R_a) is intended to provide an indication of the average colour rendering properties of the light source for use in the domestic, industrial and commercial environment where no fluorescence is present.

Test Source

The spectral power distribution of the light source under consideration is measured using a spectroradiometer. Measurements are often made within the wavelength range 380nm to 770nm at 5nm intervals and sometimes as much as 360nm to 830nm at 1nm intervals. The chromaticity of the light source is then calculated with respect to the CIE 2° standard colorimetric observer and, from that, its correlated colour temperature is determined.

CIE Standard Observers

In 1931 the CIE published a set of tables representing the spectral colour matching functions of a standard observer having normal colour vision over a 2° field of view. In 1960 the CIE published a supplementary set of functions but this time for a standard observer having a 10° field of view. Both sets of functions are still in use today and provide the basis for all colorimetry[1,2]. Figure 1 shows the spectral colour matching functions of the CIE 2° standard colorimetric observer.

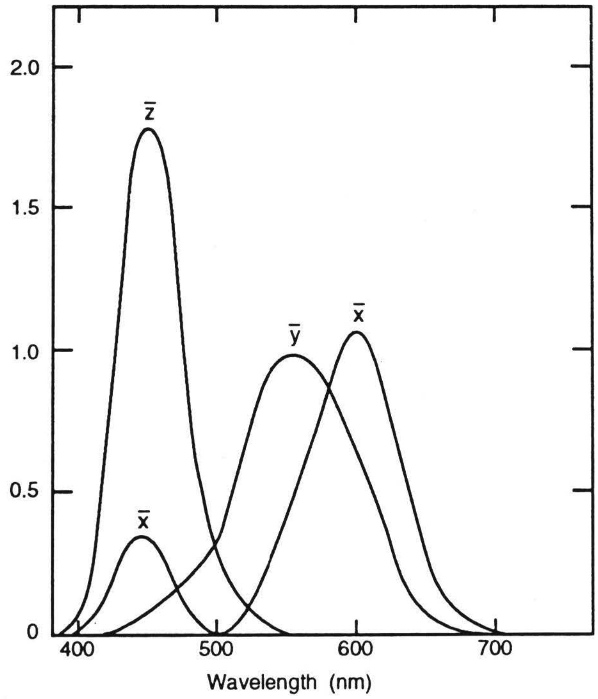

Figure 1. CIE 2° Standard Colorimetric Observer

Test Colours

CIE Publication 13.2, Method of Specifying the Colour Rendering Properties of Light Sources[3], gives the relative spectral radiance (reflectance) characteristics of a set of 14 test colours. The first 8 test colours are of approximately equal saturation and lightness distributed on a circle of hues around the chromaticity of an equal energy white. The other 6 samples represent Caucasian skin, green foliage, blue sky and more saturated colours. The chromaticities of the 14 test colours are calculated with respect to the test source

and the colour matching functions of the CIE standard 2° colorimetric observer.

Reference Illuminant

The reference illuminant against which all colour difference comparisons are made is determined by the chromaticity and, consequently, by the correlated colour temperature (cct) of the test source. If the test source has a cct of less than 5000K, the relative spectral power distribution (spd) of the reference illuminant is determined using Planck's equation. If the cct of the test source is equal to or greater than 5000K the reference illuminant is determined by calculating the relative spd of a phase of daylight having the same cct. The locus for Planckian and reconstituted Daylight chromaticities is illustrated in figure 2 below.

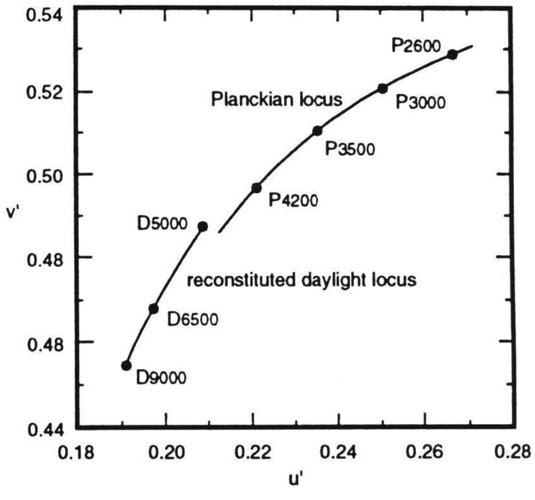

Figure 2. Planckian and Daylight locus on the CIELUV 1976 chromaticity diagram.

Chromatic Adaptation

Whilst the test source and reference illuminant are intended to have the same cct there will in most cases be some difference in their chromaticity. It is, therefore, necessary to include some calculation to take into consideration the change in chromatic adaptation that would be involved if an observer were to view the set of test colours first under the light source under test, then the reference illuminant. This is achieved using a linear transformation devised by von Kries.

Colour Difference Evaluation

The chromaticity of each test colour is calculated with respect to the reference illuminant and the colour difference between test source and reference illuminant for each colour determined.

TELEVISION ILLUMINANT CONSISTENCY INDEX

This index has been developed to provide an indication of the suitability of a light source for use in colour television. Unlike the Colour Rendering Index, the television system must take into consideration the spectral properties of the television camera (instead of the standard observer) and the reference illuminants must represent typical light sources used in the studio or on outside broadcast. Figure 3 is a block diagram showing the difference between the methods of calculating the Colour Rendering Index and the TV Consistency Index.

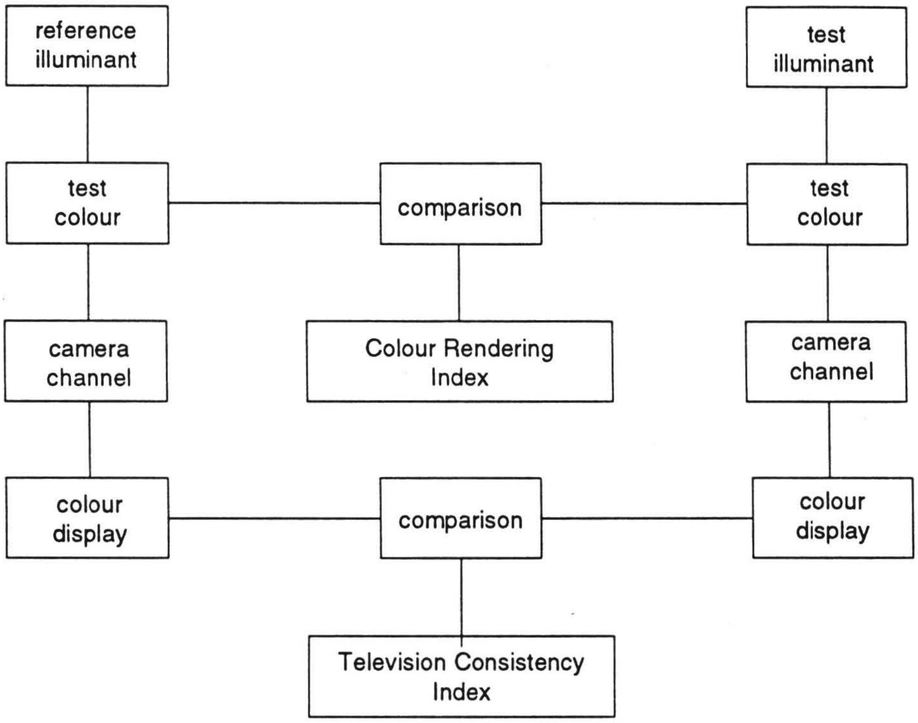

Figure 3. Block diagram showing the different methods of calculation of the Colour Rendering and Television Consistency Indices.

Reference Illuminants

The Television Consistency Index[5] is based on the principal that a lamp would be considered suitable for colour television if it gave consistent colour reproduction when compared with one of two reference illuminants. One reference illuminant[4] represents a phase of daylight typical of that encountered in outside broadcast (CIE Illuminant D_{65}) whilst the other represents conventional tungsten lighting used in a colour television studio operating at a colour temperature of 3000K. This reference illuminant is designated P_{3000} since it has the spd of a black body (Planckian) radiator operating at 3000K.

Camera Reference Analyses

Like humans, different cameras have different spectral characteristics so it was necessary to establish a standard set of characteristics that was representative of the majority of broadcast quality cameras that could be used in the calculation of the Television Consistency Index. This set of characteristics, shown in figure 4, is known as the Extended-red Reference analysis since it was based upon cameras fitted with this type of tube.

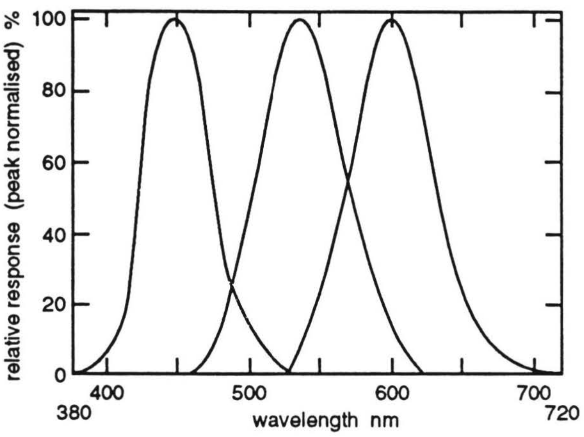

Figure 4. Extended-red Reference Analysis for a typical broadcast quality, colour television camera.

Tests were performed using the spectral sensitivities of a number of real cameras and the Extended-red reference analysis to determine what influence the analyses had on the Television Consistency Index. The principal methods of analysis were regression and rank order difference analysis. In both cases, the analysis was in terms of comparisons between two sets of Index values, each using the same lamp spd and set of test colours, but changing the camera analyses. The results of these tests indicated that calculations could be performed with confidence using the Extended-red Reference analysis to determine the TV Consistency Index without having prior knowledge of a particular camera's spectral characteristics.

Test Colours

Three sets of test colours were used while developing the TV Consistency Index. Each set was chosen to ensure that all test colours had chromaticities that were contained within the gamut of reproducible colours using EBU standard phosphors. This gamut is illustrated in figure 5.

The first set consisted of 25 theoretical colours specified by their spectral characteristics. Skin tones are the most critical colour for the television system has to reproduce so this set of test colours includes 8 different skin tones.

The second set of test colours consisted of the measured spectral reflectance characteristics of the 18 colour samples used on the Macbeth Color Checker. Two of these colours represent dark and Caucasian skin.

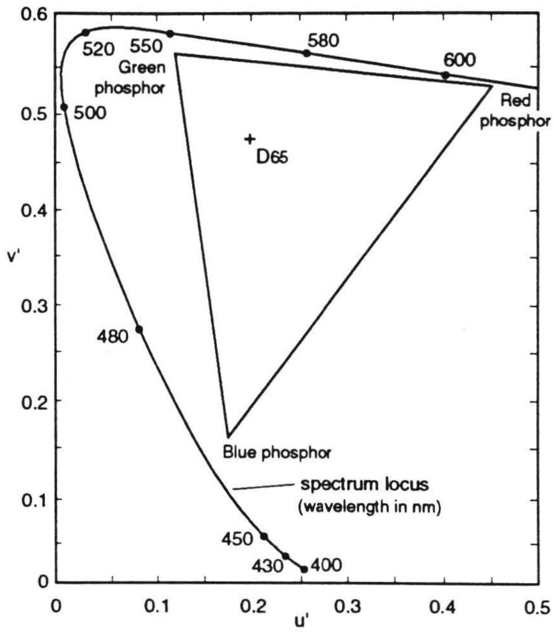

Figure 5. Gamut of chromaticities that can be reproduced by the EBU standard phosphors.

The third set of colours was based on a set of 23 test colours used by the European Broadcasting Union (EBU) to evaluate the colorimetric performance of colour television cameras.

Calculations were performed to determine the influence of each set of test colours by calculating the TV Consistency Index for the Extended-red Reference analysis and a particular light source with each set of test colours. These results indicated that, whilst the overall index may vary by a small amount, the rank order for different lamps remained constant.

Scaling

The scaling of the TV Consistency Index is performed in a similar way as for the CIE Colour Rendering Index. That is

$$R_{ti} = 100 - 4.6\,\Delta E^{*}_{uv,i}$$

where $\Delta E^{*}_{uv,i}$ is the colour difference for the i^{th} test colour as given by the CIELUV 1976 colour difference formula. This means that a perfect match will be obtained when there is no colour difference and the resultant Index will be equal to 100 for the given reference illuminant whilst light sources having a poorer Consistency Index will have an index of less than 100.

The overall Consistency Index is determined by taking the arithmetic mean of the individual indices for each test colours excluding skin tones and a special index for skin tones is determined by taking the arithmetic mean of the indices for the skin tones.

The Consistency Index calculations are performed for both reference illuminants so that one can determine whether the light source is more suited to studio or outside broadcast applications. In each case, the Consistency Index should be expressed as four numbers with respect to the reference illuminant. They are:

(i) Overall Index
(ii) Skin-tone Index
(iii) Worst Index
(iv) Number of the test colour giving the worst Index.

Field Trials

Field trials of the TV Consistency Index are presently being undertaken by various broadcasting organisations around the world but progress has been slow due to the high cost and limited availability of studio time. Initial tests, however, indicate that the Index provides a better indication of a light source's suitability for colour television in "daylight" conditions than that provided by the CIE Colour Rendering Index but the difference is not so great for "studio" illumination.

DAYLIGHT SIMULATORS

Daylight simulators, or colour matching booths, are used in industries where critical colour matching is required between a sample and reference material. For example, companies involved in the manufacture of paint, plastics, textiles or graphic reproduction (including printing) would use such a booth. The difficulty, however, is always finding a light source that closely matches a given phase of daylight.

The CIE method of evaluating the suitability of a light source as a simulator of CIE Standard Illuminant D_{55}, D_{65} or D_{75} is described in CIE Publication No 51, A Method for Assessing the Quality of Daylight Simulators for Colorimetry[6]. This system is based on colour differences between metameric pairs of test colours illuminated by the light source under test.

Test Colours

Spectral radiance factors are specified for 5 pairs of non-fluorescent, metameric, test colours, for each of the reference illuminants. The colour differences of the five pairs are calculated for the test source and the average of the differences provides a Visible Range Metamerism Index. Three other pairs of test colours, each consisting of a fluorescent and non-fluorescent sample, which are metameric under each of the reference illuminants are used to calculate an Ultra-Violet Range Metamerism Index.

Metamerism Index

The Metamerism Index (MI) is calculated from the mean of the individual colour differences for each test colour. Light sources producing smaller colour differences have lower MI's and are more suited for use as daylight simulators.

SUMMARY

This paper is intended to provide only a brief overview of each method of determining the suitability of a light source for different applications. For more detailed information the reader is referred to the following list of references that are available from the author of this paper.

REFERENCES

1 CIE Publication 15.2 (1986)
Colorimetry

2 CIE Standard S001
Standard Observers

3 CIE Publication 13.2 (1988)
Method of specifying the colour rendering properties of light sources

4 CIE Standard S002
Standard Illuminants

5 E.W. Taylor (1989)
A Television Illuminant Consistency Index
BBC Research Department Report

6 CIE Publication 51 (1981)
A Method for Assessing the Quality of Daylight Simulators for Colorimetry

ABSTRACT ONLY

LIGHTING FOR COLOUR VISION EXAMINATION - AN OUTLINE OF THE PROBLEM

S. J. Dain

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In exactly the same way as precisely controlled illumination is required for colour assessment and reproduction care must be taken in the illumination for colour vision assessment. The requirements set out in the instructions for colour vision tests vary from extremely vague through to the precise and impractical specification of a CIE Standard Illuminant C. In practice fluorescent tube sources are widely used for lighting colour vision tests. In a previously published paper we made an assessment of such sources for use with the Farnsworth-Munsell 100 Hue Test (FM100). The method was based on the aim of establishing uniformity of colour difference between adjacent caps. The method and results will be described. At the recent Xlth symposium of the IRGCVD we reported the results of investigating the effects of fluorescent tube sources on the Ishihara Test . This investigation was based on the aim of placing the confusion colour as close to the protan and deutan confusions lines as possible. Acceptability of the fluorescent tube sources varies with the type o~ plate. Again this work will be described. The future aim is to assemble a list of suitable fluorescent tubes for each colour vision test and then to seek to establish a criterion which is appropriate for all colour vision tests. The first step will be to look for common acceptable sources for the colour vision tests and consider assessment as a daylight simulator, that category of daylight simulator necessary and the CIE general colour rendering index.

ABSTRACT ONLY

COLOUR MATCHING USING FLUORESCENT LAMPS AND THE JUDGEMENT OF THE WHITENESS OF PAPER

Dr. -Ing. Ursula E. Schultz

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To simulate standard illuminant so as D65 or D50 luminaries with fluorescent lamps are used in photography and printing. The spectral power distribution of modern fluorescent lamps differ from those used ten years ago. To control the usefulness of these illuminants, they are tested by using the relevant CIE method. This tests show that modern lamps exist, which are able to simulate D65 and D50 resp., if these lamps are used in suitable fittings.

Combined with this other tests of matching properties are discussed, for example uniformity the ratio of illuminance. Comments will be given about the problem of the influence of whiteners in printing papers.

ABSTRACT ONLY

QUALITY OF DAYLIGHT SIMULATORS

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Unter den Eichen 87 D - 1000 Berlin 45, Germany

Indoor illumination with artificial daylight is common practice. However the requirements for the quality of the simulation of natural daylight vary according to the different tasks of illumination.

For general illumination it is-almost sufficient that the artificial illumination renders the most unsaturated colors so that they appear as being illuminated by natural daylight. Therefore the CIE introduced already in 1968 the " Color Rendering Index" method. For saturated colors however the CIE Color Rendering Index proved to be insufficient. This at least became obvious when energy saving lamps conquered the market.

In this investigation the spectral power distribution of common lamps were evaluated for several methods: integral errors of spectral distributions, index of metamerism, color rendering index and color difference of the simulating spectral power distribution compared with the CIE D65 spectral power distribution.

SIMULATING SURFACE COLORS ON CRT DISPLAYS: THE IMPORTANCE OF COGNITIVE CLUES'

Roy S. Berns* and Mark E. Gorzynski

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P.O. Box 9887, Rochester, New York 14623-0887 U.S.A.

INTRODUCTION

CRT displays are being used increasingly in visual experiments. When the graphics display controller yields 10 bits of color resolution per channel, they offer tremendous flexibility. Psychophysical techniques including method of limits, method of constant stimuli, paired comparison, and magnitude estimation are easily implemented. It is often desirable to present stimuli as related colors to possibly simulate surface colors. In several recent color appearance scaling experiments,[1,2] this was achieved by having a neutral background surrounding one or more rectangular color patches. The neutral background had the chromaticities of a spectrally non-selective background illuminated by a light source of interest. Nayatani, who has developed a mathematical model for predicting color appearance,[3] has stated[4] that his model will not accurately predict the appearance of CRT stimuli, whether they are related or unrelated stimuli. We believe his reluctance to extend his model to CRT stimuli is due to the psychological discounting of the illuminant color that occurs when viewing objects (but rarely CRT stimuli) under conditions of incomplete chromatic adaptation. As an example, imagine a CRT display with a white point equal to 2856 K, the correlated color temperature (CCT) of CIE illuminant A. The "white" appears very yellowish. At the luminance level typical of high resolution or broadcast monitors (50-150 cd/m^2), our visual system will not completely adapt. No matter how long we look at the screen, the display will appear yellowish. If we place a piece of copier paper in front of the display and use the display as a source of illumination, we perceive the paper as white, despite the obvious yellowish appearance of the illumination. We discount the color of the illumination. If the paper were a perfect reflecting diffuser, the relative spectral radiance entering our eye in both cases would be identical. Yet one stimulus is described as yellowish and the other, white. The effect was found by Arend and Reeves[5] where color matching was performed on two CRTs with different CCTs. When the observer instructions were to ignore surrounding stimuli, colorimetric matches occurred and because of different color balances, the stimuli mismatched when evaluating the entire image. When observers were instructed to adjust a test patch to "look as if it were cut from the same piece of paper", cognitive discounting occurred. Thus, we must seriously question the validity of extending the results from CRT experiments to real surface colors unless the observer is given more cognitive information.

Discounting the color of the illumination is well known. Interestingly, Hunt, who has also developed a mathematical model for predicting color appearance,[6] has accounted for this psychological phenomenon. Unfortunately, it is not always obvious under what viewing conditions this will occur. Because of the utility of computer-controlled CRT displays and the importance of predicting the appearance of surface colors, we performed an experiment to gain insight into the differences between CRT and surface color visual observations.

EXPERIMENT

Achromatic colors, as the most unambiguous of all colors, provide a simple way of estimating the state of adaptation when an observer views a scene.[7] This technique has been used successfully by Fairchild[8] in measuring incomplete chromatic adaptation to complex scenes for different scene-average chromaticities. The same technique was used in the present research. Four experiments were performed, labelled A-D. In the first, an image was displayed consisting of 2 cm squares each separated by 2 cm forming a 5x5 grid pattern. The CRT white point of the scene average was either 2700 K or 6000 K with a luminance of 91 or 109 cd/m^2, respectively. Each square was at constant luminance factor of 0.2 but of different chromaticity. Observers selected the stimulus that appeared the "most neutral, that is, without redness, yellowness, greenness, or blueness". Based on their own variance, the range in chromaticity of the test patches was reduced and the visual task repeated until a standard deviation of 0.005 in u' and v' was achieved. The experiment was performed with three different ambient lighting conditions: none, tungsten (2700 K, luminance of 9I cd/m^2), and daylight fluorescent (6000 K, luminance of 109 cd/m^2). Note that the ambient and CRT white points and luminances were matched. Thus six matches were performed by three observers.

Ambient illumination had minimal effect on subjective neutral judgments in the CRT images. Therefore, the mean result for the three observers and three ambient conditions of each CRT white point is shown in Figure 1. This clearly shows the incomplete chromatic adaptation for the 2700 K balanced CRT images. The subjective neutral is shifted significantly towards higher color temperatures. The 6000 K neutrals are also shifted. This is likely a result of observers preferring bluish neutrals despite the instructions.

A similar experiment was next performed where 4x4 grids made with photographic papers mounted on white cardboard were scaled under the two ambient conditions. Light entering the observers' visual system was the same colorimetrically in this experiment as the CRT stimuli. Six observers performed experiment B and their mean results shown in Figure 2. In this case, observers discounted the color of the illuminant for the 2700 K condition. We presume that the same level of incomplete adaptation occurred in experiments A and B. Thus the difference in subjective neutral chromaticity is due to cognitive differences. The differences between experiments A and B for the 6000 K condition was much smaller since adaptation was nearly complete.

A third experiment was performed where two white boards each with a single 2.5 cm square sample placed in the middle was constructed. The chromaticities matched the mean results from experiment B, one sample for 2700 K and one for 6000K. The experimental design was the same used in experiment 1 except in this case, the visual task was to select the patch on the CRT that was the "closest in color to the sample on the table" rather than select a subjective neutral. There were four combinations of ambient and CRT correlated color temperature. The mean results for three observers are shown in Figure 3. When the ambient and CRT white points were not matched, observers judgments were similar to experiment A. Observers matched their memory of the appearance of the stimulus within its own illuminant. In the case of adjusting the 2700 K CRT to match the reflection sample illuminated by 6000 K fluorescent daylight, observers judged the reflection sample as neutral. They in turn adjusted the CRT stimuli until a neutral was achieved, i.e. experiment A. When the CRT and ambient source were both 2700 K, observers discounted the yellowness of the CRT display and performed a colorimetric match to the sample on the table, i.e. experiment B. This was surprising.

A final experiment was performed where a photograph of the room showing the CRT and the table with the experiment C sample on it was digitized. The image color balance was adjusted until the average chromaticity and luminance was equal to the other experiments. Three observers adjusted the chromaticity of the CRT simulation of the sample square until it "matched the square on the table". Judgments were performed under the four combinations of ambient and CRT correlated color temperature. The results are shown in Figure 4. For all combinations, observers discounted the color of the illumination in the CRT image. Having cognitive information in the CRT display giving the observer clues to the color of the illumination enabled the cognitive discounting to occur. Thus, experiment D results have greater similarity experiment B (surface colors) than experiment A (related, CRT colors).

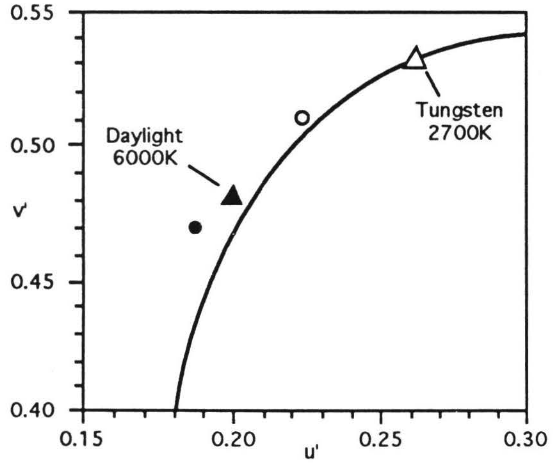

Figure 1. Mean experiment A results
○ = 2700 K CRT, ● = 6000 K CRT

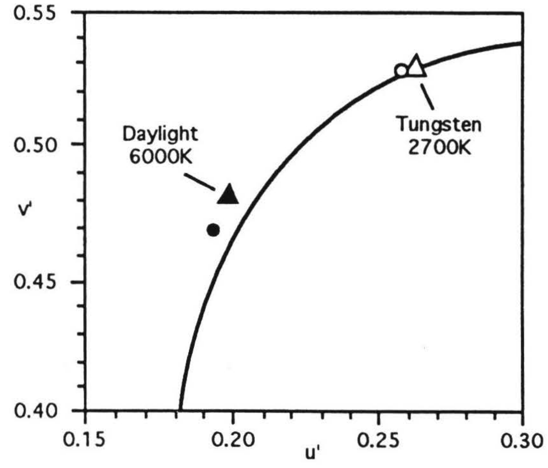

Figure 2. Mean experiment B results
○ = 2700 K CRT, ● = 6000 K CRT

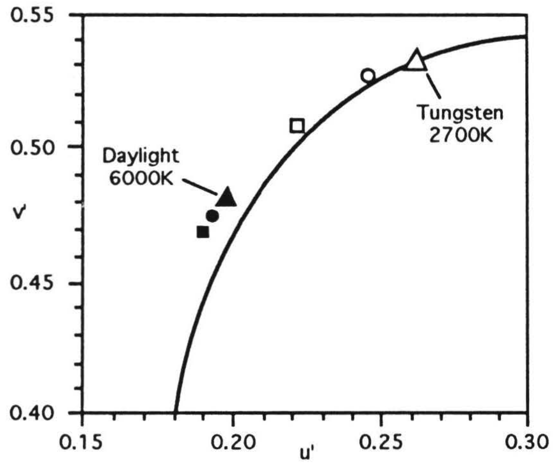

Figure 3. Mean experiment C results

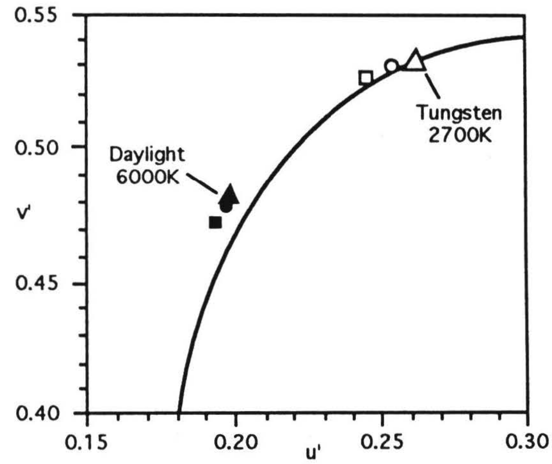

Figure 4. Mean experiment D results

LEGEND
—— Planckian Locus
○ T,T
□ D,T
● T,D
■ D,D

T = Tungsten
D = Daylight Fluorescent

First Letter in Legend is Color of Ambient Illumination, Second is CRT Image Balance.

CONCLUSIONS

When simulating surface colors under conditions of incomplete chromatic adaptation, the simulations may not be accurate unless cognitive information about the color of the light source is imparted to the observer. This can be accomplished by using complex scenes as shown in our experiments or by appropriate instructions to the observer as found by Arend and Reeves.5. Clearly, more research is required to better quantify cognitive discounting of illumination color and its interaction with color appearance.

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THRESHOLDS AND SCALING OF LIGHT AND COLOUR BY AN OPPONENT MODEL OF VISION

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INTRODUCTION

An improved model of vision for color and light is based on psychophysical and some physiological experiments with monkeys and defines equations to describe scaling and threshold data for a large range of luminances and chromaticities. The luminances of central and surround fields vary between 1 and 10.000 cd/m^2. One basic result is a new relationship between scaling and threshold data e.g. for a red-green series of colors. At threshold either the red D-process (D=Deuteranop) or the green P-process (P=Protanop) is the more sensitive along the red-green color series of equal luminance and defines the threshold. For large appearance differences both processes are far above threshold and the model has to use both processes to describe chromaticness of the red-green series. Similar results describe the yellow-blue and white-black directions of the color space e.g. two processes are active in each of these directions. The 4 figures of the color series 9098 describe some ideas as function of wavelength. The 4 figures of the color series 9099 describe some ideas as function of luminance.

RECEPTOR SENSITIVITIES AND CHROMATIC SATURATION

We have looked into the basis of the visual system with the aim to calculate the two processes in red-green direction by the known receptor sensitivities. In Figures 1 and 2 (color series 9098) two of three receptor sensitivities (P=Protanop D=Deuteranop T=Tritanop) and a linear (Y according to the "Abney Law") and a logarithmic (U) photopic luminous efficiency function are shown as function of wavelength. The curves show simple approximations in form of symmetric parables changing the maximum on a wavelength scale. Figures 3 and 4 show the ratio of the cone sensitivities and the luminous efficiency functions Y or U. The ratios P/Y D/Y P/U and D/U which are normally labelled "saturation" or "colorimetric purity" look like results of threshold experiments in red-green direction of Richter (1985) and Krauskopf (1991). Either the red P-process or the green D-process is the more sensitive and defines the threshold. Above threshold a linear summation of both processes describes scaling experiments of red-green color series.

ACHROMATIC AND OPPONENT SIGNALS; AMPLITUDE MODULATION FOR COLOR INFORMATION

In Figures 1 and 3 (color series 9099) the firing rate of opponent (ganglion) cells within the retinal area is shown. There are two opponent chromatic processes e.g. a red (P1) and a green (D2) process. The processes 1 and 2 are the more and less sensitive processes compared two the achromatic processes on a luminance scale. The achromatic and the two chromatic processes split in two processes a black (N=noir) and a white (W) process labelled by light and greyish colors. The difference of the two opponent chromatic processes (e.g. P1 and D2) is the chromatic signal of either the N- or W-process. In Figures 2 and 4 these differences are added and subtracted to the achromatic signals. This procedure is an amplitude modulation of the color information on top of the achromatic signals. Such a type of modulation is known for coding in color television. Valberg and Lee (1988) have measured firing rates in the ganglion cells of the retina which show many properties of the Figures 2 and 4 and this is a basis of our model on physiology.

CHANGE OF THE SIGN FOR COLORS OF CERO BLACKNESS AND UNIQUE HUE.

In Figures 1 and 3 (color series 9099) the signals of the black process N (dark red or blue) and the white process W (light red or blue) cut at a luminance near $0.1L_u$ or $0.01L_u$. The difference of the black and white process change the sign at these luminances. At these luminances the colors appear equal greyish compared to the surround. In a white surround they have a blackness of cero. In the model there is a change of the sign at cero blackness. The colors of cero blackness are described by Evans (1974) for achromatic and chromatic surrounds. His experimental results and therefore the luminance's for colors of equal blackness can be described by our opponent model. The color signals must be split up in two opponent signals which again show a change of the sign at unique hues. Evans has postulated such a relationship.

Farbbildserie 9098 Nr. 1 bis 4; Color series 9098, No. 1 to 4

Farbbilder Nr. 1 und 2; Color Fig. Nr. 1 and 2:

Log. der Empfindlichkeit von Rezeptorfunktionen P, D, T und Approximation von "W" durch eine lineare Function Y (Nr. 1) oder eine logarithmische Funktion U (Nr. 2)

Log. of the sensitivity of receptor functions P, D, T and approximation of "W" by a linear function Y (No. 1) or a logarithmic function U (No .2).

Farbbilder Nr. 3 and 4; Color Fig. No. 3 and 4:

Log. der Y- (Nr. 3) oder U-Sättigung (Nr. 4) von Rezeptorfunktionen P, D, T sowie der Funktion W und ihrer linearen (Nr. 3) oder logarithmischen (Nr. 4) Approximation; Gleichungen von Y und U siehe Bilder.

Log. of Y- (No. 3) or U-saturation (No. 4) of receptor functions P, D, T and of the function W and its linear (No. 3) or logarithmic (No. 4) approximation; equations for Y and U see figures.

Farbbildserle 9099 Nr. 1 bis 4; Color serles 9099, No. 1 to 4

Farbbilder Nr. 1 und 3; Color Figure No. 1 and 3:

Impulsraten-Signalfunktionen $Q[2(x-u+p_i)]$ und $-2Q[1(x-u+p_i)]$ mit $x = \log L$ und $u = \log L_u$ für visuelle Prozesse P1, U=Unbunt und D2 mit Sättigungen $p_i=1,0,-1$ (Nr.1) and $p_i=2,0,-0.5$ (Nr. 3)

Firing rate (Impulses/s) signal functions $Q[2(x-u+p_i)]$ and $-2Q[1(x-u+p_i)]$ with $x = \log L$ and $u = \log L_u$ for visual processes P1, U=achromatic, and D2 with saturation $p_i=1,0,-0.1$ (No.1) and $p_i=2,0,-0.5$ (No. 3)

Farbbilder Nr. 2 und 4; Color Figure No. 2 and 4:

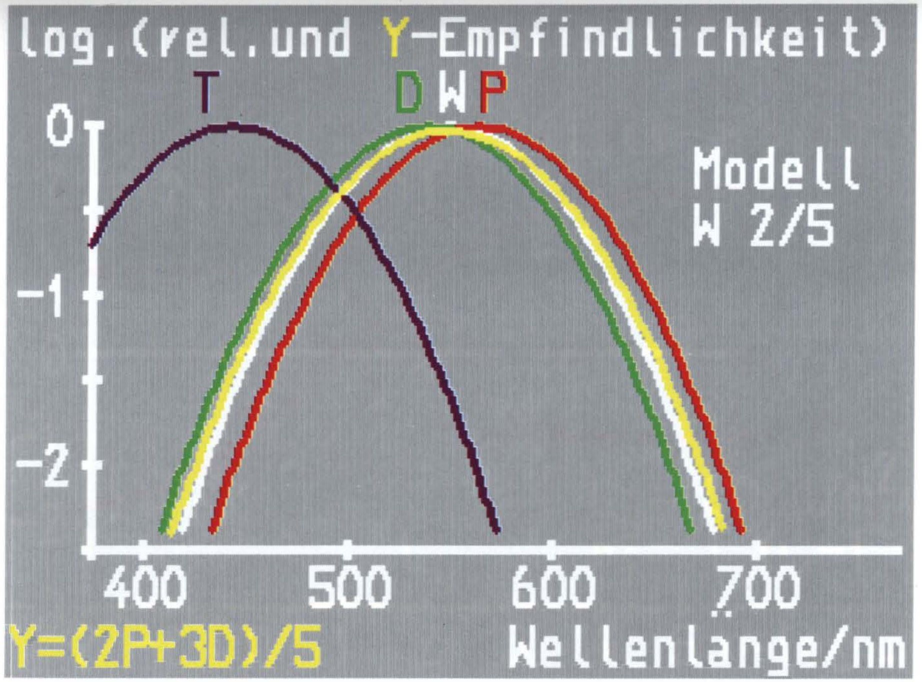
Impulsraten-Signalfunktionen $Q[2(x-u+p_i)]$ und $-2Q[1(x-u+p_i)]$ für Prozeß U=Unbunt mit plus/minus Buntsignale errechnet aus Prozessen P1 und D2 mit Sättigungen $p_i=1,0,-1$ (Nr. 2) and $p_i=2,0,-0.5$ (Nr. 4)

Firing rate (Impulses/s) signal functions $Q[2(x-u+p_i)]$ and $-2Q[1(x-u+p_i)]$ for process U=achromatic with plus/minus chromatic signal computed from processes P1 and D2 with saturation $p_i=1,0,-1$ (No. 2) and $p_i=2,0,-0.5$ (No. 4)

Description of luminance contrast L/dL by two opponent processes

In the last figure the contrast UdL (L=central field luminance and dL luminance difference) is plotted as function of log L for short (0.1s) and long (25s) presentation time of the central bipartite field in a grey steady background of different luminance. The curves for 0.1s presentation time reach their maxima at the surround field luminance L_u for all surround field luminance levels. The slope cero near the maxima indicate that in a small region the Weber-Fechner law (L/dL=1) is valid. There are large changes by presentation time, discussed by Richter (1990). The curves for short presentation time (0.1s) can be approximated in the left (dark) parts by the black (N-) process and the in right (light) parts by the white (W-) process see Richter (1988). The two parts correspond to the sigmoid firing rates on a log luminance scale of two cell types described by Valberg Lee et al (1986) which are approximated in the color Figures 1 and 3 of the last color series. The two N- and W-processes correspond to achromatic colors either darker or lighter compared to the surround.

There is further an important relationship between threshold and scaling experiments (Richter 1990). The scaling experiments can be described by a linear summation of the N- and W-process. The model seems the first based on two opponent mechanisms in red-green yellow-blue and black-white direction. There are two opponent processes (N- and W-) for greyish and



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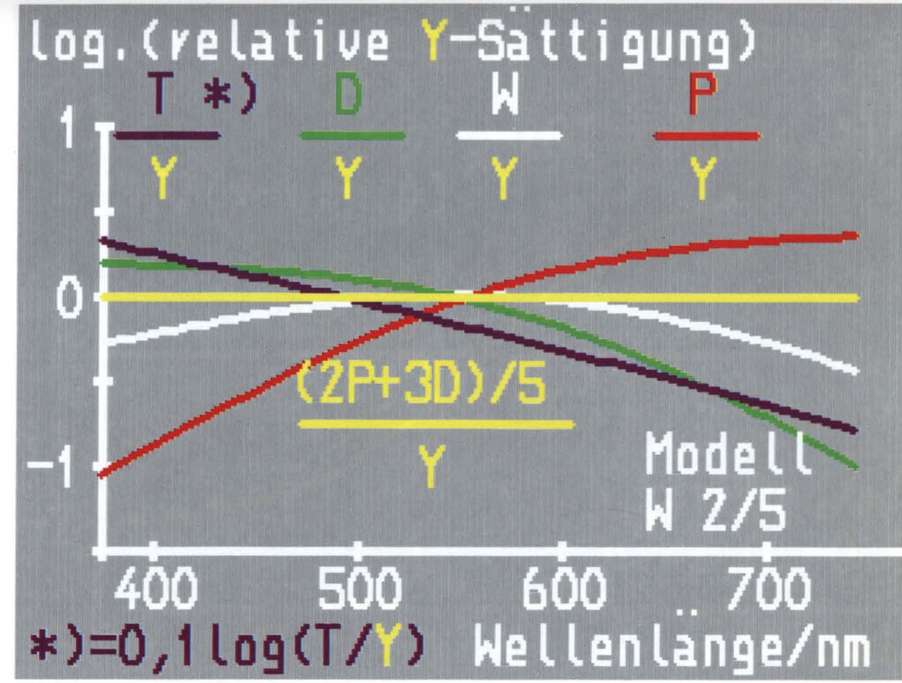

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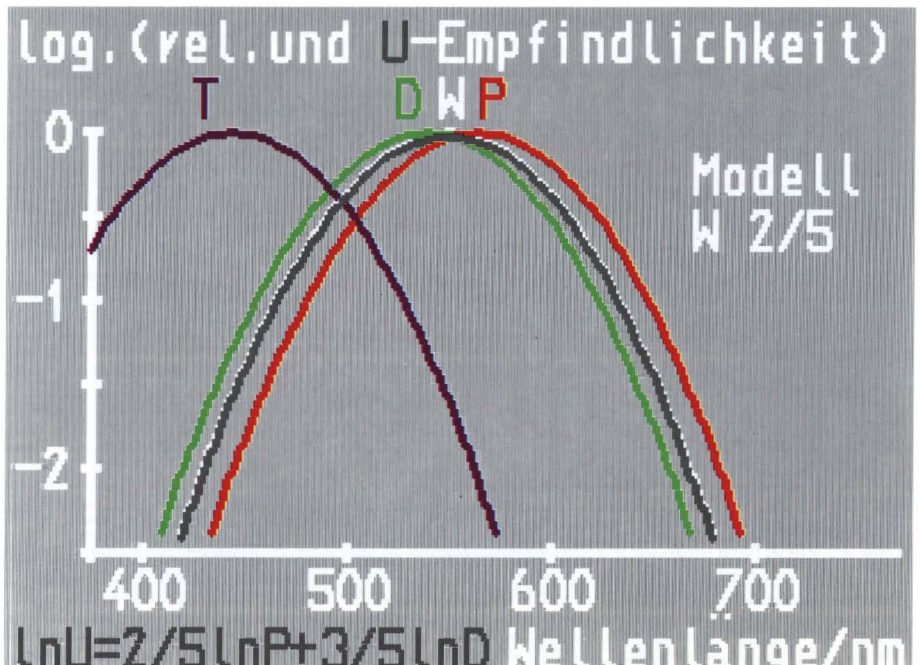

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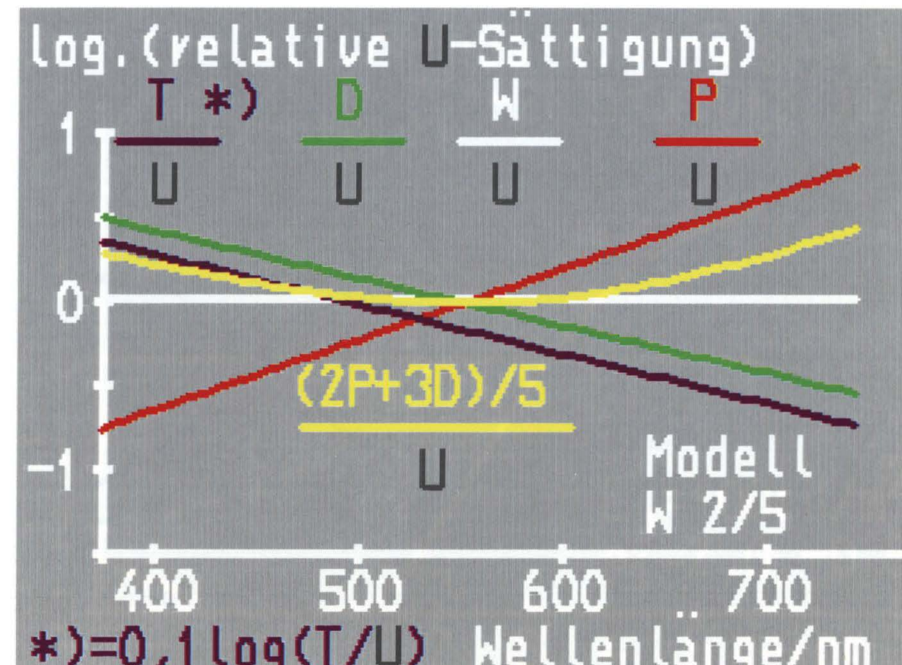

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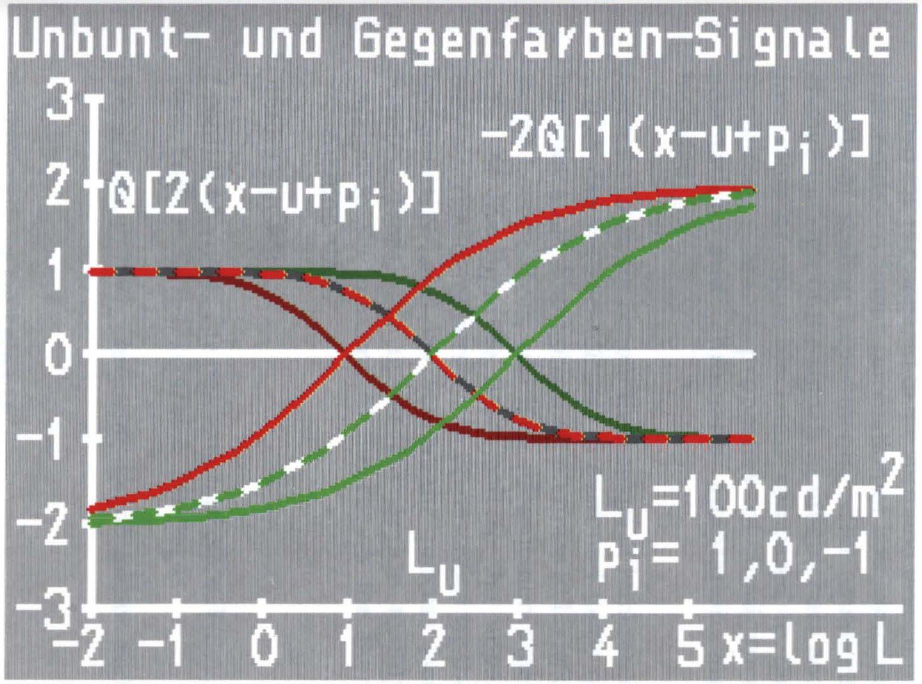

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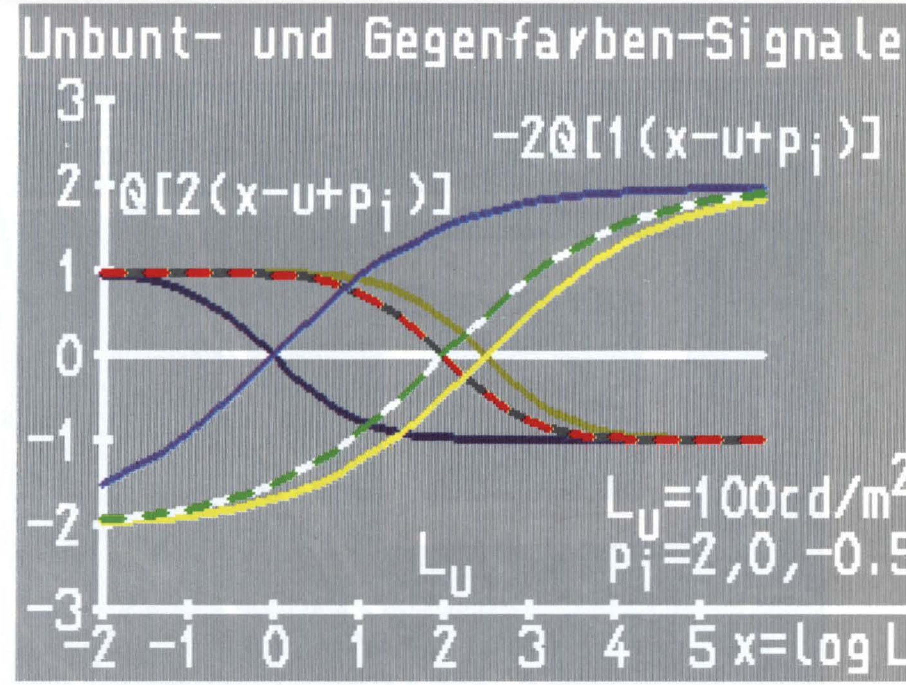

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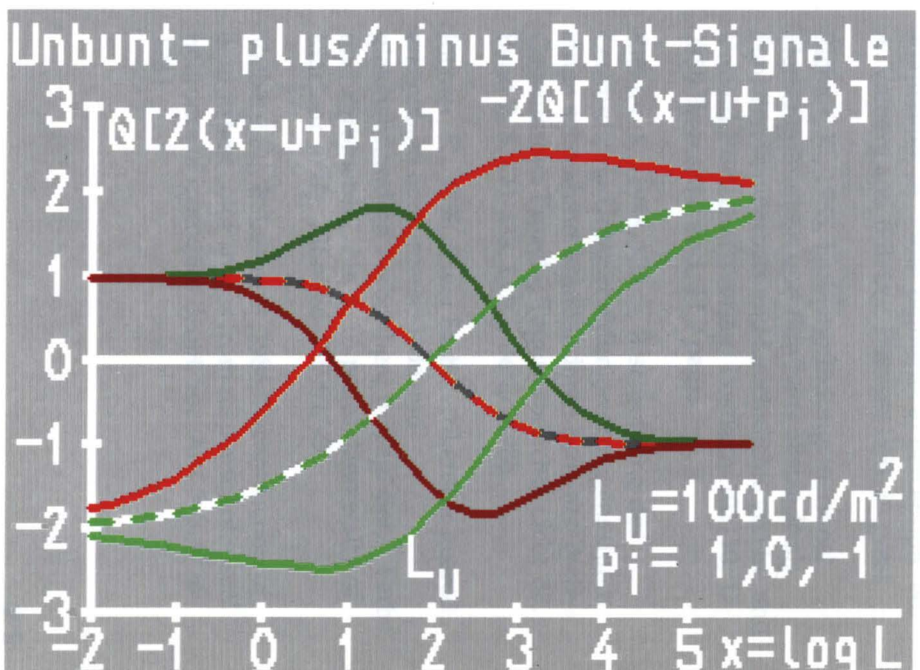

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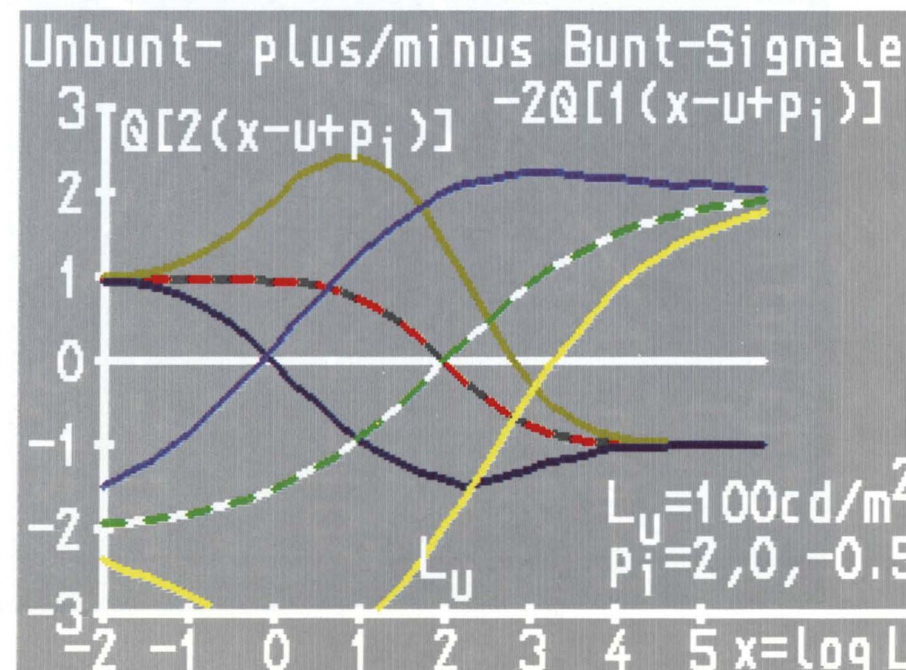

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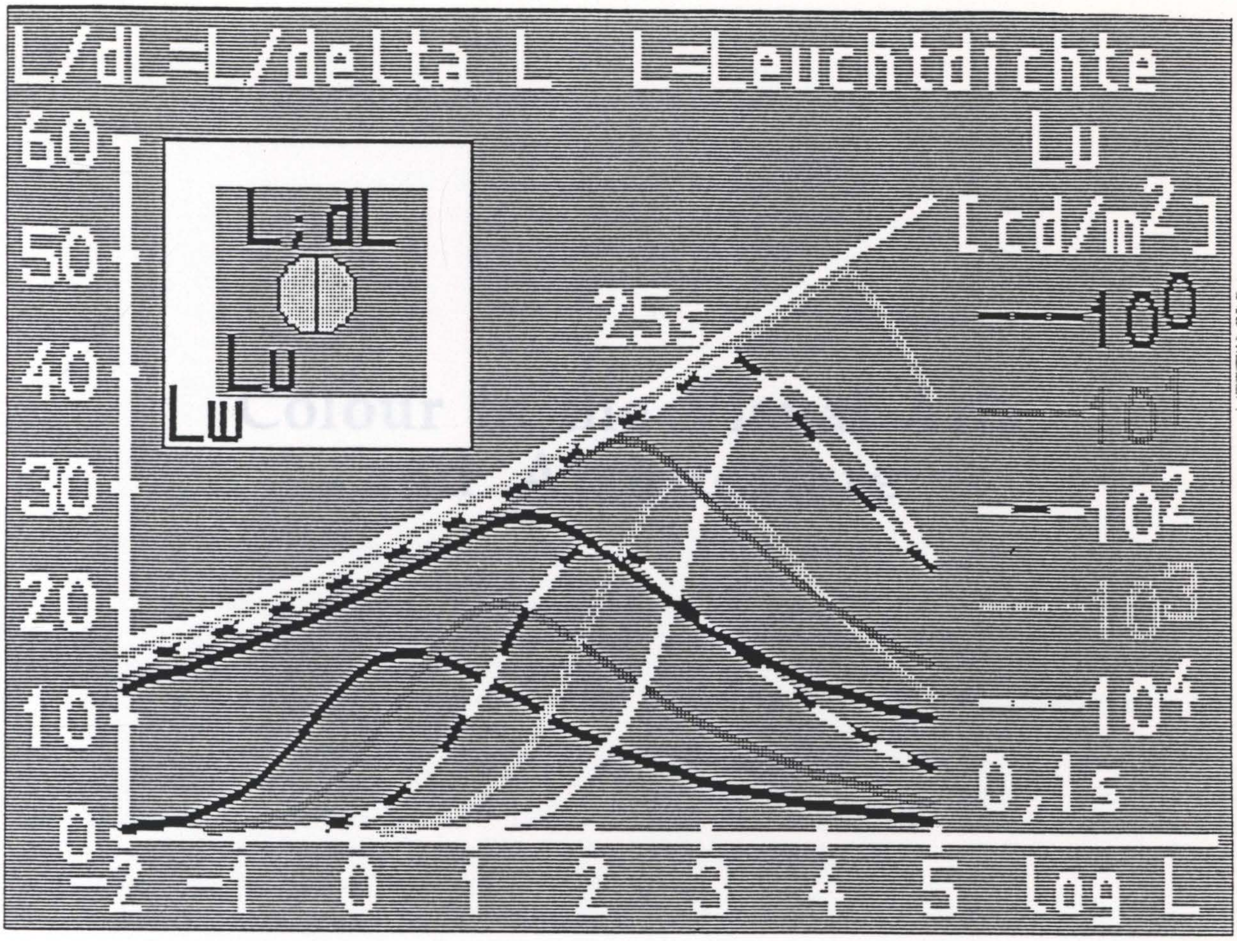

whitish colors compared to the surround describing thresholds. A linear summation of both describe results of scaling experiments. The equations change the sign of the signals at unique hues and for colors of equal blackness compared to the surround. Many properties of luminance adaptation and chromatic adaptation are included.

Contrast L/dL for central field colors of luminance L (German = Leuchtdichte) in surround fields of luminance L_u. Short presentation times (0.1s) lead to the lower curves, and long presentation times (25s) of the bipartite field lead to the upper curves. The lower curves can be described by the opponent N- and W- achromatic process (see Richter, 1988), the upper curves are mainly parallel to the maxima of the curves for short presentation time.

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Colour in the Visual Arts and Architecture

COLOUR AND LIGHT IN ENVIRONMENTAL DESIGN

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PROGRAMMATIC REMARKS

It is part of the task of a keynote speaker to draw attention to problems which are of special importance or which might be overlooked. A keynote address should contain some programmatic appeal.

BALANCE BETWEEN SCIENTIFIC AND DESIGN-ORIENTED ENDEAVOURS

About half of the contributions to our conference on "Colour and Light" are in the section of Visual Arts and Architecture. This is an important step forward towards a fruitful balance between scientific and design-oriented endeavours within the AIC. Such a balance must become an explicit aim of the AIC if we really wish the results of scientific research to have a positive influence on our environment.

The situation in the AIC was expressed so well by Paul Green-Armytage in his Newsletter report on the 6th AIC Congress in Buenos Aires that I would wish to quote a few of his sentences: "It is both a strength and a weekness of an AIC congress that it attracts people from such a wide range of disciplines. Colour can bridge the gaps within and between the arts and sciences; it can also drive a wedge between them ... I did sense a growing openness and a desire on the part of some groups to understand the concerns of others. I believe it should be a prime aim of the AIC to encourage this".

It is quite clear that the transfer of knowledge in both directions can only work if the AIC manages to bring together scientists and designers, and if the AIC meetings become attractive for practicing architects and environmental artists. Our Sydney Meeting '91 seems to me a good step in the right direction. But in what way can the AIC make itself attractive for design-oriented people?

DESIGN-RELEVANT RESEARCH

The practising designer must experience a feeling of being understood and accepted by scientists within the AIC. So, in the interesse of a better understanding of the concerns of designers let me say some words about the relationship between science and design:

Architects and designers devote themselves to the creation of suitable environments for human activities. Although much scientific work has been done in the field of colour, the design-relevant problems concerning the effects of colour in real environments on human beings, ie. their feelings and behaviour, still await more scientific investigation.

Research in design-relevant problems must be encouraged and favoured by the AIC. The practising designer will be interested in attending AIC meetings if he can acquire design-relevant information there.

The sophisticated colour designer certainly welcomes every scientific study which offers him real help in solving his daily problems, but he is still left with many other problems in his work for which there is no scientific answer. And he cannot wait until science in a distant future might have removed every uncertainty in the colour environment-man relationship. He is forced to make a decision now, to arrive at a synthesis in order to propose a design solution for impending tasks today. Therefore I must draw attention at a very important fact:

COLOUR SENSITIVITY AND CONSCIOUSNESS

For professionals responsible for environmental design it is not enough to know more about colour. The main problem for them is to develop their colour sensitivity and consciousness as well as their comprehensive visual awareness in real environments, including the aspects of light, form and texture.

For scientists it might be difficult to understand that these abilities which seem to be so far removed from scientific behaviour are so important in environmental design. Nevertheless they are! If we look around us, we comprehend that most of the ugly things in our environment have usually come about through the unsensitivity or underdeveloped visual awareness of some planners or builders.

So, finally we have come to the primordial problem which we may not overlook: How can we, the experts, reach those who are responsible for our everyday environment? How can we make them understand that good use of colour and light are so important for a better built-environment?

MOTIVATING ARCHITECTS TOWARDS COLOUR TRAINING

For several years I have been trying in lectures and courses to make architects understand that colour and light are essential space-modifying design agencies which unfortunately are still widely neglected even in schools of architecture and design. Alongside my teaching at the Department of Architecture in Winterthur Polytechnic, ten years ago I began my Winterthur Colour Course for practising architects, designers and planners. Last year, In recognition of this activity, the patronage of the Swiss Architects Associations was offered to my institution.

It Is an intensive four-day course: A series of twenty exercises alms at developing the sensitive and conscious colour perception which is really fundamental to a good use of colour in the environment. These exercises are accompanied by a sequence of lectures based on rich visual material which directs the attention towards various aspects of colour in the built environment.

The following part of my lecture is concerned with giving you an idea of how I approach the problem I have mentioned dealing with architects. My approach is totally based upon pictures because I believe that for architects and designers the sensual experience of light and colour in real environments is essential in order to convince them.

Light and colour are important phenomena in our world and they are essential factors of environmental design. They appeal directly to our visual sense and affect the state of our condition.

While our sense of touch is dependent on some physical contact with objects, the visual sense can give us information about distant things as well. It can substantially anticipate touch experience.

In some cases even partial illumination gives us a vague idea of what happens in the environment. In other situations optimal illumination is urgently requested, when exact visual and manual work is demanded.

Our ability to discriminate various colours allows us to recognize forms, not only the outline of things, but also their plasticity. The perception of visual form is even dependent on our ability to recognize colour differences. Colour can also give us information about the status of things.

LIGHT AND COLOUR IN INTERIOR DESIGN

The change of day and night determines the rhythm of our life. A special problem in interior design is that of bringing daylight into the interior space: From in front of the room, as in the Farmers' Bank by Louis Sullivan, or from the side, as in the early concrete church by Karl Moser, or from the top of the room, as in the library by Alvar Aalto? This is a fundamental question which has to be answered by the architect, at least in principle, at the very beginning of the architectonic design process, because it is tightly linked with the structural system. This becomes quite clear when comparing the two different ways of letting daylight come through the ceiling in Aalto's library and in Jörn Utzon's church, and it is quite obvious when one is within the interior of Buchminster Fuller's geodetic cupola. The wish to cover an assembly hall with a translucent hemisphere calls for a very special structural system. While in Fuller's room the daylight Is tinged by the yellowish membrane and the interior filled by a warm tempered light, the showroom of Cassina Milan Is characterized by a cool coloured atmosphere. By illusionistic means and artificial illumination the Idea of a glass cupola with a view to the blue sky Is suggested. On the other hand It Is rather unusual when the light enters the room through the floor, giving an effect of shock which certainly is intended in this corridor.

The lightest area in our visual field has a tendency to attract and direct our attention, as we can see in Hans Scharoun's Philharmony in Berlin or in Gustav Peichl's ORF studio in Salzburg. This is a very banal fact, I agree. Nevertheless, it is sometimes overlooked. It is really not enough to mention this simple fact verbally. When making architects and designers aware of it, it is better to make it an impressive visual experience as the next comparison may show. When dealing with visual phenomena we have to use "visual explanations". Where differences in brightness are very low, everything seems to have the same importance or nothing appears of special importance. Even very slight contrasts of brightness when distinct enough are sufficient to prevent eyes lingering around. Such contrasts are able to organize the room's elements into some kind of visual hierarchy.

We saw a few examples of how natural or artificial light can enter a room. Similarly, it can be interesting to see how artificial light emerges from a room, or, in other words, how the interior appears from outside the building. At the entrance to a lighting shop in Basel we are looking through some sort of curtain consisting of chains of small lamps, emitting a warm light, into an interior with a predominantly cool atmosphere.

The famous candleshop by Hans Hollein in Vienna presents a cool metal facade in daylight, offering a consciously reduced insight into a warm-coloured interior. He thus makes the potential client interested in seeing the whole interior when entering. The client is then plunged into an extremely warm atmosphere. Sometimes a very fresh and cool atmosphere is created by colour and light as we can find in an office in Melbourne.

In other situations a combination of warm and cool colours has been chosen, as in the cafeteria of the domus publishing house in Milan, or in a schoolroom. Both are offering the user the opportunity of moving his eyes from warm to cool and from cool to warm colours, simply according to the wish or need of the moment. This offer of polar stimuli is especially appreciated in rooms designed for longer stay. Hue combinations need by no means be complementary. A yellowish green and a yellowish red linked by there intermediate hue can create a cheerful and sunny atmosphere.

Even one hue or similar hues can be used when combined with neutral colours because they also avoid the visual stress sometimes produced by a strictly monochromatic deslgn solution In rooms for longer stay.

Another important point is the degree and quantity of chromatic colour which is used. There are of course situations when the user really aspires to an extremely intensive stimulation through colour, light, movement and sound, as for instance in a disco where he seeks distraction. On other occasions the quantity of strong colour must be considerably reduced, as we find in Barbican Centre for Arts and Conferences in London. The same red colour is combined with a lot of grey. The lit curtains in the office of an insurance company certainly create an interesting and attractive interior, but one may question how far this is appropriate to the function of the room. I am not so sure whether this is quite the right environment for doing daily an eight hours' work at the desk. There is no doubt, that sometimes very strong or lively contrasts be suitable for special human activities, especially if the attraction of attention is intended, but sometimes even very fine and subtle contrasts are exactly what is needed.

STATEMENT

We have seen how much the architect needs to develop his sensibility for visual stimuli in complex environments in order to create suitable conditions for various human activities. In a long process he needs to enrich his experience in real environments to become prepared to make design decisions with great responsibility. If AIC can offer him real help in his daily work, he will certainly be interested in coming to our meetings.

COLOUR AND BUILDING DESIGN

Many architects admire the buildings by Richard Meyer with good reason. His monochrome white structures look marvellous, especially when seen in direct sunlight and in front of a blue sky. But sometimes monochromatic grey structures in diffuse daylight in front of a grey sky look really depressing as is the case of this hospital building.

When looking at flowers we spontaneously enjoy the totality of their appearance, the synthesis of colour and form, what we call the Gestalt of an object. Architects when approaching objects of nature also do so. They do not separate the structural form from the colour. Only in their professional work do many of them still deal exclusively with the structural form of their buildings and mostly neglecting their colour appearance, because they believe that in architecture form is more important than colour.

This is a strange idea especially endemic amongst 20th Century architects though we know that the integration of colour and form in architecture was the most natural thing for at least 5000 years previously. Nevertheless, already in the first half of the 20th Century we find some architects who have considered colour as an integral part of architecture, e.g. the Russian Jakov Chernikhov published in 1933 a marvellous collection of polychromatic architectural structures. And in recent years we can notice a growing number of architects who recognize colour as an important factor in architecture.

We can see this tendency in a school building in Italy where the reddish cubes are combined with the distinctly contrasting linear elements in blue, or in another example from Spain where the volumes are presented in a smooth hue transition.

Aldo Rossi is one of those architects who include the colour aspect of a building from the very beginning of the architectural design process. This is shown in an idea sketch and in a control drawing. In this case the colour differences underline the different parts of a heterogenous structure.

Natural objects sometimes show colour changes even on the same surface. So does James Stirling in his project for an Olivetti building. Colour patterns in architecture need not always be so striking. Cesar Pelli in his Rice Hall for Houston University and Adolfo Natalini in his bank building in Como use patterns in a more discrete manner.

The consciousness of what we called architectural gestalt is gradually growing among up-to-date architects. This fact we find confirmed in two recently erected sky scrapers near Times Square in New York. We can encounter buildings with an impressive individual gestalt in southern Switzerland as well as in the new Lufthansa Building at Madison Avenue. And we find subtle and distinct articulation in entrances to recent buildings which I saw in Lower Manhatten.

These last examples demonstrate very clearly that refined polychromatic architectural design does not at al! aim at increased use of highly chromatic elements, but at a cultured enrichment of the visual qualities in our environment by integrating colour, texture and formal composition in a sensitive and sophisticated manner.

CREATIVE USE OF COLOUR AND LIGHT

How can colour and light regain their proper place as essential design elements in architecture? We must surely start at the level of the professional training of architects.

Before my students introduce colour into their own architectural projects, I try to awaken their Interest In colour In space. I encourage them to create any three dimensional polychromatic structure free from all those limits which ordinary building tasks usually impose on the architect.

Lois Swirnoff in the book Colour Dimensions shows creative experiments of colour reflexion done by students of the University of California at Los Angeles (UCLA).

Several artists devote their creative fantasy to environmental design. I can of course mention only a few:

Herman Kuijer, a young Dutch artist, designed the ceiling in the PTT Building in Rosendahl as well as another ceiling in which he produces very fine colour variations by chromatic inter-reflexion. In a design for a subterranean car park he made an installation of light sources in various colours.

Charles Ross uses prisms in his projections of refracted light in the atrium of the Spectrum Building in Denver. The South American artist Cruz-Diez created monumental colour transitions in a power station and on silos in Venezuela, in the airport at Caracas, and in the entrance hall of a computer centre in Zurich.

After all these interesting examples I come back to everyday reality and an argument in excuse often heard from architects: "I don't use chromatic colour because people's dress brings enough colour into the room." A consequence of such a believe is this railway station. Obviously, throughout the complete architectonic design process no-one ever paid attention to the question of how an elaborate structure would appear to the user's eye and the resulting room atmosphere. Soon after it had been finished the responsible persons at last realized how drab and oppressing it looked and they finally came to the conclusion that something had to be done. At enormous supplementary expense they had changed the whole of the illumination, the colour of the supporting structure, and the ceiling panels over it. The result is obviously better, but the overall procedure cannot be described as a professional approach to the problem.

CONCLUSIONS

1. The planning of light and colour must be totally integrated in the architectonic design process, as they are so important factors in creating a comfortable atmosphere in our environment.

2. The AIC must offer a platform to creative artists and practising architects for presenting those works in which the aspects of colour and light have been seriously and successfully included.

ABSTRACT ONLY

COLOUR AND ARCHITECTURE: THE COLOURING OF THE CRYSTAL PALACE FOR THE GREAT EXHIBITION OF 1851 IN LONDON

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The Crystal Palace has been conceived as the prototype of the new machine age architecture. Owen Jones, the "adviser on decoration", was charged of the colouring. For the interior, he conceived an original scheme based on the scientific principles of the Newton theory. Jones used in fact the primary colours (blue, red and yellow) separated by a white strip and applied to the different building components following functionally the form of each of them. To reach the maximum of brightness, indispensable for the exhibition of the products, he used the three primary colours in the same proportion in which they were supposed to be present in the light composition.

As a reaction to this unusual "scientific" scheme, immediately after the official presentation of the Jones scheme of colouring at the RIBA, more than 40 different persons (not only artists, architects or engineers, but also simple visitors and exhibitors) sent to the professional magazines and to the local newspapers their own alternative colour projects of the Crystal Palace, based on the most various aesthetical, philosophical, psychological and also practical and economical principles. The paper will describe analytically and discuss critically each different colour scheme proposed for the same building, following its incredible chromatic metamorphosis!

Due to the complexity of the data involved in the research (more then 50 different colour names, techniques and materials proposed, referred to the tens of architectural elements involved in the colour schemes), the problem has been approached under the form of a colour data bank set up by the author with the cooperation of an informatic specialist.

ABSTRACT ONLY

SO WHAT IS NEW ABOUT COLOUR ? INTERIOR DESIGN COLOUR SCHEMES IN 1870 AND 1970

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There is a tendency to think that at any given time, we currently know all there is to know about colour theory and colour applications. This paper will illustrate that, in two earlier periods of time (1870 and 1970) colour was used in an Australian context, in much bolder and yet more subtle ways by interior designers than it is today.

In the 1870 s we will see the myriad of subtle colour combinations of patterns and materials that were possible when decorating skills were at their height and skilled labour was cheap and plentiful. Discords, extended harmonies, contrasts in tone and chroma, stencilling, tiling, faux marbling, counterchange, pattern on pattern, you name it - the Victorians did it, with confidence, skill and a subtle, intuitive knowledge of their craft and how it would enhance the architecture of the day.

Two world wars intervened and colour in interior design once again shone forth, prompted by the brilliant applications of colour to interior spaces by Sydney designer Marion Hall Best. The 1970 s wanted to look modern and break new ground, and what better way to do this but by using bold colours in new, luminous and different ways.

This paper will explore and graphically illustrate two of the most colourful periods of interior design in Australia .

COLOUR AND LIGHT: THE VISUAL REALITY OF ARCHITECTURAL SPACE

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Three main factors shape the perception of form and of architectural space: Texture, color and context with form and space. All will change appearance with the intensity and direction of the light falling on it. We can encounter the dramatic difference of day and night architecture, the spectacle of buildings at dawn and dusk against the rising or setting sun. Concrete or steel, wood or glass are the same, but your encounters with the building masses are not. Daylight entering a space through skylight or window can influence the visual reality of a space by change in weather condition, time of day, season and orientation. A space that appears lively, exiting and inviting on a clear day, may look gloomy and forbidding on a cloudy late afternoon.

If an architectural space is illuminated with pools of light, leaving large parts in darkness, visual reality may well attempt to perceive these as separate spaces, especially if the perimeter enclosure is difficult to comprehend. This, as a point for thinking of older people in unfamiliar surroundings.

Moving from one space to another can produce pleasant or adverse encounters with visual reality. Walking rapidly from a well-lit lobby to a dark bar can be disconcerting and disorienting, because of the relatively slow process of adaptation of the pupil of the eye. After the first moment of disturbing near-inability to see, the gradual opening of the pupil will allow comprehension of space, scene and people.

After having been in a dark space for a while, sudden return to a better lighted space can cause glare effect to which the eye responds much faster.

The second factor influencing visual reality is surface texture and color. These are encountered variably, depending on viewing distance, color temperature of the light, its level and distribution, besides the viewing distance. The visual realities of forms and colors are influenced by the distance so, that they become a never ending adventure. Take a cityscape seen from a mountain top: I must think of the slim prisms of skyscrapers piercing the ever-present smog of Caracas, as they look when seen from one of the surrounding mountains. Or the statue of Liberty in New York Harbour, seen form the Hudson River or from the harbour entrance. As you approach buildings or statue and come within arm's length, textures become palpable and colors become more saturated. A new relationship develops between you and the object.

Such visual scanning is greatly influenced by the lighting condition, surface character and coloration. These factors combine into the "color tone" of the entire space. To be specific: color tone results from the spectral composition of the light emitted from the luminaire and reflected from the major surfaces in a modified form by partial absorption ..

So far we have touched on objective, measurable realities. Now we must consider the next major factor that bears on the visual reality of Architectural Space: Subjective perception by personal experience, shaped by societal and shared concept. If you think now of spaces within the architectural structure, these realities will take on a more personal, intimate aspect. After all, the spaces within most buildings are designed to be used by people - in one activity or another. With the ever-increasing number of new light sources we can change the perception of colors on an object or in a space, and yet, we speak of the "green room" where musicians or speakers might prepare themselves for a performance, or of a "red rose" for love expressed or exchanged. These are examples of traditional language. The color sensation that is triggered by the light reflected from a glowing flower, or from the walls that surround the waiting performer in the green room <u>is</u> the reality, triggered by your sense of sight. This visual reality can shift as you become aware of different associations concerning specific textures, colors and forms. They could be memories from earlier occurrences, from smells or sounds, from people or events. The perfume of a rose, the temperature of the green room, the sounds of a musical phrase, the warbling of a violin being tuned .

Visual events combined with other sensory stimuli and with memory associations make you realize how much you can experience in the encounter of one form or space. You sense how much visual reality depends on your location, the time elapsed while viewing and the lighting condition - just to mention a few variables. In his studies on the response of people to different lighting modes, John Flynn was aware of the differences that surface color would make. Speaking strictly of light source color, he found that under cool-toned light people would underestimate physical temperature and background noise, but overestimate the size of a space. Under warm-toned light, they would overestimate temperature and noise, but believe space to be smaller than its actual dimensions.

The visual reality of space can influence the behaviour of people. Sucov and Taylor showed in a well-documented experiment that, given a choice, people will move away from a dark door toward a lighted door in to an adjoining space. Color tone will influence people to move toward a warm <u>appearing</u> space (lighted with lamps of 3000 Kelvin or lower) in a cold climate and seek out a cooler <u>looking</u> space (with lighting of 4000 Kelvin or higher) in a hot climate. Such reactions are spontaneous and independent of actual, measured temperatures.

These three complex factors, light, surface and subjective perception, combined with other sensory stimuli produce the visual reality of a space or object to which people respond. Lighting designer, interior designer and architect share in the conditioning a space for the user's response. Consider the simple search for the place preferred for an intended activity: the best light for reading, the best seat to watch a movie, the most private corner for conversation. Only after orienting oneself visually is there awareness of other sensory factors: Draft from the air conditioning outlet or window, excessive noise from a close-by loudspeaker. Visual scanning may help to select the preferred spot, by association with earlier, similar situations.

The designer's challenge is to shape visual reality for optimal subjective acceptance and use of architectural space.

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IMPACT OF COLOUR AND LIGHT IN THE OFFICE ENVIRONMENT: A BREAKTHROUGH STUDY

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RESEARCH OBJECTIVES

The project goals are to: (1) assess worker productivity and mood in an office which simulates NASA's space module in interior color ("NASA white") and lighting, (2) compare subject's reactions to an office painted in "NASA white" with offices of other scientifically measured and designed color schemes, (3) gather data on perceived spaciousness and color preference, (4) recommend color(and lighting for the space module, and (5) establish a color data base for scientists, designers, and industrial companies to utilize in selecting appropriate interiors for various environments.

The importance of environmental effects on worker productivity and morale has been suggested (e.g., Brill, Margulis, and Konor, 1984; 1985; Oldham & Fried, 1987; Wise, 1987), but long- term controlled experiments investigating effects of color schemes have not been conducted.

In a review (funded by NASA) of more than 200 articles on color research, Wise (1987) concluded that few generalities can be drawn about human response to color. Previous experiments are plagued by inconsistent procedures and broad latitudes taken in interpreting results. Wise stated that the present state of knowledge on color is impoverished and good experimentation involving realistic interior treatments and settings needs to be conducted.

In addition to providing sound research to aid in selection of interior color(s) for SSF, the project will gather information on worker productivity and mood--important data for business and industry. Results of various studies (e.g., Brill, 1984; 1985), indicate that the more satisfied people are with their office environment, the more satisfied they are with their work. Job satisfaction has been linked to job performance and productivity which have economic value for the employer.

Oldham and Fried (1987) found that darkness of an office, along with three other environmental factors, contributed to 24 percent of the variance in employee turnover, 34 percent of the variance in withdrawal during discretionary periods, and 31 percent of the variance in worker dissatisfaction. Since a darker office is perceived as more confining than a lighter office (Baum & Davis, 1976), and working in a darker space appears to negatively influence employee behavior, then perceived spaciousness of one's office is important in job satisfaction. This experiment is designed to assess Wise's (1987) recommendations for maximizing a sense of spaciousness through color in a confined space.

COLOR SELECTION

Experimentation is based on Wise's (1987) theory that value (lightness or darkness of a color) and saturation (brightness or dullness of a color) are the salient characteristics in human response to color. The experiment assesses productivity and mood in offices painted with one monochromatic, "NASA white," (US Federal Standard 595b-27875) and two complementary color schemes. Complementary color choices were selected using the Munsell Color System. Lighting has been equalized in three test offices at approximately 60 footcandles for the desk work surface.

Based on Wise's theory, colors were selected for Office Two and Three to create three-color schemes. For an enclosed environment to be perceived as spacious, Wise suggests that the largest area be of low value and low saturation, the second largest area be of medium value and medium saturation, and the trim (accent) in the space be high in saturation and either low or high in value.

According to these suggestions, Office Two was painted with a color scheme predicted to be an unpleasant and less productive work environment: Office Two's Color Scheme -- Strong Red (Munsell 5R 5/12: CIE: L=52.74, a=49.84, b=26.01), for the largest area in the room with Light Bluish-Green (Munsell 4BG 7/5, CIE: L=72.54, a=-25.73, b=-0.57), for the lower third of the room's walls and Pale Pink (Munsell 6R 9/2; CIE: L=90.45, a=4.34, b=2.89) trim accents.

Office Three was painted a color scheme predicted to be a pleasant and more productive work environment: Office Three's Color Scheme -- Very Light Bluish-Green (Munsell 5BG 9/2; CIE: L=87.90, a=-9.59, b=-0.52), (Aqua) for the largest area; Strong Yellowish-Pink (Munsell 5R 7/7; CIE: L=70.99, a= 25.44, b=13.96) for the lower third of the room's walls; and Strong Bluish-Green (Munsell 4BG 5/8; CIE: L=54.45, a=-40.81, b=-5.04), (Turquoise) for the trim (accents).

METHODOLOGY

To date, 46 office workers in three offices (approximately 15 subjects per office) have been tested. This phase has been sponsored by the Institute of Business Designers Foundation (IBDF) and funded by BASF, Corp. and Interface Flooring Systems, Inc. Several months were spent constructing various realistic, clerical tasks for the subjects to complete over a work week. The experimental procedures have been developed and refined; they are routine at this time. Tasks for an involved screening process were also developed and organized.

To qualify for the experiment subjects pass the Ishihara Color Blind Test; type at least 40 words per minute; pass the Social Desirability Scale of Eysenck's Personal Inventory; indicate no prior knowledge of the experiment; are not dyslexic; and, have no physical impairments interfering with clerical tasks.

Eligible males and females work in one office Monday through Thursday 9:00 am - 5:00 pm with an hour lunch and two 15-minute breaks. Subjects type, proofread, file, and answer the telephone. The Profile of Mood States (POMS) is administered prior to and at the end of each workday to assess changes in mood. The POMS provides six mood factors: Tension-Activity, Fatigue-Inertia, and Confusion-Bewilderment. On Friday of the work week, subjects complete an extensive evaluation which includes viewing and evaluating all offices.

PRELIMINARY RESULTS

At the end of Day 4, the fourteen clerical workers in the predominantly bright red office scored significantly lower (M=129.40) than the 16 office workers (M=155.38) in the predominantly light aqua office on the Name Comparison proofreading task (200 pair items) of the Minnesota Clerical Test (MCT). The average score (M=143.15) of the workers in "NASA white" office fell between the average scores for workers in the predominantly bright red and predominantly light aqua offices.

At the end of Day 4, the clerical workers in the predominantly bright red office reported significantly more fatigue (versus workers in the "NASA white" office), more confusion-bewilderment (versus workers in the "NASA white" office), more anger (versus workers in the predominantly light aqua office), and less vigor (versus workers in the "NASA white" and predominantly light aqua offices) as measured by the POMS Questionnaire. The Preliminary findings represent trends. For the hypotheses to truly be tested, more workers will be examined.

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HONG KONG HOUSING AUTHORITY
HARMONY CHROMATIC CHART PROJECT

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COLOUR DOES NOT EXIST.....

It is important to always have in mind that physically:

- Colour is a vibrant, living, dynamic material.
- Colour reveals: minerals, plant, sky, flower, water...
- Colour of materials appears different with light and temperature.
- Colour mood of a site is as permanent as the geographically area aspect. Chromatic map is an "identity "sign of the site.
- Colours affect us physiologically, and psychologically and so are linked to notion of well being.

WHY A CHROMATIC GUIDE LINE ?

There are various goals:

- To provide comfort and well being for inhabitants.
- To suggest identity or new tradition in respect of cultural identity, through new materials, new textures and coloured aspect possibilities.
- To provide a various scales, harmony and coherence between architectures and surrounding spaces either internal or external to the site.

MORE PRECISELY IN HONG KONG:

- To complete or provide "materials " or "possibilities " to be used for the tower concept shape and to supply to their standard effect.
- To introduce complementary range to the existing families.
- To help to a better understanding between suppliers and architects with a precise coherent range.
- To be concrete in using the same vocabulary based on the NCS system, Colours Atlas. This atlas describes the coloured visual aspect of the colour spectrum .

WHAT IS THE USE OF A CHROMATIC GUIDE LINE ?

- We will try not to speak of "colours" we will prefer "coloured aspect"
- That expression includes both the texture of the material and the pigments. For example, a glazed ceramic may be smooth or gloss or mat with the same green pigment, but the "coloured aspect" will be different.
- Colours cannot be ruled - the some with music - to use colours for the sake of their functions or symbolism is totally different.
- The Chromatic Guide Line will be a proposal of coherent colours with different ranges or colour families in harmony with various criteria.

- It will not provide a recipe that some are looking for, but only we hope, the spirit of colours families for various site. These ranges of colours will fit to the sites because they are originally coming from them.

In fact it is the first step to attend this Harmony is the Chromatic Guide Line. In a further stage a more precise location on site is necessary to achieve.

WHO WILL PRACTICE - THE CONCEPTION CHROMATIC GULDE LLNE ?

- Architects, Landscapers, Engineers of the Housing Department
- Manufactures for various building materials as :- Coating - Ceramic - Enamelled steel - Glass tile -

WHAT IS A CHROMATIC GULDE LINE ?

It is a complementary concept tool for Architects and Landscapers which proposes a general coloured aspect mood specific to a site:

- This coloured mood covers land, water, plants, materials, (natural or built), texture.
- It is a synthesis of the "natural " aspect plus added coloured aspects technically worked to fit to the colour potentialities of the site.
- The coherency and the harmony of the range is a support to new coloured events which may be eventually included.
- The range is not a closed square but the feeling of Architects may provide complementary coloured aspects.

More precisely for this survey, the Chromatic Guide Line: - is tight to materials:

> Research of the colours which can he used from the standard chart of a company.

> Proposal of new complementary colours for the company range.

- is translated into a simple general vocabulary the NCS.

THE HARMONY CHROMATIC GULDE LINE INVOLVEMENT IN A HOUSING ESTATE ?

The survey covers the Harmony Block policy, but everyone understands that this guide line may apply to the various amenities as schools, commercial centre, play ground area, various "furnitures" as footbridges, guard rails, banks, shelters, pavements, lamppost.... plants, of an Housing Estate. In fact the colour synthesis map ,as part of the site colours and mood analysis ,may be used on a larger scale with slight modifications issued from programme and scale of study. The Chromatic Reference map of a site is applied more precisely to the Housing Estate. We understood, that the general urban policy for a site as Junk Bay or Tin Shui Wai does not take into account the notion of visual harmony, identity, site character, in the urban brief: Coherence and order appear through a grid of roads, railways, parks, malls outside the "boarder" of each development.

The Chromatic Guide Line is first, part of urban treatment, then it applies to the architectural events of a site, of an estate.

In both situations the Chromatic Reference map ,introducing coloured aspect aggregates, may be completed by more precise information referring to each step of urban design scale.

HARMONY ARCHITECTURE

The constraints:

- the tower concept.

- the standards, Hl, H2, H3.

- the precise location of materials. -

- the cost, the percentage of materials allowed, added to a fixed list, tight to contracts.

- The tower concept is specific to Hong Kong; these are functional and technically studied.
- Shapes are simple; the surfaces of "open " walls seem to appear more in important, than plain concrete wall.
- The vertical close rhythms appear more as a "textured ' facade than a design.
- The structure of plain concrete, appears as grid which provides a secondary rhythm.
- The design of windows presents another scale.
- Ground level, public areas and entrance increase scale variations .

- The choice of Harmony Blocks either l, 2 or 3 depends on the area surface and programme level
- From the material choice and its location on facades the complementary or "camaieu" link has to be proposed between glass mosaic tiles and coating.

The coloured aspect is more simple to solve than the colour treatment of the glass tiles with .semi-gloss aspect, systematically located.

Steel window frames are replaced by aluminium. We regret this choice, even if it is technically the best. The restrictive choice of the colour range, and the fact that inhabitant are unable to modify their aspect provide no identity and seems a loose of character .Proposal of colour variation are presented in RAL range, temporarily in use, translated in the "nearest NCS" (e.g. Frames range).

On the steel topic, we regret what seems to be a need for Hong Kong inhabitants, the "aerial garden", the "green room" or more officially the illegal structure.

- The cost and percentage:

We may say we have proposed in each map a range of various colour "values". We think necessary to think over the percentage notion in accordance with the site mood. Logical and Economical constraints does not reinforce the adopted link with a site, the identification, the inhabitant involvement.

So it appears that we cannot work simply on the logic of the architecture design. (e.g. same aspect on all facades.)

We propose to use Hl, H2, H3 as "shapes", "volumes " in the mass map and in the general landscape.

They are themselves part of the Iandscape that they create. For example in one site the top of the towers need to be darker than the same design in another site.

This concept perhaps will provide feed back on further projects to introduce some modifications in % of material classification

There is no recipe, it is a way of thinking and depends on the Architect and Landscaper ,feeling, creatively ,understanding of urban spaces on a site with its own identity and life.

COLOUR AND LIGHT: A POST-OCCUPANCY EVALUATION OF A STUDENT HEALTH CENTER

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INTRODUCTION

The study of colour and light in health care facilities is influential to the subjective reactions of end users. In 1983, Illumination Roundtable III was conducted "to identify user needs during the decade of the 1980's and to establish a basic and applied research agenda for lighting." During the Roundtable, the lighting needs of health care facilities were addressed by a panel of experts. The Health Care Facility workshop recommended the use of post-occupancy evaluations to determine satisfaction with the colour and light environment.

The post-occupancy evaluation (POE) is the most effective tool available to those who plan and design building interiors for determining user reactions and needs. (Preiser, Rabinowitz & White, 1988; Zimring & Reizenstein, 1980). In a POE, definite evaluation criteria are presented for determination of user satisfaction. The main focus of a post-occupancy evaluation is on the reaction by the end users to a building's design. The result of a POE articulates the success of an area or facility, and develops necessary information useful for future design and building needs. (Zimring & Reizenstein, 1981).

In the past, designers have simply drawn conclusions from site visits, photographs and an occasional comment from a building end user. The post-occupancy evaluation uses standardized criteria and a specific process of evaluation which prevents partiality and ensures credibility. (Zimring & Reizenstein, 1980).

METHODOLOGY

POE documents user satisfaction of the architectural space by analyzing colour and light in the University of Texas Student Health Center Waiting Area The data obtained establishes subsequent colour and light criteria for future design and new construction. To date, a review of the literature provides minimal documentation of POE's on colour and light. Dr. Wolfgang Preiser, a leading authority on POE recommends the use of a multi-dimensional approach. The qualitative and quantitative research methodology provides a multi-dimensional approach by including three components. These components are: 1) a walk-through evaluation that qualifies colour and light criteria by direct observation to determine performance issues; 2) the readings from the Illumination Quality Meter, designed by Dr. William Thornton, that express the quantities and qualities of colour and light in the space; and 3) a two page questionnaire completed by 109 multi-cultural student users that quantifies their reactions to colour and light. The research findings will be used to provide recommendations for construction of a new facility. In addition, this preliminary research provides data for subsequent studies related to health care occupants and end users.

The walk-through evaluation provides a visual assessment of the physical surroundings. A preliminary four page evaluation form was used by a team of an architect and interior designer to study a wide variety of colour and lighting aspects. A refined, shorter form is being developed and will be implemented for future walk-through evaluations.

The Illumination Quality or IQ meter designed by Dr. William Thornton of Primer Color, Inc., measures twenty characteristics of the lamplight. These lamplight characteristics include brightness of a scene and visibility in a scene. Other characteristics include colour-attractiveness, colour-scheme stability, colour-rendering index, colour-preference index, colour gamut, colour temperature, chromaticity x and y as well as brightness units and visibility units per footcandle and per ultraviolet milliwatt per square meter. The ultraviolet, violet and visible microwatts per lumen of lamplight can also be measured. These readings will be studied and compared with the information obtained from the walk-through and the questionnaire.

The two-page questionnaire documents users' response to the colour scheme and lighting in the waiting room (page 4). The comments about what they would like to see different in a new waiting area will also be evaluated.

CONCLUSION

The data will be analyzed and the findings using this multi dimensional approach will be reported. Recommendations for future colour and lighting designs will then be made to the architectural interior design firm involved in the new building.

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The University of Texas at Austin Interior Design Program

Student Health Center Questionnaire

This Questionnaire is part of an interior design student project. Your assistance in completing the Questionnaire will provide important information for future needs of the University of Texas Student Health Center and furnish data for academic research. Thank you for your cooperation.

1. Age: Please check one.

_______ 17 - 20 _______ 26 - 30 _______ 36 - 40

_______ 21 - 25 _______ 31 - 35 _______ 41 - 45 _______ over 45 state: _________

2. Sex: Please check one.

_______ Male _______ Female

3. Ethnic Groupt Race: Please check one.

________ white ________ African-American ________ Native American

________ Hispanic ________ Asian & Pacific Islander

________ Other state: ____

4. College level: Please check one.

________ Undergraduate ________ Graduate

5. State degree: ____

6. Is this your first visit to the University of Texas Student Health Center? Please check one.

_______ Yes _______ No

The following section examines your viewpoint on the color used in the waiting room of the UT Student Health Center.

7. How would you describe the color scheme used in the waiting room of the UT Student Health Center? Please circle one.

very pleasant	somewhat pleasant	neutral	somewhat unpleasant	very unpleasant
1	2	3	4	5

8. What is your reaction to the color scheme (walls, floors, columns, furnishings) in the waiting room of the UT Student Health Center? Please circle one number for each description.

a) relaxing		neutral		exciting
1	2	3	4	5
b)interesting		neutral		boring
1	2	3	4	5
c) cheerful		neutral		depressing
1	2	3	4	5

The University of Texas at Austin Interior Design Program

Student Health Center Questionnaire

(Page Two)

The following section examines your viewpoint on the lighting used in the main awaiting room of the UT Student Health Center.

9. How would you describe the lighting used in the main waiting room of the UT Student Health Center? Please circle one.

very pleasant	somewhat pleasant	neutral	somewhat unpleasant	very unpleasant
1	2	3	4	5

10. What is your reaction to the lighting in the waiting room of the UT Student Health Center? Please circle one number for each description.

a) relaxing		neutral		exciting
1	2	3	4	5
b)interesting		neutral		boring
1	2	3	4	5
c) cheerful		neutral		depressing
1	2	3	4	5
d) bright		neutral		dim
1	2	3	4	5
e)glare-free		neutral		glare
1	2	3	4	5
f) clear		neutral		hazy
1	2	3	4	5

13. What would you like to see different in the main waiting room of the UT Student Health Center? Please explain.

PLEASE RETURN COMPLETED SURVEY TO CHRISTINE ANDERSON OR LEAVE IN THE RED BOX MARKED "SURVEYS". THE RESULTS WILL BE POSTED AT A LATER DATE. THANK YOU.

ENTROPY AND COLOUR

Wendy Light

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1. INTRODUCTION

Hypothesis 1. Homeostasis In colour order can limit colour design to a static and negative concept.

Hypothesis 2. Following the second law of thermodynamics, (Entropy) the dynamic impulse towards disintegration can be hamesseci to provide the difference between minimal functioning and maximal vigour in colour design.

My last paper to this association addressed the issue of how best to teach colour design to students of architecture and my discussion revolved around the daemma of subjective and objective colour design.

During experimentation related to this study I observed that students both at the Bartlett School of Architecture at University College, London, and the Victoria University School of Architecture, Wellington, produced some very appealing spontaneous and expressive intuitive colour designs. When these designs were assessed, together with similar schemes produced from some 'classical' or 'accepted' colour order ideology, they were adjudged by the student group to be both move lively, and more interesting. I brushed this off a little too lightly in my last paper referring to these schemes as • "happy accidents" without fully bringing into question the incompleteness of any colour design conception based on 'accepted' or 'classical' order alone. I am also now aware that this issue has been raised by others, notably by psychologists and by a few incautious physicists and chemists (so why not by an incautious architect?!)

If we accept that colour harmony, per se, is an obsolete rejected subjective term (of interest perhaps only to 'inferior desecrators') then the sense In which colour affectiveness can be judged as 'pleasant', sic, 'unpleasant' or as 'preference' has to be investigated more closely. It would seem that this investigation must also include the identification of the origins and directions of these 'happy accidents- and the determination of why they exhibit more energetic and more appealing effects. If this can be achieved then these stimulating results can be repeated or reproduced and • "unhappy accidents" avoided.

Initially I characterised these • "happy accidents" as being • "on the edge" or as displaying some • "inversion or rearrangement of 'accepted' or 'classical' order". Interestingly enough I have observed that this tendency to • "expand" on accepted gestalt and order is in no way limited to colour design but extends to all design areas including an and architecture. I have found that in judging of preference in any situation of organised whdes where each individual pan affects every other pan (the whde being more than the sum of its pans) examples of balance, equilibrium, proportion, form, etc. were actually disliked or liked less when compared with examples where a certain disecjuilibrium or disintegration pertained; these examples were less boring; more stimulating. At the same time however absolute lack of resolution or total disintegration (chaos) continued to be disliked; a 'reason' or a 'generator' for the breakdown of stability had to be appreciated. This is a design contingency that goes beyond tension and even dynamics and is something that I characterise as 'entropy' or a least 'conditional entropy'.

I use the idea of entropy as a theoretical concept with little immediately in common with thermodynamics per se, (see 2.2.). The pleasure of stimulating colour simultaneously contains and dissolves the mental construct of order. The ultimate pleasure is that moment when colour, brought to excess, reveals both the trace of reason and the undeniable experience of movement towards disintegration - entropy; a reference to, or reflection of, distant realities and origins.

What we need to be clear about is that environmental colour is not an end in itself. Within a narrow span of time and space colour reflects a view of human perceptions, attitudes and values as influenced by historical, cultural and contextual influences. We are in a time of change or of conditioning towards a new world view of entropy In which the spatial and configurational complexities of entropic colour interactions have their place.

2. THE HYPOTHESES

2.1 So why is homeostasis (tendency towards equilibrium not suffiecient aesthetic reward and what exactly is required to assure an extended reward? As Rudolf Arnheim put it, 'Simplicity is not enough'.

Basic gestalt psychology holds that any visual pattern will tend towards the simplest configuration available. However this tendency cannot compete with what we see In nature and in art and consequently it leads to a very one special description unless it can be balanced by an equality influential principle of variety w complexity.

In the physical world the simplicity principle nJies unopposed only in closed systems. The organism however is by no means a closed system and it counteracts the running down of visible stimulation by constantly absorbing information through the senses, processing and transforming it Internally. Brain and mind envisage change and crave it; they strive for growth, invite challenge and adventure. We prefer life to death, activity to inactivity. We respond to tension whilst at the same time seeking tension reduction and acknowledging the tendency towards simplicity. Of course tension reduction cannot function without interplay with tension heightening as tension heightening Is checked by an anabdlc or a constructive tendency towards the creation of a 'structural' theme, derived visually from first simplifying and then restructuring the Information. Peter Smith calls these two phases, aesthetic arousal; the primary reward and aesthetic de-arousal; the secondary reward. As arousal or tension ascends to a peak the awareness of unity and order overtakes the perception of complexity and challenge, resulting in an immediate change of emotional 'sign' to tension reduction.

The ultimate pleasure and pain of tension reduction has been referred to as "a sense sublime": a sense certainly not unknown in colour.

"..I have felt 93
A presence that disturbs me with the joy
Of- eievated thoughts; a sense subiime
Of something far more deeply Interfused
Whoes dwelling Is the light of setting suns,
And the round ocean and the living air,
and the blue sky, and in the mind of man.
..........................."

William Wordsworth "Lines composed a few miles above Tintern Abbey".

This sudden switch can also be regarded as a controlled catastrophe In the meaning used by catastrophe theorists and which is a paradigm for survival. Uncontrolled arousal or tension heightening might well fulfil the conditions of chaos, which is not a paradigm for survival, any more than are totally balanced or average conditions. This contention can be characterised by the resultant of the suggestion of a confused flat land dweller, that if all of Switzerland's mountains were dumped into all its lakes, two unnecessary anomalies could be got rid of at once!

2.2 The word 'Entropy' comes from the Greek En-energie and trope - transformation, and 'n is in this theoretical definition of energy flowing inexorably from the orderly to the disorderly, that transformation, Inherent motion and direction, offer a dimension to be tapped. I perceive entropy as the dissdunion or disconsertion of seemingly inviolate principles - a kind of degradation if you like, involving the challenging of very debatable and historically hamstrung, mores and 'classical' constraints.

It Is clear from books like Jeremy Rifkin's "Entropy - A New World View," that the notion of entropy has changed over time.- During the last cel1tury it seems to have been diagnostic of the deplorable degradation of culture; more recently it seems to represent a possible rationale for an escape from, or a slowing down of, Impending nothingness. Of course the historical idea of entropy spawned a multiplicity of dysfunctional arts including minimisation and nihillsm. Schönberg wrote that dissonance should be considered • "a piquant seasoning for tasteless sounds". And Kandinsky wrote of Debussy and Schönberg (also a painter at this time) they were • "almost alone in abandoning conventional beauty and in sanctioning every means of exipression". Entropies are logical components of composition that have gained a vitality inherent in order but which are not of • "classical" order.

An interesting corollary to the entropy law suggests that whenever a sembiance of order is created anywhere it is done at the expense of causing greater disorder in time surrounding environment. The thought that a deliberate introduction of entropy might, by extension, reduce disorder In surroundings has immediate appeal and obviously would be derivative of mutual information. Either way round entropy refers not to primitive chaos but to a state of order from which it has been transformed. It is only in this way that productive (or conditional) entropy can be distinguished from unproductive confusion. Confusion or chaos will obviously be approached as the entropic input is too strong or the originating footprint too weak. In other words a lapse into an indiscriminatory state is the opposite of an entropic focus in design.

A parallel can be drawn here with deconstruction in architecture which uses a contingency of rhetorical figures and devices derived from various texts which signally fail to construct. Our Western logocentric tradition is subjected to displacement, dislocating forces, inversions and paradoxes (including entropy) which subordinate but do not exclude 'classic', 'accepted' or natural texts.

"For thence a paradox
Which comforts me while it mocks -
Shall life succeed In that it seems to fail!"

Elizabeth Barrett Browning
"Rabbi ben Ezri"

INVERTED AND AMBIGUOUS COLOUR COMBINATIONS

Many ideas of colour order have been promulgated down the years and often 'harmony' simply meant some sort of order with general principles based on observation and personal experience. Today these 'harmonies' appear as reflections of 'the taste of the times'. Chevreul's view that "red and orange are very bad together" illustrates this contention well.

Alfred Munsell and even Johannes Itten, that tenacious Bauhaus teacher, on the assumption that harmony implied 'balance' and "symmetry of forces" considered that the eye "needs" medium grey and becomes " discjuieted by its absence". The doctrine of complementaries emerged and it was suggested that "two or more colours are harmonious only if they yield a neutral grey". All other colours items called 'expressive' or 'discordant' (expressive sounds wonderful!).

In 1946 Aemelius Müller proposed that colour combinations could only be harmonious H the colours are in the same relation of lightness as that naturally existing between them. He further stated that non-harmonies combinations derive from inverting the relations of natural lightness of colours. He called the harmonies colours 'correspondent colours' and the 'supposed' non-harmonious colours, 'Inverted colours'. This approach bore some relationship to Munsell's inverse ratio (value/chroma) of colours to area, balancing about neutral grey.

More recently Sivik showed In his experimental work that this conclusion was restrictive, finding no statistically significant difference between preference for 'correspondent' and 'Inverted' combinations. My findings to date do not support this, but I do concur with respect to the restrictive nature of Müller's theory.

In 1985 Spillmann drew attention to the importance of whiteness and blackness the perceptual characteristics which strongly condition the appearance of colour combinations and he divided Muller's 'inverted' combinations into two groups calling them 'vague inverted' and 'distinct inverted' combinations. 'Spillmann called upon others to further 'test' how 'acceptable' these combinations were. Both da Pos and Frabrize took up the challenge and using the pair comparison method produced results consistent with Spillmann's hypothesis. Whiteness and blackness emerged as influential variables.

My recent experiments employing similar pair comparison and preference sequencing techniques for three types of combination; 'similar', 'contrasting' and 'ambiguous' (See Fig 1), indicate for both the 'contrasting' and 'ambiguous'

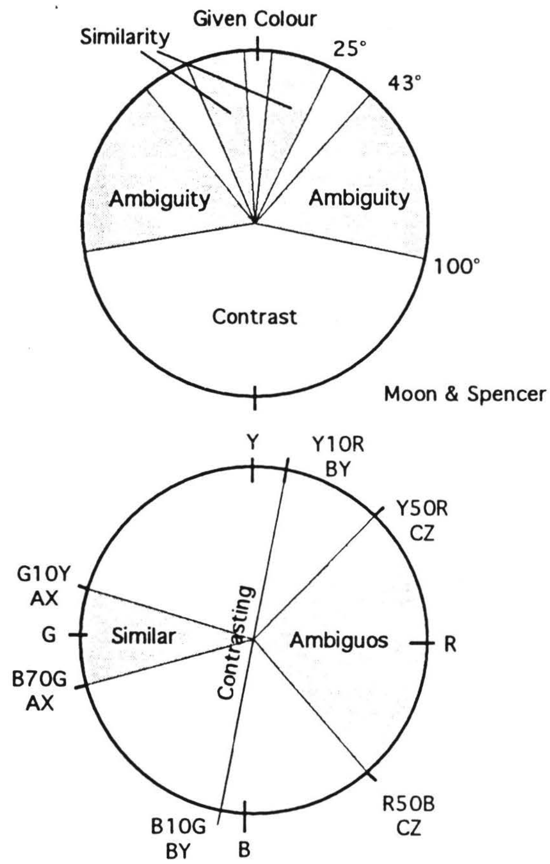

Figure 1. Results of experiments employing similar pair comparison and preference sequencing techniques

combinations, clearly defined preferences for firstly 'correspondent', then 'vague inverted' and lastly 'distinct inverted' combinations. With a neighbouring or 'similar' colour combination (Blue green/green) these groupings were not clearly defined and were in fact some what intermixed.

Obviously further tests are necessary with a wider range of both combination types and subject groups, but to date I can report a significant preference for 'correspondent' over 'inverted colours' in 'contrasting' and 'ambiguous' combinations. I am also prepared at this stage to propose a further breakdown to the three categories, dividing Spillmann's 'vague inverteds' to include another very influential variable working in conjunction with lightness contrast i.e. chromatic intensity. In the case where the chromatic intensity of the combination colour is greater than that of the given colour, I would identify a found group of 'chromatic inverteds'.

I will make some further comments on my experiments here but for full details and illustration of results I would refer you to the Appendix and References to this paper which is available to those interested. Suffice to record here that the experiments showed no statistically significant differences between male and female preferences or between figure ground inversions (see example in Fig. 2).

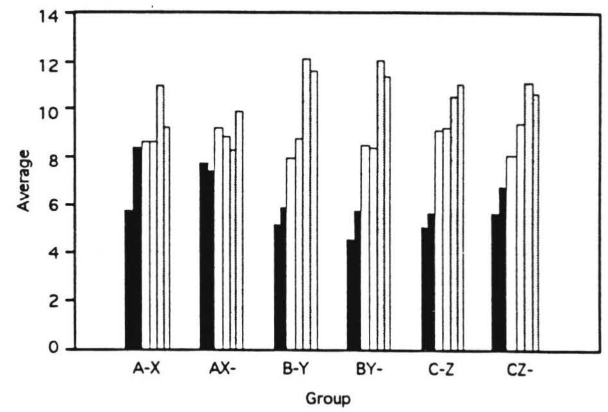

Figure 2. Average colour score by sex (Female and Male)

In the fundamental 'blue'/'yellow' 'contrast' combinations 'vague inverteds' followed 'correspondent' pairs as the 'dirtiness' effect of lighter hues and the 'milkiness' effect of darker hues did not necessarily make the combinations unattractive or at least they were more attractive than the 'distinct inverted' colours which 'suffered' from the practical fact that yellows cannot be darkened without losing its chromatic character and becoming greenish and murky.

In the case of the 'purple'/'orange' 'ambiguous' combination the preferences were still clearly defined in their respective groups except for two migrations; one where the chromatic intensity was higher (50-70) accompanied by more whiteness (20-00), (3) and one where a substantial increase in chromatic intensity (50-80) was also accompanied by more whiteness (20-10) (6), which fell in rating. These I would consider both come into the 'chromatic Inverted' group. In the case of the 'blue green'/'green' 'similar' combinations it was interesting to note that although the groupings were less distinct a similar migration of these 'chromatic inverteds' (3) and (6) occurred and in this case a third (9) with higher chromaticity (50-60) and similar blackness (20) was particularly unfavoured, so that (9) also comes into the classification of 'chromatic inverted'. These three instances became ever more problematical (i.e. less liked) when the given colour was presented as the insen (see example in Fig 3). In effect, the given colour was

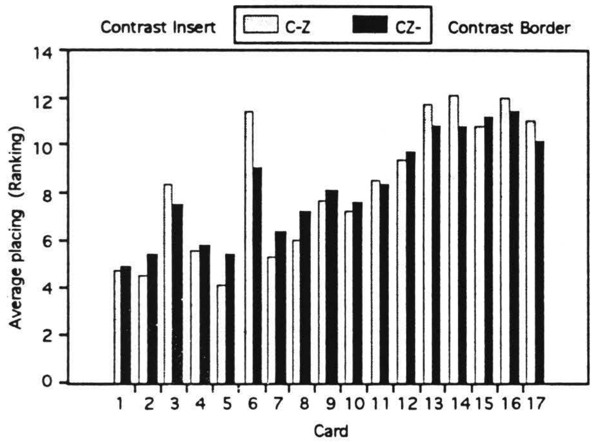

Figure 3. Preference of cards [Figure/Gound effect] (All)

surrounded by a colour which made it look 'dirty' or 'milky' or degraded by comparison. (This was not so critical when the 'given' colour was the border.) The reason why this effect did not occur in the 'blue'/'yellow' 'contrast' combination would seem to be because simultaneous contrast helped to clarify and enrich the given blue so that the resultant colour was not degraded and the combination not so disliked. 'Vague inverted' combinations were liked after 'correspondent' combinations because they were 'interesting' and 'distinct inverted' although generally disliked were preferred when the contrast of both blackness and chromaticity compared with the given colour was larger. In fact lightness ratio difference in some 'inverted' examples played a role in their preference rating and colour combinations of similar chromaticity and blackness (traditionally considered to represent 'accepted' or 'classic' balance) were not rated highly at all. This supports da Pos's findings that the 'correspondent' 'vague inverted' and 'distinct inverted' assumed well defined forms, with combinations where there was a strong contrast or difference being preferred over ones with indeterminant differences or close similarities.

CONCLUSION

All colour interactions are expressive and 'discord' can only mean a relatively unpleasing interaction. As the experiments demonstrated it is a measure d pleasantness or sequencing d preierence only which determines relatively amongst thousands of potential interactions which go way beyond any neutral grey balance theory (which doesn't in any case hold up at all well,) or accepted or classic 'rules'. Instead of talking about consonance and dissonance we would ioe better off speaking of static, dynamic or entropic combinations considered as part of a total field of colour Interaction. We crave colour constructs in the environment which create tension as well as equilibrium.

Colour should not be isolated by design. We must recognise that the limbic brain needs stimulus as well as the intellect and environmental colourists must be prepared to step down from effete sterility, to broach 'life' and assimilate the aesthetic vaiences of the 'different- and the 'entropic'. It is no accident that art and architecture march to a similar beat; manipulating discontinuity and dislocation of forms, materials, and colours without however losing contact with archetypal iconography. It was no 'accident' that (Jack the Dripper) Pollock's controlled spillages created entropic dissolutions, or that Oldenburg "called home" on a giant soft telephone. We have 'enjoyed' musical performances presenting nothing but silence and contemplated Daniel Buren's blank patches on striped walls where perhaps paintings once hung. Robert Smithson in "Entropy and the New Movement" said of sculptures like Olderburg's, Baseball Bat Column in Chicago that, "they are not built for the ages but rather against the ages" and "provide a visual analogue for the second law of Thermodynamics". At the other end of the scale excrescences like the Victor Vasarely Foundation in southern France, bore the pants off everybody and only Albers's last "Homage to the Square" holds much but nostalgia now for most people.

Of course colour can be employed environmentally to 'stay' entropy where distance or disintegration is becoming problematical. Tschumi at Parc de la Villette in Paris for example, paradoxically uses one colour (red) in a major role to provide necessary "classical ordering" or 'grounding' of his deconstructed texts. Peter Eisenman, discussing his houses 'for not living in' told an audience that 'any woman who subscribes to classicism is self destroying'. (I wonder what is does to a man?)

Finally then just as entropic art is not anti-art and entropic architecture is not anti-architecture, entropic colour is not anti-colour. Equally I am not advocating chaos theory or a zero degree of stability or even anti-culture or anti-environment. I am not advocating the rejection of any system of colour order or communication (these become of critical necessny); what I am suggesting is that a cultural change and a new awareness of impending direction open our intellect and our brain to a release from restrictions of 'accepted' or 'classical' design and allows supplementation with stimulating entropic dimensions.

I do not see entropy as the absence of all order but as the harnessing of the energy and transformations spinning off from the fragmenting, dislocating and disconcertion of order. The results of an entropic colour approach are likely to be complex and difficult, remembering that mere randomness does not suffice to create readabie or intriguing complexity. As architecture is harder these days so in colouring. These perhaps 'beautiful' but at least 'interesting' results will be ones in which the colours leave each other sufficient references and sufficient freedoms to set up tension and rewarding interactions.

"In madness equilibrium is established, but it masks that equilibrium beneath the cloud of illusion, beneath feigned disorder; the rigour of the architecture '(read colour)' is concealed beneath cunning arrangement of these disordered violences".

M. Foucault, Historie de la Folie

"A plan so cunning you could put a tail on it and call it a weasel"

Edmund Blackadder.

LIGHT AND COLOURS IN CHINESE ARCHITECTURE AND ARCHITECTURAL PAINTINGS

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Light through colour exposes the beauty of all objects in the universe. The long standing and excellent artistic achievements of Chinese traditional architecture and its decorative painting find the expression through the play of light on colour and judicious introduction of contrasts of relationship among the multicipality of colours thereby to bring out expressiveness of light and colour, visual effects, and psychological impacts such interplay is imbued with great charm. All those have visited China have been greatly impressed by these symphonic poems of colour as being unique composition.

The following will deal with some aspects of colour contrasts to start off to lead to comments on the characteristics of handling light and colour in Chinese traditional architecture and decorative painting:

1. CONTRAST OF COLD AND WARM TONALITY:

In Chinese traditional painting, colour may be divided into two categories viz. Yin and Yang. The Yin colour, in common parlance is the colour of cold tone; the Yang, the warm tone. In the colour wheel, red, yellow, green and blue are the brightest hues most illustrative of the tonality of colour and under daylight bringing forth the vivid contrasts.

For instance, in the palatial buildings wherever the orientation is towards the sun yellow tiles (yellow glazed tile - 9.5YR6.1/10.2), red walls (9.9R3.5/3.7), red pillars, red door and window frames (6.4R3.7/12.1) are employed. Yellow and red hues, being Yang possess the warmest tonality. Under the shining light, the slanting glazed tiles emitting scintillating gold yellow coloured light to enhance the redness of walls, pillars, doors and windows demonstrative of the power of maleness in the Yang colour. The entablature and parts thereabouts under the projective up to a depth of about three meters in depth are all in the shade which require the use of the Yin colour - blue (2.5PB3/14.4), green (1.9BG5.1/9.7) cold colour and it is here that decorative painting is to be applied with great care to release fully the beauty of the softness of the Yin.

Chinese palatial buildings often aim at the search for the variation of tones caused by the play of light on colour. By virtue of the reflection principles and characteristics of colour, light and colour may be integrated to produce the desired chromatic atmosphere in the environment of daylight to give the enjoyment of subtle variation and fine sentiments.

The yellow glazed tile has a slight touch of red hue and thus appears as orange yellow therefore in perception it is even warmer than red colour and seems especially bright and under brilliant daylight more splendour is brought out touch viewers' heart. The use such colour scheme which was monopolized by the monarchal and ecclesiastical power in the not only lightness to the heavy roof structure but also enhance the prestige and dignity of the palaces. Because of the apparent heaviness of red hue which gives a feeling of solidity, stability and weightiness when applied to the walls and pillars will give the appearance of great firmness and capability to bear great mass to these elements.

In the shade cold colours aptly and organically form blocks of blue green. Blue soars to the sky and green links with the vegetation on the ground. Such colouration in the shade give out feeling of airiness, lightness and distantness; it will not only bring lightness to the large roof but also apparent height to the building and adds a cloak of mysticism to the palace.

Furthermore, inside the palace, pillars mostly painted in red and gold which are warm; for the ceiling decorative painting blue green used that is cold; because of weightiness of warm tonality pillars are imparted with the look of strength, stability and load bearing capacity and on the other hand, the cold tonality of the ceiling appears to be afloat thereby an appropriate colouration is achieved for the interior space.

2. CONTRASTS OF COMPLEMENTARY COLOURS:

The orange yellow of the large pitched roof in Chinese palace buildings vying with the azure sky over Beijing shows the complementary relationship of the co-existing orange yellow and the azure hues, the contrast of the natural complementary colour.

Red roofing tiles and red walls and purple green for parts of decorative painting in the shaded area under the eaves thereby red and blue green are complementary with each other artificially accentuating the contrast of complementary colour to give emphasis to the architectural unity.

Blue green being the thematic colour of decorative painting with dots in brilliant red and yellow like musical staccato once again produces contrast of complementary colour artificially in part.

Chinese palatial buildings viewed from macro to micro spaces - sky/edifices, building exterior/interior, interior decoration/wall face, every pair of complementary colour has its relative individuality, e.g. azure blue/orange yellow, orange yellow/blue green, blue green/primary red. And each pair of colours gradually finds balance in the gradation of complementary intensity, chromaticity gradually gaining intensity. The performance of complementary colours in decoration under the shade is similar as the combined operation related with colours of high intensity wherein indigo, emerald green, vermilion, medium yellow mixed with black and white can produce combined effects which will convey the feeling of spaciousness produced by the use of colours of high brightness on buildings. And the means of chromatic disposition, chromatic mutation and the rhythmic variation resulting from the application of contrasts give rise to a set of technique for the design of colour scheme effective for to give forms to the building thus not only to enhance the space but also the embellishments.

3. SIMULTANEOUS CONTRASTS:

For Chinese traditional architecture the selection of colour phase and the division of colour area aim at the real effects as realized by the simultaneous contrast and to allow each colour theme to be in proper chromatic relation.

The simultaneous contrast between the scintillating yellow glazed tiles and the azure sky, on account of not being perfect complementary relationship thus in time of contrast, the sky seems to be cloaked with mist of light violet rendering a yellow/violet chromatic relation thereby colour of the building appears more vivid while the sky, heavy overcast.

The simultaneous contrast of yellow tiles, red walls and blue green decorative painting enhances complementary relation to make the warm warmer, the quiet the quieter, chromacity the more brilliant, more saturated and the contrast the more pronounced.

4. CHROMATIC CONTRASTS:

The chromacity as appearing in the Chinese palatial buildings has very high intensity, the chromacity of the brightest roof can reach as high as 10.2 and blue in the decorative painting 14.5; from the following chromatic scale, it may be noted that how varied are the layers grading from the high to the low in the chromatic gradation:

The reflected light from the roof, pillars, doors and windows, walls, balustrades and the paving has high brightness and chromatic values falling from 10.2 - 6.3 (6.1) - 3.7 - 0 forms gradation contrast. Decorative painting under the eaves in the shade absorbs the light with low brightness, therefore the strongest chromacity - 14.5, 13.1 - is adopted. Such a handling is inconsistent with the light theory. Blue green can express more fully its lustre, naturally characterizing its depth and yet in the same time not interfering the chromatic beauty of the building in the daylight.

TABLE 1

yellow glazed tiles	9.5YR 6.1/10.2	} in the daylight
under the eaves	2.5PB 3.0/14.5	}
(primary colours)	1.9BG 5.1/09.7	} in shade
	8.6R 4.6/13.1	}
pillars, doors & window (red)	2.5YR 2.9/06.3	}
(green)	2.5G 3.1/06.3	}
large red wall	9.9R 3.5/03.7	} in the daylight
white marble balustrade	N 8.1/0	}
grey brick paving	N 5.3/0	}

The theme of the decorative painting is in blue green on application these two colours are mixed with respective amount of white given to the graded colour phase; their respective chromaticity are as follows:

Blue	2.5PB 3.0/14.4
	2.5PB 6.3/8.9
	2.5PB 7.4/7.2
Green	1.9BG 5.1/9.7
	1.9BG 7.0/9.1
	1.9BG 8.6/6

These two chromatic contrasts may be applied in the coloration of a large number of decorative paintings. The graded colour phase in chromatic contrasts originated in Song Dynasty (1103 AD) and has been in use ever since. In gardens, mansions and shop fronts, the Suzhou style decorative paintings are often adopted in which the middle of beams have to be treated with coats of graded pure colours as many as thirteen in number to get the desired effects. This is a laborious process calling for skillful execution and entails great difficulty therefore usually employed in works of high prestige. For normal works, 5-7 phases of gradation would be sufficient with satisfactory results.

5. CONTRAST IN COLOUR PHASES:

The strongest contrasts can be listed 5R 4/14 and 5BG 4/6.

Contrasts in colour phase commonly encountered in Chinese traditional architecture may be as given in Table 2.

Contrasts in colour phases for decorative painting:

2.5PB 3/14.4	1.9BG 5.1/9.7
8.6R 4.6/13.1	3.3Y 8.2/11.7

The use of contrasts in colour phases in buildings and decorative paintings as if in search for a chromatic "explosion" --- with a big bang to attract --- yet without the effect of forcibleness. Taking buildings as an architectural entity, the application of colour is for designing. With the clever and subtle conjugation of the brilliant red, yellow and blue give the coloration special characters and quality and in the visual impression, the brightness and colour area combined in a respective whole to create a unique contrast in colour phase thus rendering liveliness and strong expressiveness to the majesty and formalism of architecture, another word enhances its artistic image.

6. BRIGHTNESS CONTRAST:

In Chinese traditional architecture, owing to the constraints of the climatic conditions and percepts of hierarchy, the three layers in brightness contrast, black, white and grey, are evident in different categories of buildings:

(a) Black and white contrast: it is extensively used in domestic architecture in south china. In south china between north latitude 20 to 30 degrees where the temperature is high and the humidity is

Table 2

	Roof	Underneath the eave		Walls
Palaces	9.5YR 6.1/10.2	2.5PB 3/14.4	1.90BG 5.1/9.7	6.4R 3.7/12.1
Mausoleums (for emperor's concubines)	9.3GY 3.1/04.8	2.5PB 3/14.4	1.9BG 5.1/9.7	6.4R 3.7/12.1
Altar & temples (e.g.Altar of Heaven)	1.1BG 4.2/08.5	2.5PB 3/14.4	1.9BG 5.1/9.7	6.4R 3.7/12.1

high, white walls (n9), and black tiles (n3.1) are adopted for dwelling buildings. This simple colour scheme amidst the lush green vegetation brings out the startling simplicity and elegance of the common edifices.

(b) Contrast of light and deep grey: for domestic buildings in north china, the upper exterior wall is usually painted in light grey (n8.1) to 2/3 of the height, and the rest of the height below, painted in deep grey (n3.5). In the north (north latitude 40 degrees or about) where the temperature is low and in the spring it is often swept by sand storms, white walls are obviously out of place. Then again, common dwelling house being the lowest in the social hierarchy are not compatible with the palatial homes of the nobles, so there are two sets of grey walls in use to mark the differentials but both against the vast expanse of the northern plain in winter and the greenness of the plain in the spring, the lush green of the summer, and the multi-colour of the foliage in autumn; all to bring about a very pleasant combinations.

(c) Contrasts of medium and deep grey: within the city walls of the capital the palatial mansions of the noble families are built with medium grey bricks (n5.3) and deep grey bricks (n4). Their social status lower than the imperial family but higher than the common citizenry, the grey walled courtyard houses form a class of their own. When these grey courtyards enclosing the royal household in the centre provides an excellent foil for the forbidden city accentuated by the high chromaticity, high contrasts and high colour phase of its architecture.

This contrast of greyness is also reflected in the common popular temples and monasteries. These edifices are built with grey bricks and black tiles (for those under the imperial or royal patronages, yellow, green or violet glazed tiles may be used) and grey bricks for paving which in the surrounds of vegetation, the contrast of brightness is not so pronounced easy to be in harmony with its environment thus to create a peaceful and out-of-the-world atmosphere.

(d) Contrast of grey and white: in the imperial palaces, the use of grey and white (n5.3 and n9 respectively) is adopted most satisfactorily. Large extent of grey is used in the interior of the palace, external paving and garden paving; and on these grey surfaces are set the plinth of the balustrades and terraces of white marble. Viewing from distance, buildings of high chromaticity like a piece of artistic craftsmanship sitting on a white and grey base. The loosely applied grey and the densely painted white contribute to the perfection of architectural colour scheme.

(e) Contrast of brightness of different hues: chinese palaces are not only rich in the colour variation but also rich in contents with many layers apt for sketching needs. This realized in the variation of colour phases of different chromatic intensity: yellow tiles 6.1 grade, violet green decorative painting 4.05 grade, red wall 3.5 grade, red pillars 2.9 grade, each of which basically form a gradual gradation phase; such a contrast of brightness from brightness to darkness is very subtle for it increases the chromatic weight and the plasticity of forms by degrees thus to enhance the stability of building forms.

7. AREAL CONTRASTS:

The architectural colour schemes in the ancient city of Beijing may be divided into two colour areas: (a) non-colour courtyard houses (mainly mansions of noble families) grey N5.3 grade; (b) imperial palace buildings of high chromaticity, tonal value between 9.5YR 6.1/10.2 and 9.9R 3.5/3.7.

The ancient city of Beijing has an area of 67 sq. km of which the Forbidden City takes up 0.81 sq. km. Subtracting therefrom lakes and green spaces, the large area of non-colour in contrast with the relatively small area of high chromatic area creates an effective background for the glittering incompatible magnificence of the palatial architecture.

Within the flamboyant Forbidden City, there are occasional areas of non-colour to form contrast, such as the white marble plinths and paving of grey bricks. The non-colour areas within the Forbidden City again contrasts with the micro grey and white areas about 3% of the total and in the same time provides foil for buildings in high chromatic areas to bring out the main theme of majesty and permanence to the full exploration of colour potential. Within the large area of non-colour are dotted with a few colourful imperial temple, monasteries and landscape architecture so that the flamboyant imperial palaces may not appear to be too lonely and conspicuous in the core of the city. And in the case of architectural embellishment - the application of decorative painting - in spite of the fact that the rigid social hierarchy exists to rule over all buildings, from the palaces to temples, monasteries, gardens, dwelling houses and shop fronts but the colour theme always remains unaffected - blue green of high chromacity is ever constant like broken threads lead the colour to and diffuse them to areas of non-colour to establish the relationship of the buildings and to adjust the chromatic differences among the various building ensemble thereby the colour scheme of the city becomes an organic whole unifying the building decorative styles in the city.

Planning for colour for the ancient city of Beijing is carried out according to a unified concept, it starts from the peripheries and centres on the core to build up a colour scheme like a successful works of music with its main rhythmic theme, climax and accompanying passages and in the midst of high strains there may be meaningful pauses - soundless voids and finally, the matchless softness of the grey to echo the beginning of the music just like the finale of the music. We are left with elated feelings in the enjoyment of the after-taste; colour and non-colour accomplished their contributions to this city beautiful.

Because Chinese traditional architecture is principally of timber construction which needs coats of paint for protection, hence the application is necessarily artificial, this is a concept after serious study and practice. The large area of grey needs not lead to deficiency in colour and the misuse of "explosive" colour is rare. All social stratums, out of their political requirements and basing on the natural performance of the colour and with the multifarious mutation and spectral relations to seek for an environmental disposition of colour require the exercise of restraints in application, balance of structure, contrasts and conjunction, modulation and variation so that all will be in complement with each other to realize the high possible values in colour.

Art only deeply rooted in the native soil of the country can possess strong vitality. The Chinese people with their national tradition for colour and bias, the climatic characteristics of the natural environment, the structure of architectural spaces, properties of the building materials the colour of finish and the rigid hierarchy and so on have created the traditional art of architectural use of colour which with the application of colour in the light has achieved great success to make contributions to the common world cultural treasury.

ABSTRACT ONLY

THE RELATIONSHIP OF LIGHT-AND-SHADE TO COLOUR IN EUROPEAN PAINTING

Roy Osborne

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This lecture (illustrated with slides) traces the use of light-and-shade in relationship to hue and saturation of colour from the 15th to the 20th centuries. Masaccio's decision (c.1420) to move the illuminating light source from the front to the side increased the pictorial illusion of weight and solidity by emphasizing light-and-shade at the expense of colour saturation. The 'sculptural' effect W25 stressed further by Leonardo's observation that the true or 'local' colour of a non-shiny object is in the highlight. This led to a convention for inordinately dark or 'tenebrist' paintings that was not fully rejected until the popularity for open-air landscape painting in the 18th and 19th centuries. Colour saturation in painting was further heightened by the use of symbolic 'memory colour' and by the 'optical mixing' experiments of the neo-Impressionists who placed small points of unmixed colours side by side to avoid the darkening effects of traditional subtractive colour mixing. The novelty of transferring brushstrokes of saturated colour directly onto the canvas eventually led to the rejection of Renaissance chiaroscuro by the French and German Expressionists early in the 20th century. The lecture discusses how- such developments were dependent on technical, scientific and aesthetic innovations.

COLOUR IN THE FOURTH DIMENSION

Paul Green-Armytage

"Viewed from afar, Ayers Rock looks like an impregnable fortress. But while the massive bulk of the Rock appears immutable and infinitely durable, the constancy of its colours is as fleeting as time itself. In the first light of morning, the Rock is suffused with a rusty flush. Later, as the sun climbs towards its zenith, the monolith appears bleached. When clouds trail across the sun, the hot-hued surface deepens to a richer brown. After rain, Ayers Rock turns leaden. Evening provides the most spectacular colour change. When the sun sinks low, its rays transform Ayers Rock into a gargantuan ember. Outlined against the wan blue heaven, the incandescent Rock seems to scorch the sand for miles around." (1)

Chromaticity coordinates for the rock surface have been obtained by measurement: x0.411 yO.358 YO.352 CIE 1931 Ill C. Those figures, and the means used to obtain them, would not bear close scrutiny, but that does not invalidate my point: while the rock surface may be uneven and somewhat mottled, from the point of view of colorimetry it does not change "colour". The colour of the rock surface is constant in a way that the skin colour of a chameleon is not.

Equally constant is the formula used to mix a paint from the Taubmans range which is identified by the name "Ayers Rock". The formula is useful to the paint company. Chromaticity coordinates for the rock surface would be useful to a geologist. Also useful would be a notation such as 10 R 6/6 which would locate the colour in the three dimensional space of the Munsell System. Formula, coordinates and notation all deal with something physical, measurable and permanent, but they convey nothing of the actual experience of the Rock itself which does indeed appear to change colour and which draws tourists in their thousands. The three dimensions of a colour system are not enough to describe this. No account of the "changing colours" of Ayers Rock is adequate without reference to the fourth dimension - the dimension of Time. The different colours are particularly clear in photographs which have been taken at different times of day, from different viewpoints, at different distances and under different weather conditions.

W.D. Wright (2) has offered an answer to the question "what is colour for": "Surely this...to tell us about objects". Colour can certainly help us to distinguish between an orange and a lemon and to determine whether a tomato is ripe or not, but there is additional information about objects which can only be picked up when colours change. Perception of change requires time and movement. If a change of viewpoint produces a change in colour at Ayers Rock, then the way in which the rock surface changes colour tells us something about the rock.

Important information about an object can be conveyed by the degree to which its surface is or is not glossy or textured.

It can be important to know whether a ceramic jug is glazed or not. Glaze is revealed by changes in colour - the highlights. One might conceivably interpret the highlights as patches of white paint, but that reading becomes impossible as soon as there is movement; when the angle of illumination changes, the positions of the highlights also change.

Richard Hunter (3) has pointed out how "In assessing color, the eye looks at a uniform area of the object; to evaluate gloss and texture it looks for non-uniformity across the whole surface of the object, as indicated by variation in the intensity of light reflected from the object." We are acutely conscious of such non-uniformity. Colour changes which indicate degrees of gloss and texture help us to identify and evaluate objects. These are the features which enable us to tell the difference between a brick and a glazed ceramic tile. Changes of colour alone, however, which appear in a "uniform area of the object", are a different matter. Now we would judge that the object itself is different, that it has undergone some physical change. If it is, in fact, the same object, physically unaltered, we would not want to be misled. This is where the phenomenon of colour constancy comes in.

As Jacob Beck (4) explains: "Color constancy refers to the fact that the perceived color of a surface tends to remain constant despite changes in illumination that alter the intensity and spectral composition of the light reflected to the eyes." So we read as uniformly coloured two walls of a building where one wall is in bright sunlight and the other in shadow. There is a very subtle interplay of consciousness and unconsciousness. We notice the difference because it helps to reveal the form of the building but, having extracted that information, we discount the difference so that we are not misled into believing that different bricks have been used. On a smaller scale, we extract the information which reveals the texture of the bricks and then discount it so that we are not misled about the material from which the bricks are made; we can distinguish between those colour changes which are indications of texture and those which reveal that there has been surface staining or that the clay body of the bricks contains other ingredients.

Colour constancy might make tourists at Ayers Rock sceptical about the different colours in the postcards and souvenir books. (A two dimensional photograph does not contain all the information required for colour constancy to operate.) It is the colour changes at sunrise and sunset which give credibility to the photographs. It is because, at those times, the interaction of light and rock surface produces such rapid and extreme changes in the "intensity and spectral composition of the light reflected to the eyes" that colour constancy breaks down and people want to ascribe the colour changes to the rock itself as though the Rock had some magical property or were even alive.

Living things do change colour and these colour changes also "tell us about objects"; they tell us about changes in an organism's physical state. Green leaves turn brown when they die. The very fact that a lizard changes colour helps to identify it as a chameleon. With different pigments in special cells which can expand or shrink in different layers of its skin, a chameleon can display a repertoire of patterns to inform or deceive. A male can change colour to let a female know what is on his mind and change again to warn off a rival. Some chameleons escape predators with a colour pattern that makes them seem to be part of the background.

Colour changes play a role in many branches of science. The litmus test reveals the presence of acid or base by a change of colour. Crystals of potassium ferricyanide appear orange. When added to a ferrous sulphate aqueous solution they turn blue. This tells us that a new complex has formed. Colour changes can play a role in the identification of minerals. Al Pegler uses photomicrography to record the different colours which appear when a thin slice of rock, mounted on a microscope slide, is rotated in polarised light. This process makes it possible to measure the angles between the crystal axes and this, together with the colours and colour changes, contributes to positive identification of the minerals. In each case the before and after colours which "tell us about objects" can be measured.

More difficult to measure are surfaces where there are no physical changes in the object or light source but which exhibit different colours when seen from different viewpoints. These are the kinds of colour changes which tell us that a surface is glossy or textured, but which occur most dramatically when the surface is pearlescent. Allan Rodrigues (5) has described how at least three separate measurements, each with a different viewing angle, are required to establish whether or not two pearlescent surfaces will match.

Colour changes present problems and opportunities to those who apply colour - artists and designers. Colour constancy and the associated phenomenon of memory colour can make it difficult for painters to see and record accurately what is before them. These issues are raised by Roy Osborne (6): "...it is not incorrect for a member of the general public to describe the entire facade of Rouen Cathedral as "stone coloured" ... however, the Impressionist painter Claude Monet repeatedly depicted the Cathedral using numerous colour combinations, each observed accurately but under different conditions of illumination. Monet realised that the key to undermining constancy is to "Try to forget what objects you have before you - a tree, a house, a field, or whatever. Merely think, here is a little square of blue, here an oblong of pink, here a streak of yellow, and paint it just as it looks to you, the exact colour and shape ....."". Monet is known to have had several paintings of the same scene in progress at the same time. As the changing light brought about corresponding changes in the colours he would put aside one canvas and take up another. It is interesting to compare his paintings of the "limestone coloured" cathedral with photographs of the "sandstone coloured" Ayers Rock.

Howard Taylor is a Western Australian artist who is also concerned with the interplay of light and colour, especially the way that changes of colour reveal form, texture and surface quality. Full appreciation of his work - painting no less than sculpture - is not possible from a single viewpoint. Because a change in viewpoint brings about a change in appearance the viewer becomes actively involved in Taylor's work.

New materials and new processes have extended the opportunities for designers to engage the public in a similar way. Designs printed on a surface in clear varnish appear lighter or darker than their background or they can disappear altogether as the surface is tilted towards or away from the light. "Shot" fabrics, similarly tilted, also change colour. Pearlescent pigments offer particularly dramatic possibilities. Not only can pearlescent surfaces change hue quite radically with a change in viewing or lighting angle they can also change from very light to very dark. Allan Rodrigues (5) has shown how this extreme lightness contrast can accentuate the contours of a three-dimensional object.

Animated films and videos, neon signs and laser light shows are some of the new media where movement and colour changes in controlled sequences are an intrinsic element. Effects of movement and changing colours can also be achieved when a design in cellophane tape on a slide of polarising material projected through a second sheet of polarising material rotating in the projector beam. Colour, light and movement united in the work of Peter Sedgley. The light itself provides the energy to activate motors which rotate dichroic glass filters. When beams of light strike these filters some wavelengths are transmitted, others reflected. Curved mirrors reflect the beams back again. The beams multiply, change direction and change colour in continuously changing patterns. The richness of Sedgley's work is due in part to his exploitation of colour in the fourth dimension.

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ON THE SUBJECTIVE COLOURS OF STAINED GLASSES

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1. INTRODUCTION

Visitors of Roman or Gothic cathedrals are always delighted by the magnificent stained-glass windows of these edifices. The aesthetic impression is composed by many factors of architectural, artistic and coloristic character. The coloristic factor has to play a major role as one of the most general remarks is that the coloured glasses used by medieval artists show a brilliance not found in contemporary stained-glass windows.

We have set us the task to find out whether this splendour of the colours observed in these masterpieces of the 11th to 13th centuries is an inherent property of the stained glasses used, or whether it can be explained on the basis of modern colorimetric knowledge.

As the two most often used colours in Gothic stained-glass windows are the blues and the reds, we have chosen two different blue glasses and a red one (recently manufactured to be used in repair work of stained-glass windows) and measured their colorimetric properties. Using these data we applied colorimetric evaluation techniques suggested in other fields of colorimetry to reach meaningful appearance characteristics (brightness - luminance corrections, a non linear colour appearance model) and performed experiments to simulate viewing conditions in Gothic cathedrals for investigating the effect of transient adaptation.

2. ADAPTATION WHEN VIEWING STAINED-GLASS WINDOWS

To find the proper colorimetric description of the colour of Roman, Gothic and modern stained-glass windows the illumination of the samples and the state of adaptation of the eye of the observer has to be determined. The stained-glass windows, when viewed under natural conditions (not 20th century floodlighting), are illuminated by natural daylight, therefore in our calculations we will use tristimulus values determined for Standard Illuminant D65 (in the following Ill.D65). Data for Standard Illuminant A (Ill.A) will be shown for comparison.

2.1 Adaptation in a Roman or Gothic Cathedral

The interior of a Gothic cathedral is usually dim. It is illuminated partly by the light penetrating through the stained-glass windows and partly by candle light or by the light of other incandescent sources. The surroundings of the windows are usually achromatic with a low luminance.

As the interior lighting is produced mainly by the filtered daylight, the light transmission of the stained-glass windows will influence the colour of the adapting illuminant. For the present investigations we will suppose that the state of adaptation is near either to Ill.A or to III.D65, depending on the proportion of blue and red glass panels and the amount of incandescent light used.

The adaptation level is always much lower than the luminance of the samples. This can also lead to a transient adaptation when, after being adapted to the interior, one looks at the stained-glass windows.

2.2 Adaptation in a modem interior

In contrast to the situation in a Gothic cathedral, in a modern church or other interior with stained-glass windows the illumination level is much higher. In modem stained-glass windows far more colours are used, large parts of the windows are prepared from achromatic "white" window glass. Thus the state of adaptation is much higher and it is reasonable to assume Ill.D65 adaptation chromaticity.

3. COLORIMETRIC PROPERTIES OF THE SAMPLES USED

The two blue (RBL21 and RBL31) and the one red (RBL41) samples were measured spectrophotometrically and their tristimulus values were determined both for Ill.A and Ill.D65. Chromaticity coordinates and luminance factors are seen in Table 1.

4. COLORIMETRIC EVALUATION

As discussed in Sec. 2, for evaluating the colorimetric properties of the stained-glass windows one should use the tristimulus values as determined under Ill.D65 but apply - wherever possible - as adapting illuminant Ill.A. The calculations were performed both for Ill.A and D65, and for the colour appearance model also for the mixed situation (sample chromaticity: Ill.D65, adapting chromaticity: Ill.A).

TABLE 1.

Y, x, y and L_{eq} values of coloured glasses.

RBL21	Y(A)	47.75	RBL21	Y(D)	51.77
	x(A)	0.3710		x(D)	0.2431
	y(A)	0.3700		y(D)	0.2483
	L_{eq}	43.69		L_{eq}	62.05
RBL31	Y(A)	29.28		Y(D)	34.29
	x(A)	0.3093		x(D)	0.2094
	y(A)	0.3560		y(D)	0.2224
	L_{eq}	28.25		L_{eq}	44.10
RRED	Y(A)	8.06		Y(D)	4.3914
	x(A)	0.7093		x(D)	0.6950
	y(A)	0.2886		y(D)	0.2888
	L_{eq}	12.42		L_{eq}	6.4891

4.1 Brightness to luminance correction

It is well-known that highly saturated red and blue lights seem to be brighter than white or yellow ones with equal luminance [1]. The CIE has proposed for trial and evaluation a method to determine the brightness-luminance ration of coloured lights [2]. In Table 1 we have incorporated the Leq values as well. It can be seen that for Ill.A there is an extra brightness only for the red sample, but for Ill.D65 all these samples show a somewhat increased brightness.

4.2 Application of non-linear colour appearance model

The non-linear colour appearance model by Nayatani and co-workers (see l3, 4]) has been developed to be used for the quantification of the colour appearance of surface colours for different adaptation conditions. In this paper we are investigating its use describing the colour appearance of stained-glass windows.

Calculations were performed for sample illumination levels between 10 lx and 1000 Ix and for setting the adaptation value for each illumination level between 2 % and 64 ~. From among the colour appearance characteristics supplied by the Nayatani model here the brightness (B), the colourfulness (M) and the chromaticity (location in the P, T plane) were evaluated*.

Figure 1 shows the brightness versus adaptation level plot for sample RBL 21, sample irradiation: Ill D65 but viewed under Ill.A at different sample illumination levels. As seen from the graph, at low illumination (10 lx to 100 lx), the apparent brightness in the dark surrounding is high and decreases with increasing surrounding lightness. As the illuminance of the sample is increased, the decrease of brightness with increasing surrounding lightness becomes smaller and at high surrounding lightness the brightness can surpass the value obtained for the lowest lightness.

At the highest illuminance, the brightness becomes independent of the surrounding lightness. For the darker blue sample (RBL 31A) and the red sample (RBL 41A) the general trend is similar.

The colourfulness calculations show interesting results: Figure 2 shows the surrounding lightness dependence of the light blue (RBL 21) sample under Ill.A illumination and adaptation for different sample illuminance levels: At low illuminance the colourfulness undergoes a similar change with lightness as seen with brightness. As the illuminance level is raised, the colourfulness still shows a distinct minimum, but at the highest lightness its value surpasses that of the colourfulness calculated for the lowest value of YO.

*) Authors are indebted to Prof. Nayatani for providing unpublished material on the use of his model as well as a computation program that helped checking the authors' calculation software.

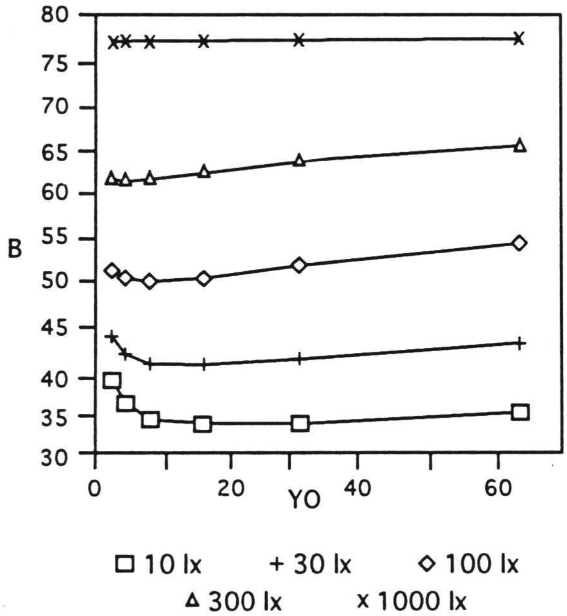

Fig. 1. Adaptation dependence or brightness.

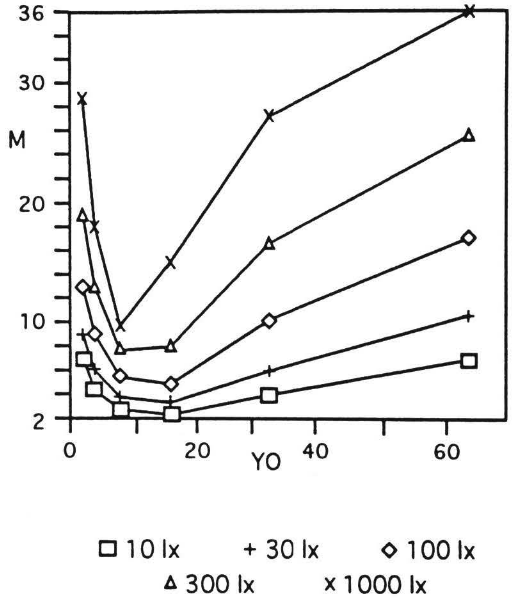

Fig. 2. Adaptation dependence of colourfulness of sample RBL2.

For Ill.D65 illumination and adaptation at low illumination levels the trend is similar to that of Ill.A illumination and adaptation; for high illumination, on the other hand, the colourfulness increases continuously with adapting illuminance.

The red sample shows the highest colourfulness at the lowest adapting illuminance, irrespective of target illuminance.

Colourfulness is a scale moving out from the origin to high brightness and chroma. Therefore the change of apparent chromaticity can give further insight into understanding the peculiar behaviour of colourfulness.

Figure 3 shows the adapting luminance dependence of the P-T chromaticity of the RBL 21 sample for different illuminance values for illumination and adaptation to Ill.A. As seen, with increasing the adapting luminance, the P yellowness-blueness coordinate changes sign, while the greenness coordinate increases continuously. This explains the strong minimum in the colourfulness.

For the red sample a decrease in colourfulness is due to a decrease of the yellow coordinate for every illuminance level as the adapting luminance is increased.

5. TRANSIENT ADAPTATION EXPERIMENTS

5.1 Experiments with the red glass sample

A sample of red stained glass (RBL 41) has been applied on a small window, the only light source in a big room, facing the east sky. An iron grid of 4 x 4 squares, each of 20 cm side, the bars being 1.5 cm thick, was applied at the opening of the window. The red glass covered one square through which the sky could be seen. The viewing distance was 8m. The observer first pre-adapted to the general indoor level. He/she was instructed to fixate on a white wall. The ration of the luminance Lw of the wall and that of the square of the window at the left top square was 0.2. Thus when the observer shifted his/her gaze to the boarder between the red sample and the adjacent uncovered window square (point P), he/she was looking at a target of greater luminance than that to which his/her eye was adapted.

5.1.1 Qualitative evaluation

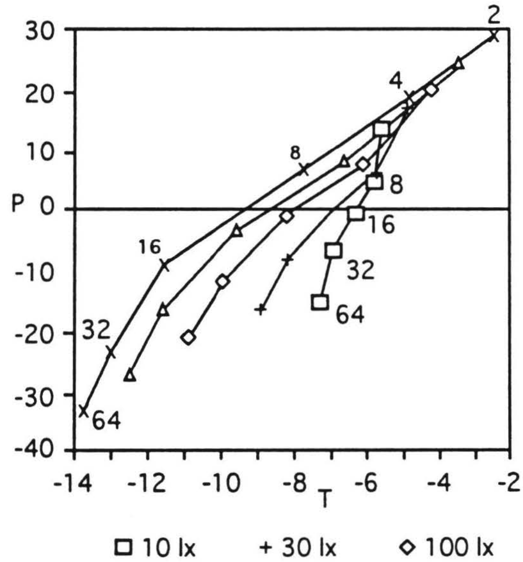

Fig. 3. Adapting luminance dependence of the P-T chromaticity of the RBL 21 sample

Ten observers (educated laymen with normal colour vision) were (separately) invited to look at the window after about 10 min. of adaptation to the dim indoor level. As a general consensus they reported that the "red looks brighter than the sky" seen in the adjacent square.

5.1.2 Quantitative experiments

Two female observers, aged 25, took part in a set of observations performed throughout a whole day each. They agreed that:

1) The red glass first appeared brighter, under prolonged viewing it decreased in brightness, compared to the sky, and ultimately became darker, provided fixation was rigorously maintained at point P.

2) Under fixation at P, the red glass also changed in colour, by becoming purplish (this has its counterpart in the colour appearance model, where the chromaticity shifts in the direction to become more purplish).

3) The effect depends on the time of day, and the situation is radically different in the middle of the day (of a relatively serene day) when much light is available. (The darker-than-the-sky situation in the mesopic range is related to the Purkinje shift, and will not be treated in this paper.)

one of the observers (AMcL) took part in a one-day session to measure the time of persistence of the situation "red brighter than the sky". Figure 4 shows time laps, after starting fixation at point P, over which red appears brighter than the sky and, because of decay, becomes equally bright to it versus window illuminance. "b" stands for "blitz" (the effect is too short to be recorded).

5.2 Experiments with a blue glass

An experiment similar to that for the red glass was performed throughout a serene day by two trained 25 year-old A; female observers. The glass was applied on the grid of the window facing the east sky. The observers were adapted to the strongly reduced indoor level, and, after a warning signal, shifted their gaze to fixation point P. Their task consisted in telling whether the bluish brightness was greater, equal or less than that of the unfiltered sky. As for the red glass, there is a luminance range where the sky filtered through the bluish glass appears brighter than the unfiltered sky. At some levels, the effect is fugitive, at other levels it is longer-lasting and more quantifiable. Excess brightness lasted as long as 30 seconds for an adapting luminance of appr. 300 cd/m2.

6. DISCUSSION AND SUMMARY

The L_{equv} equivalent luminance values show an extra brightness, but this is by far too low to be responsible for the visual effects observed in a Gothic cathedral.

The non-linear colour appearance model by Nayatani and co-workers delivered for every sample an increased brightness, if the surroundings were dim. Also the colourfulness of the samples was high. This corresponds to the visual situation in a Gothic cathedral. If, however, both the adaptation luminance and the test field illuminance are high, no such extra brightness is observed. This may correspond to the visual situation in a modern interior.

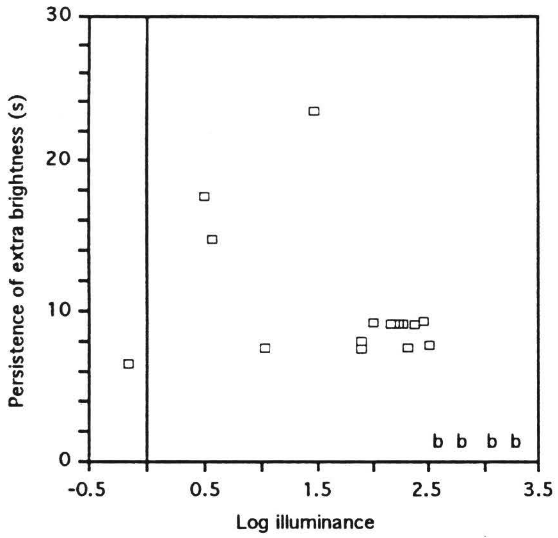

Fig. 4. Persistence of extra brightness, red

Further differences might occur depending on the colour temperature and level of the illumination on the sample, leading to relatively higher brightness or colourfulness of the blue and red samples, resp. This reflects itself in seasonal and time-of-the-day changes of the observed colour appearance of stained glass windows.

The transient adaptation effects can also have a non-negligible effect on the aesthetic sensation. As seen in Sec. 5, at luminance levels as observed in Roman or Gothic cathedrals, the observed extra brightness persists for several tens of seconds, probably long enough to produce a first positive impression. At the high luminance levels of a modern interior, on the other hand, this extra brightness is so fugitive that no cognitive perception occurs.

By no means can the aesthetic impression gained when viewing a stained-glass window be fully explained on the basis of colorimetry alone, nevertheless we hope we were able lo show that some of the effects observed by every layman visiting a Gothic cathedral can be explained by using modern colour appearance theories and that transient adaptation can have an additional effect in the observation.

In the present paper we have concentrated on two colours frequently found in Gothic stained-glass windows. For a more complete description of the colour appearance of coloured glass chips occurring in stained-glass windows (medieval and modern) further investigations are needed. Investigations will be performed to determine the real adaptation chromaticities and luminance levels occurring in different medieval and modern churches, so that these can be used in the colour appearance model. Finally, experiments are planned to test the colour appearance model for the transmissive colour samples and the partly very low adapting luminance levels. By this it is hoped that the model can be extended to incorporate also the extra brightness of coloured samples.

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COLOUR IN MARKETING: IS THERE ANY RELIABILITY IN THE ANTICIPATION OF THE COLOURS TO COME ?

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ABSTRACT

Consumers' acceptance of a product is influenced to a large extent by its visual style. Colour in this context plays an important role, because it acts as a powerful "visual code" on consumers' perception of a product, revealing to him much about its "style", "modernness" and "value". Hence, the success of product innovation and segmentation strategies depends much on the reliability of the anticipation of new colour trends. The concept of a cyclic recurrence of colour preference provides a useful approach to this problem. Two empirical studies were carried out to investigate the model.

INTRODUCTION

"Colour management" - today, is a term commonly used in industry and commerce. It is interesting lo notice that this term usually refers to the control of colour, in particular to the assessment, the production and the reproduction of colour. But there is another - at least equally important - aspect of colour management: The Consumers' acceptance of a product is influenced to a large extent by its visual style. The style of a product is determined by form, surface qualities, texture and colour. In this context colour is probably the most critical quality, because it acts as a powerful "visual code" on the consumers' perception of a product, revealing to him much about its "style", "modernness" and "value" (Oberascher, 1990). Choosing the "wrong" colours for a distinct product, often is a reason for consumers dissatisfaction, economic loss or complete failure of a product in a market.

In 1988 for example, violet and/or lilac once again were introduced to the German market as "new colours" for ladies' fashion. It was fascinating to observe, how since then the consumers' acceptance has steadily shifted towards violet and lilac nuances not only on clothes, but on all kinds of products, vehicles, interior design and even exterior architecture. By the end of 1990 there was virtually no product left, which was not available in violet or lilac. The focus of the preferred colours could be located in the NCS at approximately 3050 R50B and 3050 R60B. In addition to these nuances, combinations with turquoise (2040 B80G) also became very popular (Oberascher, 1990). This impressive shift in colour preference was not a pure matter of the "avant-garde", nor was it restricted to the German market, but affected different social milieus and could be noticed in other European countries as well.

In view of the fact that the product colour itself, rather than exact colour reproduction, is the crucial parameter for a broad acceptance of a product in a market, there is a remarkable shortcoming of research work dealing with the question of colour trends. While much is known about the physical and psychophysical conditions to control colour effectively, only a very few studies have dealt with this issue (Koppelmann & Küthe, 1987). A plausible explanation for this shortcoming is the complexity of the task and the fact that the postulation of theoretical concepts must be speculative to a certain extent. Nevertheless it is the aim of this paper to outline a theoretical framework, which in particular considers the origination and consolidation of colour trends.

Based on Charles Darwin s theory of evolution and on a psycho-physical model of overstimulation, Koppelmann and Kuthe (1987) postulate a cyclic recurrence of colour preference.

According to them, a period of bright "spectral colours" is always followed by a period of blackish "autumn-colours", which by themselves are replaced by "earthy" nuances after a short period. The period of "earth colours" is usually of long duration, but will finally be followed by a period of whitish "pastel colours". After a while also the "pastels" start to fade out and the time is ready for the "achromatic colours". But also the "achromatic colours" do not last forever. After some time they are replaced again by bright "spectral colours" and a new colour cycle starts. Between the phase of the "achromatic colours" and the beginning of a new cycle with bright "spectral colours", there comes an interim phase of violet.

Essential input for the formulation of this model came from a study on architectural colours (Darmstadt,1985) and a study on interior colours (Koppelmann and Küthe,1987), in which the authors analysed 10 years of cover design of the well know German magazine for interior design "Schöner Wohnen". The central idea of their approach was that the journal sensitively monitors common colour trends and colour preferences of and for its readership, and presents them in a comprehensible manner in its front page illustrations.

EMPIRICAL STUDIES

Study A: To investigate the model of colour cycles thoroughly, we decided to repeat the study of Koppelmann and Külhe. Contrary to their approach we considered the whole content of the journal, including all illustrations and verbal information in our analysis, because we are of the opinion, that the cover design alone is limited in its informative value. The reason for including verbal information is its explanatory function, as well as the assumption that it is the total of pictorial and verbal symbols, which generates semantic commitment between the communicator and the recipient (compare: Volkmer, 19X8). Altogether we studied 234 editions of "Schöner Wohnen", which were published between 1973 and 1991*. The dominant colours of the illustrations were estimated and defined with the help of the NCS atlas (Natural Colour System, 1990). Since photographic reproduction does not exactly display "true" object colours, NCS notations were adjusted according to our knowledge of the "real world colours". In addition verbal comments were written down, whenever they referred to colours or materials shown in the illustrations.

Results: In 1973/75 colours are highly chromatic. Yellowish greens (2070 G9OY, 2070 G30Y, 3060 G40Y - G60Y), yellow (0080 Y - YlOR), orange (1080 or 2080 Y30R - Y60R) and red (2080 Y60R - Y9OR) are very popular. Dark blue (5050 R80B), brown (5050 Y60R, 6040 Y60R - Y80R) and clear white is used, too. Combinations of green with yellow, orange or red and white dominate. Very often green and yellow is also used together with brown. In 1975 the bright greens seem to be the favourite colours.

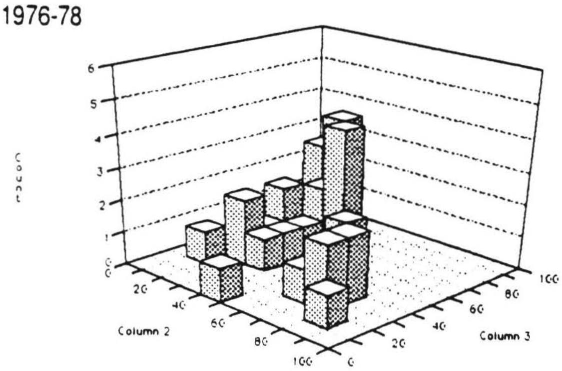
In 1976/1977 the colours become darker. In the beginning of 1976 "bright" yellow (1070 Y) and green (2050 G9OY, 3050 G60Y) is still used, but are now always combined with brown. Strong red (2080 Y80R) seems to be still popular. Subsequently green goes olive (6020 G70Y, 8010 G9OY, YlOR) and more and more brownish (4040 Y20R, 9005 Y20R;4040,6030,7030YSOR;6030Y70R) and beige colours (3010,4010Y30R) appear. Brown (7020Y70R) with olive green (7020Y70R) or light green (2030G30Y) and yellow (1070Y) are also very popular. In 1978 some brown, olive green, orange, yellow combinations can still be found. But the general tendency is towards "natural" hues in the beige or brown range (1010, 2010, 2020, 2030 Y30R) and towards warm "creamy" or yellowish whites (0005 Y20R - Y80R). Additionally some pastel colours are introduced (1030 RlOB, 2020 Y30R, BSOG, GSOY). 1979/80 is dominated by "natural" colours and materials. Sometimes they are combined with light green (2020 G30Y, G70Y) and "rose" (1020 Y70R, 2020 Y9OR, 2020 RlOB). During 1980 white persistently becomes clearer and clearer. In 1981/82 the clear whites dominate. Often they are combined with yellowish or beige nuances, or pastel colours. "Biological" material, like "blond" woods, linen etc. and green plants are now very popular. In 1981 the first "high tech" kitchens in grey appear sporadically. In 1983 greyish and anthracite colours in combination with glossy "high tech" materials, like steel, chromic, glass etc. start to disseminate. Beige and brownish colours are more and more replaced by white. 1984 achromatic colours are well established. One finds a lot of clear white, black, anthracite and grey (4500, 6500, 4502 G, 5502 Y, 7502 G, 7005 R20B). Beside achromatic combinations, white is sometimes combined with "elementary" yellow (0070 Y) or red (1080 Y9OR). New combinations are anthracite (7502 G) and grey (4500) with "apricot" (1030 YSOR), "rose" (1030 Y80R) or"pink" (0030 R). Pale "Memphis colours" (1050 Y, 0030 RlOB, 1030 R80B, 1030 B9OG) are introduced for the first time. In 1985/88 achromatic colours, alone or in combination with one or two chromatic colours, are very common. "Pale" colours lend towards slightly more blackish nuances. Natural woods are often whitish or greyish. In 1985 "rose" (2030RIOB)/ "turquoise" (2020B70G) combinations come up. In 1986 black is often combined with "elementary" red (1080 Y9OR) and while, or with "deep blue" (3080 R80B). "Turquoise" nuances grow stronger and "multicolored" or textured surfaces are "discovered". In 1987/89 colours in general seem to become darker.

Summary:

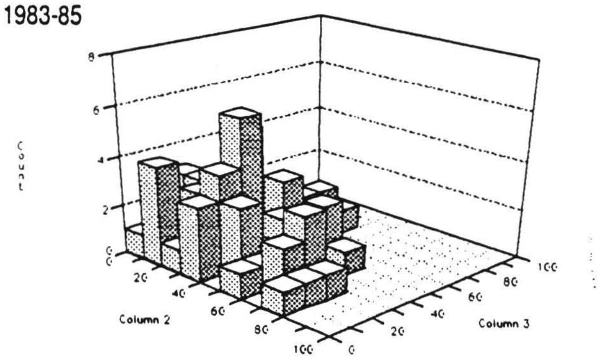
- chromatic colours 1973/75
- blackish colours, brownish colours 1976/78
- "natural" colours, beige, brown, "off' whites 1979/80
- clear while, "natural" colours, pastels 1981/82
- clear white and achromatic colours 1983/84
- achromatic colours, achromatic + chromatic colours 1985/88

Study B: The second aspect we were interested in, was the question if these colour cycles had actually been anticipated by colour stylists or other "colour experts", who claim to "forecast" new colour trends. For this reason we analyzed the trend colour charts of Hoechst AG, which are frequently published for the interior textile market two years in advance, for the years 1975 till 1992. For all the colour samples the approximate NCS notations were obtained by visual comparison under D65. Samples were arranged in such a way that the overall colour impression included special visual effects caused by the material or structure of the textiles. Verbal comments referring to colour were also analyzed and included in the final interpretation. From the NCS values, frequency distributions were obtained for blackness, chromaticness and hue respectively, and the results plotted in two- and three-dimensional histograms.

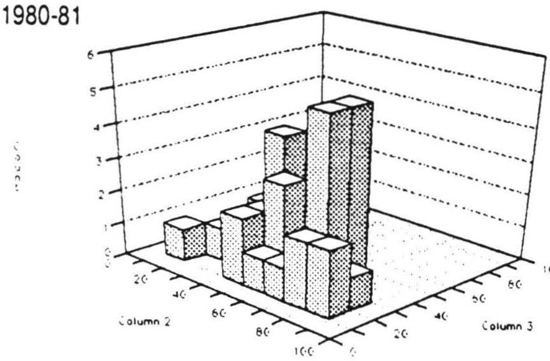
1976-78



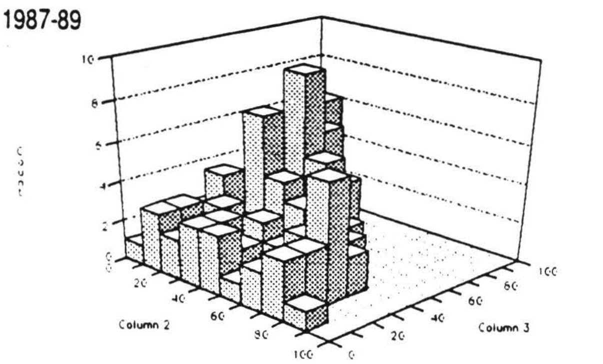
1983-85



1980-81



1987-89



RESULTS

From 1975 to 1978 colours were clear, extremely chromatic and contained all hues. One may call them "spectral colours". Yellow, orange, brown and "olive green" were very typical for this period. In 1980 colours became quite dark ,less chromatic, and less clear. The stylists described them as "dark, ripe and full". In 1981 colours remained dark but exhibited a tendency towards "warmer" nuances. "Autumn", "evening sky", "a smack of the forest","relaxation" and "regeneration" were some of the terms used to describe them. In 1983 colours "brightened up". They became whitish and rather achromatic. Greyish nuances and pure whites appeared in the palette newly. The accompanying text pointed to the influence of the "High Tech", with its preference for "cool" and "metallic" effects. In 1984 the colours shifted further towards whitish nuances. A new quality was their glossy and lustrous appearance, similar to "pearl", "slate" and "stone", as mentioned in the text. In 1985 gloss and glimmer were the most obvious attributes to determine the overall impression of the colours. Due to the gloss, colours appeared very whitish and shiny. A greyish silver tinge gave them a "metallic" and "technical" look. In 1986 colours split up into two major groups: Achromatic and chromatic colours. Achromatic colours contained while, metallic greys, anthracite, cold blue, silver and brass. The chromatic colours contained "deep night colours" and very clear nuances; in particular yellow, red, turquoise and green. In the text, combinations of "anthracite and strong red" were said to become important. In 1987 colours in general became more chromatic and a bit darker, blue and turquoise nuances grew stronger, pure yellow was weakened, but achromatic colours and white remained in the pallet. According to the text, the colours were going to be "lush, full and deep" and were going to "replace the pale pastels". 1988 and 1989 did not bring real changes. Nuances remained within a range of low and medium chromaticness and were slightly blackish. In comparison with yellow, blue and turquoise nuances appeared rather chromatic. "Strong colours ... become more reserved in intensity", "tendency towards cool living atmosphere", grey colours become colder", "blue and green incline towards a turquoise hue" the text commented. In 1990 colours basically stay in the same range, but in addition to it, a new group of bright "neon colours" is introduced. Pure withes disappear and warmer nuances like "apricot" or "rose" are gaining influence. In 1991 and 1992 colours tend towards "veiled" or "faded" nuances. There will be no real whites and colours will be warmer in general. They are described as the colours of the "Neo-romanticism" ,"rather reserved and cuddlesome" with" closer combinations". "Clear white" is said to be "exchanged inevitably for powdery nuances".

SUMMARY

- very chromatic colours ("spectral colours") until 1978/79
- dark "warm" colours ("autumn colours") 1980 - 81
- light colours of low chromaticity ("pastels") 1983-85
- achromatic + very chromatic colours 1986
- achromatic + medium chromatic colours ("cold" colours) 1987-89
- medium chromaticity + "neon colours" 1990
- "veiled" colours (blackish, whitish, greyish) 1991/92

Interpretation: Both studies support a theses of a cyclic recurrence of colour preference. The succession of colours we obtained from the analysis of the interior design magazines in detail resemble more closely the "ideal" succession of colours Koppelmann and Küthe described in their model, than their own empirical results. They also correspond very well with the series for architectural colours, which was found by Darmstadt. In the trend colour charts we observed a similar colour succession, but it did not correspond very well with the colours published in the interior design magazines. In the years 1978 till 1983 colours of the trend colour charts seemed to be "behind" the trend, rather than ahead. Between a colour innovation and the establishment of a broader colour preference, as published in the interior design magazine, we noticed a time-lag of approximately 3 to 4 years.

DISCUSSION

The common assumption that colour trends are artificially "made" and "manipulated" by industry, commerce and mass media, whereby fashion design and the clothing industry usually are the driving force of "colour innovation", at least for interior design and architecture, is too simple for several reasons:

1) It denies the active role of the condiment. 2) It does not explain why new colour trends often fail to be accepted by a market. 3) The influence of fashion design on the colours of interior design and architecture is not stringent. 4) Socialization through the mass media is limited (Klapper, 1973,58-98).5) It does not provide any helpful orientation for colour management.

A model of acyclic recurrence of colour preference seems to be much more plausible. There is also empirical evidence that the same concept applies to other design qualities like product-shape and silhouette as well (Abshof, 1991). For a rough orientation a cyclic model might be quite useful, but the "fine tuning" of colours or preferences for distinct colour combinations can not be predicted by it. To select the "right" colours, will remain a crucial task for designers, colour consultants and marketing experts in future.

If we basically accept a cyclic recurrence of colour preference, it does not imply that colours are reinterpreted and used the same way they were interpreted and used before. Consumers will interpret them on the basis of their cultural background and present values, norms and attitudes. They will use "old" colours in a new context and fit them into their individual "lifestyle scenery". In this respect the mass media may contribute to the consolidation of new trends by "smoothing" different tendencies and integrating them into a uniform "picture" the consumer can easily understand and identify with (Hebdinge, 1983. Luger, 1991). Receptiveness to adopt new ideas, of course, is a prior condition for the acceptance of a new colour range. "Conservative milieus" per definition are not likely to be affected by recurring colour cycles. In addition other factors, like technical and ergonomic reasons, psychological and metaphysical concepts, colour harmony and personal colour styling (e.g. "colour me beautiful") may also restrict the influence of colour trends on the consumers' final colour choice.

Beside these variables one may have the feeling that colour cycles get shorter and trends change faster today. According to our study this does not seem to be the case, but colour cycles seem to overlap more than they did before, which may be interpreted as an "aesthetical consequence" of the eclectic and pluralistic character of the "postmodern" information society.

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* The results for the years 1989 till 1991 will be reanalysed and therefore not published in this article.

NCS - NATURAL COLOR SYSTEM, A METHOD FOR DETERMINING PERCEIVED COLOURS OF OBJECTS IN ENVIRONMENT, OBSERVED UNDER VARIOUS EXTERNAL CONDITIONS

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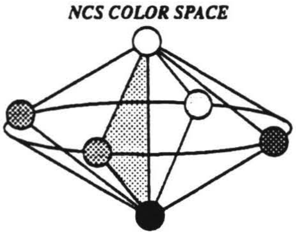
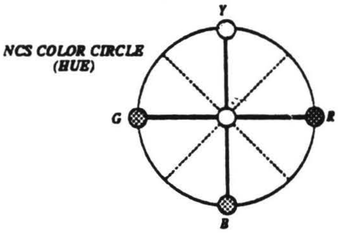
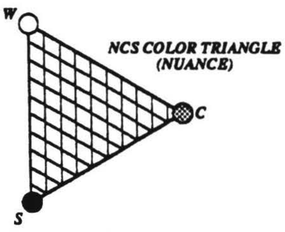
The NCS concept says that any colour percept can be defined by its resemblance to the six elementary colour sensations white, black, yellow, red, blue and green. "These are the only ones in which one perceives no other colours in direct observation". The concept has its origin in the phenomenological analysis of Ewald Hering from late 19th century on which he based his "Grundzuge der Lehre vom Lichtsinn" or "Outlines of a theory of the light sence" in Hurvich and Jameson's translation from 1964. The relationship between all colour percepts - of the surface mode of appearance - according to the NCS concept, is graphically illustrated by a three dimensional colour space in which each colour percept is represented by only one point.







For reason of clearness, the NCS Colour Space is often divided in two projections, the Colour Circle for specification of hue - and the Colour Triangle - for the nuance of a certain hue. In a research project at the Swedish Colour Centre Foundation between 1962 and 1972 extensive psychometric experiments were carried out. They showed that observers were capable, for a perceived colour, to give a figure - between 0 and 100 - for its degree of resemblance to the observers own imagination of the six pure colours - called the elementary colours - without any support of reference colour samples. A specific colour percept is composed of four of these resemblances to a sum of 100.

A colour percept= 100	*w=whiteness*
s+w+(y orb)+(rorg)=100	*y=yellowness r=redness*
s=black(ish)ness	*b=blueness g=greenness*

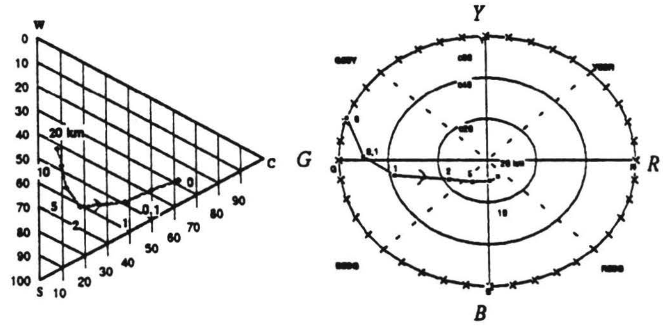
(=degree of resemblance to Black)
These are the NCS quality colour components of a colour concept

The numerical value of the attribute chromaticness is derived as the sum of the chromatic components and of hue as the relation between two chromatic components. An NCS colour notation informs directly of the blackness, chromaticness and the hue and indirectly of the six NCS perceptual quality colour components.

> *An NCS colour notation gives the nuance (s;c) by two-didget figures for the blackness (s) and for the chromaticness (c) and the hue (0) by a two didget figure surrounded by two letters for the chromatic components. NCS Notation (sc-0)* 10 60-Y9OR

With the experience of these scaling experiments the NCS research project continued in order to establish the psychophysical correlation between NCS psychometric scales and corresponding physical scales in the CIE-system. This work resulted in the NCS Colour Atlas(1) with more than 1500 NCS notated colour samples, stimulus defined by their CIE-coordinates. The Atlas consists of 40 pages, each of which holds samples of constant hue arranged in the colour triangle. Colour samples are of course representative for their NCS notations only if they are seen under the specific illumination and viewing conditions according to the Swedish standard. But, as the psychometric measures of colour percepts according to the NCS-method need no reference colour samples to compare with, the NCS method gives us a valuable possibility to make colour analyses of how coloured objects are perceived under various conditions as illumination, viewing distances and so on. Such information is of importance for a better use of colour in environmental design. Here we will give some examples of results of some pilot studies of this kind.

i) A number of untrained observers studied how the colour of leafy trees changed with increasing viewing distance from the inherent colour of the leaf up to the trees seen at 20 km distance. The observations started with the assessment of the tree colour at 20 km and then at shorter and shorter distances, at 10, 5, 2, 1 km, 100 meter and finally determining the inherent colour by direct comparison with NCS colour samples.

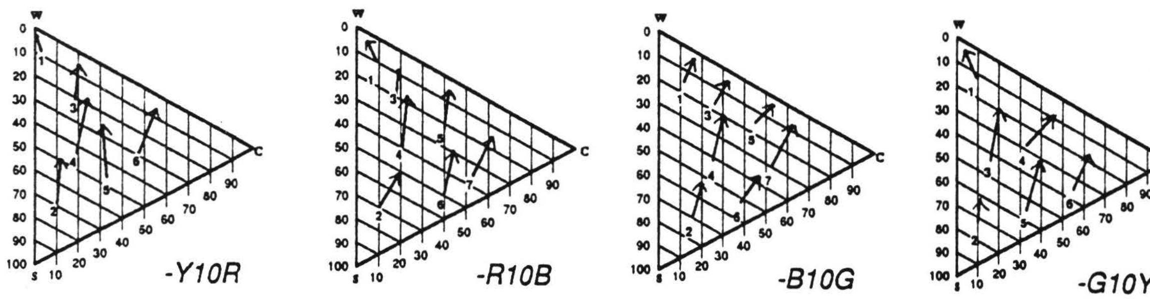


From the rather strong inherent yellowish green leaf the colour of the leafy trees becomes more and more blackish and less chromatic with increasing distance and the hue changes over to more and more blueish green. At a distance of about 2 km the colour begins to become more whitish and finally the leafy trees appears to be greyish and with a hue that is reddish blue, as shown in the colour triangle and circle. These changes can also be illustrated by the nearest NCS-colour samples looked upon at the standardized viewing conditions.

Nearest NCS colour sample:

Inherent	*0.1km*	*1km*	*2km*	*5km*	*10km*	*20km*
3060-G20Y	*4050-G*	*5040-B90G*	*6020-B70G*	*6010-B30G*	*5010-R90B*	*4010-R70B*

ii) Another pilot study of the same kind was carried out in connection with development of the most suitable colours for coil coated steel sheets for facade covering. Empirically it was known that colour of a house facade often appeared more bright and brilliant than the inherent or local colour seen at the architect's drawing board probably owing to size of sample, to the high outdoor luminance, how mat the surface was and surrounding environmental colours. In the experimental study the coloured steel sheets were about two and a half square meter. One at a time they were placed outdoor in front of trees in a garden with a brick house in the background and looked upon from 80 meters distance under a light overcast sky - diffuce - illumination. Three experienced observers assessed the colour they perceived by the absolute NCS-method. Afterwards the inherent colour was determined by direct comparison with NCS colour samples. The result of this study showed that the perceived colour of the sheets seen outdoor was much less blackish and often also more chromatic than what the inherent colour said. With no one single exception this was the case for all 52 coloured sheets studied. The results can be shown by marks in the colour triangle for colours of the same hue, here four different hues.

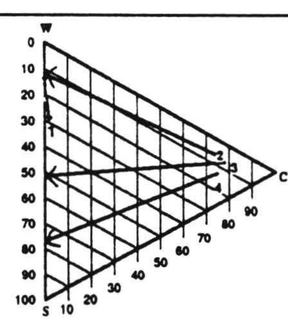


It can also be illustrated by the nearest NCS colour samples if they are viewed under the standardized conditions. We can see that for yellow coloured objects they decrease in blackness and become more bright in outdoor illuminations. For elements in mainly red hue we can see the same tendency. However, for the darker and deeper objects the colours became both less blackish and more chromatic. For coloured sheets in a blue hue we found that all of them became both less blackish and more chromatic than what could be expected from the inherent -"colour card"- samples. This also verify the empirical knowledge by architects and other that blue houses often look so brilliant that they almost appear to be fluorent. For objects in a green hue we found the same tendency to be less blackish and lighter as in the other hues. The most chromatic colours also became more chromatic in the outdoor situation compared with the local colour. Conclusion of this experiment was that if the designer wants a house to have the colour appearance as that of a sample in a small colour card he has to chose a coloured materiel for the house that is between 10 to 20 NCS units more blackish and often 5 to 15 units less chromatic than what he wants it to look. In this specific case the main interest was on the change of nuance and the change of hue was not studied.

iii) The next example is from a study at the architect department at the Chalmers University of Technology in Gothenburg. During a course in colour and light 40 students took part in some experiment in which they had to assess the NCS colour of NCS samples illuminated with different light sources. Here we will show two of the results. In the first experiment four samples were illuminated with a low pressure sodium lamp and exposed to the students who saw the samples from a distance varying between 3 to 6 meter.

Inherent NCS colour	*1500*	*0080-Y10R*	*0080-Y90R*	*1080-G10Y*
Perceived colour in Sodium lamp	*3000*	*1005-Y20R*	*5005-Y80R*	*7502-G*

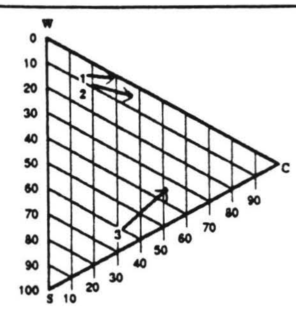
1-4= inherent colours



All three highly chromatic samples, the yellow, the red and the green, appeared to be as achromatic as the grey sample in this illumination as is shown in the nuance triangle and also illustrated with NCS notations above. In another experiment the students had to denotate the perceived colours in NCS-terms of three NCS samples illuminated by three band fluorescent lamp under the same viewing condition as before. There were one pale green, one pale red and a deep blue.

Inherent NCS colour	*1020-G30Y*	*1020-R*	*6030-R90B*
Perceived colour in three band fluorec. ill.	*0030-G30Y*	*0030-R*	*4050-R90B*

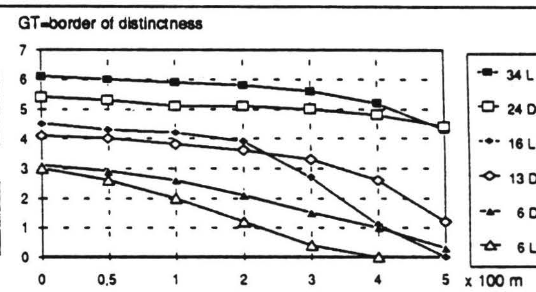
1-3= inherent colours



In the colour triangle we can see that there is a tendency that the colours of the samples are perceived to be slightly more chromatic than what the sample NCS-notation says. Especially this is true for the deep blue sample as also is illustrated. The hue was not significantly different in the three band illumination compared with the notations of the samples.

iv). Besides how coloured objects of certain inherent colours will be perceived under the various actual illumination and viewing conditions in environment there is another phenomenon of importance in environmental colour design and that has to do with legibility. With this we mean how strongly one colour element visually separates against a surrounding or adjacent colour. This colour design phenomenon has to do with the distinctness of the border between the two colours. The distinctness of border is a perceptual phenomenon of importance, not only for the legibility but also for how surface patterns are formed. Distinctness of border, called GT, and its relation to the differences in NCS dimensions has been investigated which resulted in an equation reported elsewhere(2). GT is a scale from 0 to 10, where 10 represent the most distinct border one could imagine. In relation to our interest in colour in environment we have carried out a pilot study to see how distinctness of border is related to viewing distance. Six pairs of achromatic colour samples 60 times 40 cm large were studied by a group of untrained observers. Illumination was sunlight at about 45° with light clouds all over the sky and the samples were observed perpendicularly.

Ds=	*6L*	*16L*	*34L*
NCS pairs	*2500* / *3000*	*1500* / *3000*	*1500* / *5000*
NCS pairs	*7500* / *8500*	*8000* / *9000*	*6000* / *8500*
Ds=	*6D*	*13D*	*24D*

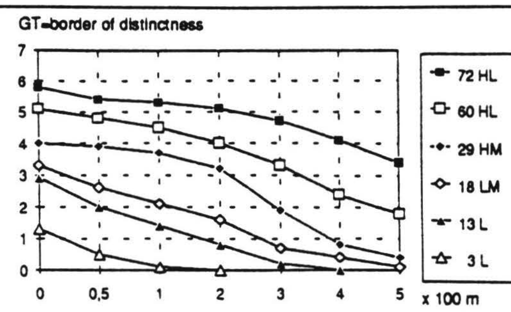


Ds= blackness difference; L and D= Light and Dark end of achromatic scale.

First the observers judged the distinctness of the border at 500 meter and continued at decreasing viewing distances. As expected the border vanished with increasing viewing distance. The most striking result was that for pairs with approximately the same blackness difference, pairs from the light part of the achromatic scale distinctness of border decreased faster than for pairs from the dark end as can be seen in the diagram. The same procedure was used for determining the distinctness of border for pairs of orange colours of constant lightness and with various difference in chromaticness.

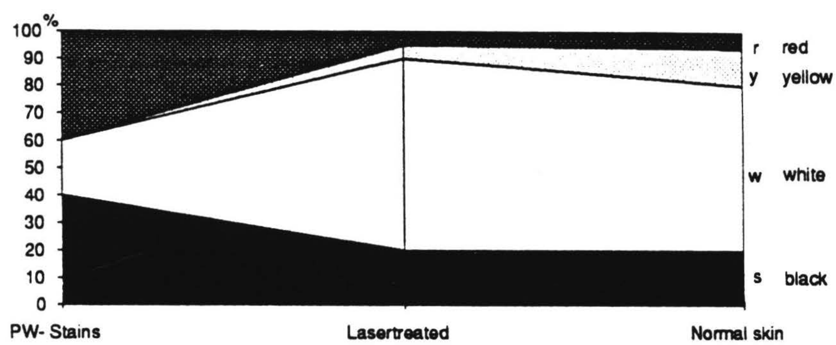
Here the distinctness of the border decreases somewhat faster than for achromatic pairs. The methods to assess both colour appearance and distinctness of border as a measure of legibility without the need for reference colour samples is of importance for further studies of these phenomenon for how to use and chose colours in environmental design.

Dc=	3L	13L	18L
	3005-Y50R	3010-Y50R	3020-Y50R
NCS pairs	3010-Y50R	3020-Y50R	2040-Y50R
NCS pairs	2040-Y50R	3010-Y50R	3005-Y50R
	1070-Y50R	1070-Y50R	0080-Y50R
Dc=	29HM	60HL	72HL



Dc=chromaticness difference; L, M and H= Low, Medium and High part of chromaticness scale.

v) In quite another field the NCS-system has been used to evaluate the qualitative result of laser treatment of red birthmarks, so called Port Wine Staines. When making his thesis on that subject a Swedish medical doctor found that the hitherto used methods to evaluate the results were both subjective and primitive. In his study he instead gave the normal skin, the birth mark and the laser bleached mark NCS notations by comparisons with NCS- notated colour samples. We evaluated the results of the treatment both by marks in the NCS graphical model but also in terms of differences in NCS elementary attributes and a calculated mean of the sum of those differences, called NCS difference. The effects were illustrated in a diagram as shown below.



Difference to normal skin in NCS colour qualities	*Ds: +20*	*Ds: 0*	
	Dw: -40	*Dw: -10*	
	Dy: -14	*Dy: - 9*	
	Dr: +34	*Dr:- 1*	
	DNCS: 27	*DNCS: 5*	
Nearest NCS sample:	*4040-R*	*2010-Y50R*	*2020-Y30R*

This is an example of a rather good result and we can see that the laser treatment has bleached the birthmark so that it is even a little more whitish than the normal skin but also that it is still somewhat too reddish compared to the yellowness.

With this expose of some pilot experiment we wanted to show that the NCS conceptually is much more than the colour samples that illustrate it in the NCS colour atlas and that the NCS can be used for analyses and evaluation of how colour of physical objects will vary with the great variety of external conditions in the environment. The kind of information wanted by colour designers will steer how many and which investigations that will be carried out.

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ABSTRACT ONLY

COMPARISON BETWEEN APERTURE AND SURFACE COLORS

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Despite the fact that colors we are perceiving are of surface color mode, the majority of basic data were obtained with colors of aperture color mode. Comparisons between two modes of appearance are made with regard to unique hues and discrimination ellipsoids. Corresponding to chromatic responses for aperture colors as functions of wavelength (Hurvich & Jameson, Boynton & Gordon, Werner & Wooton, etc.), the curves of primary hues for surface colors are presented as functions of Munsell H and also V and C. Color discrimination ellipsoids for real and simulated surface colors (by matching and the method of constant stimuli) are compared with those for aperture colors (by matching, MacAdam, MacAdam & Brown, Wyszecki & Fielder, etc.). The matching procedure yields almost the same ellipsoids for both modes, but the method of constant stimuli (discriminable or not in paired comparisons) gives larger ellipsoids than matching for aperture colors, not for surface colors, though always ellipsoids are almost the same in shape and orientation.

CROSS-CULTURAL STUDIES OF COLOUR MEANING

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Colour preferences and other aspects of colour meaning are of great interest to people in general, but also to behavioural scientists. Already at the inception of psychology as a science at the turn of the century the pioneers in experimental psychology investigated this question. Most of the hundreds of studies which have followed since that time, however, have lacked in awareness of the complexity of colour dimensions. This shortcoming prompted us to conduct studies aimed at identifying and mapping out the main dimensions of meaning in the colour space. The data from these first studies were first published some twenty years ago in Swedish in a report where the colour connotations for each of the 26 scales of meaning we used were presented individually, as so-called iso-semantic maps.

A recurring and relevant question is of course how similar or different people's associations to colours are from one culture to another. In an ongoing series of studies we have to date comparison data from Sweden, USA, Yugoslavia, Russia - and more will follow. The same colours and the same 26 semantic scales have been used in all of the studies, namely the ones that were used in the original data collections. This means that changes between time periods could also be studied.

Of the many possible ways to analyze our data, we first studied, by means of correlational methods, how similarly or differently the national groups conceived the various semantic scales in connection with colours. In each country the colour-meaning data were collected using the semantic differential (SD) technique, in which the subjects individually judged one colour sample at a time against our 26 bi-polar semantic scales:

warm [_] [_] [_] [_] [_] [_] [_] **cold**

The data were then averaged across the subjects by SD-scale within each group and correlation coefficients were then calculated between the average rating of the colours for each semantic scale of the national groups.

The data that we will present here consists of four sets of colour judgements, one set for each country: colours X semantic variables X subjects.

NATIONAL COMPARISONS

In performing analyses of our data our interest centered on the following aspects:

- **In general.** Inter-correlations between the national groups - as groups across all the semantic variables/scales, i.e. an overall estimate of between group agreement.

- **For individual scales.** Inter-correlations between the national groups, for each of the semantic scales.

- **For individual colours.** Inter-correlations between the national groups for each of the colours.

GENERAL AGREEMENT IN COLOUR MEANING

This investigation comprised 26 semantic scales. They were originally chosen by Sivik in 1968 in a study which used a larger number of colours better covering the entire NCS colour-space. The same scales were chosen in these follow-up studies in order to check for changes between two time periods (this comparison, however, is reported elsewhere). The scales were of varying semantic nature and the factor analyses performed on the original data showed that they represented four main dimensions of meaning in respect to colour. Three of these were the ones that generally appear in semantic studies of this kind: **activity potency, evaluation** and the fourth, **warmth,** has appeared typical for colour meaning. The fact that scales like cold-warm form a factor of their own thus indicates that this colour attribute, or connotation, is independent of the other factors mentioned.

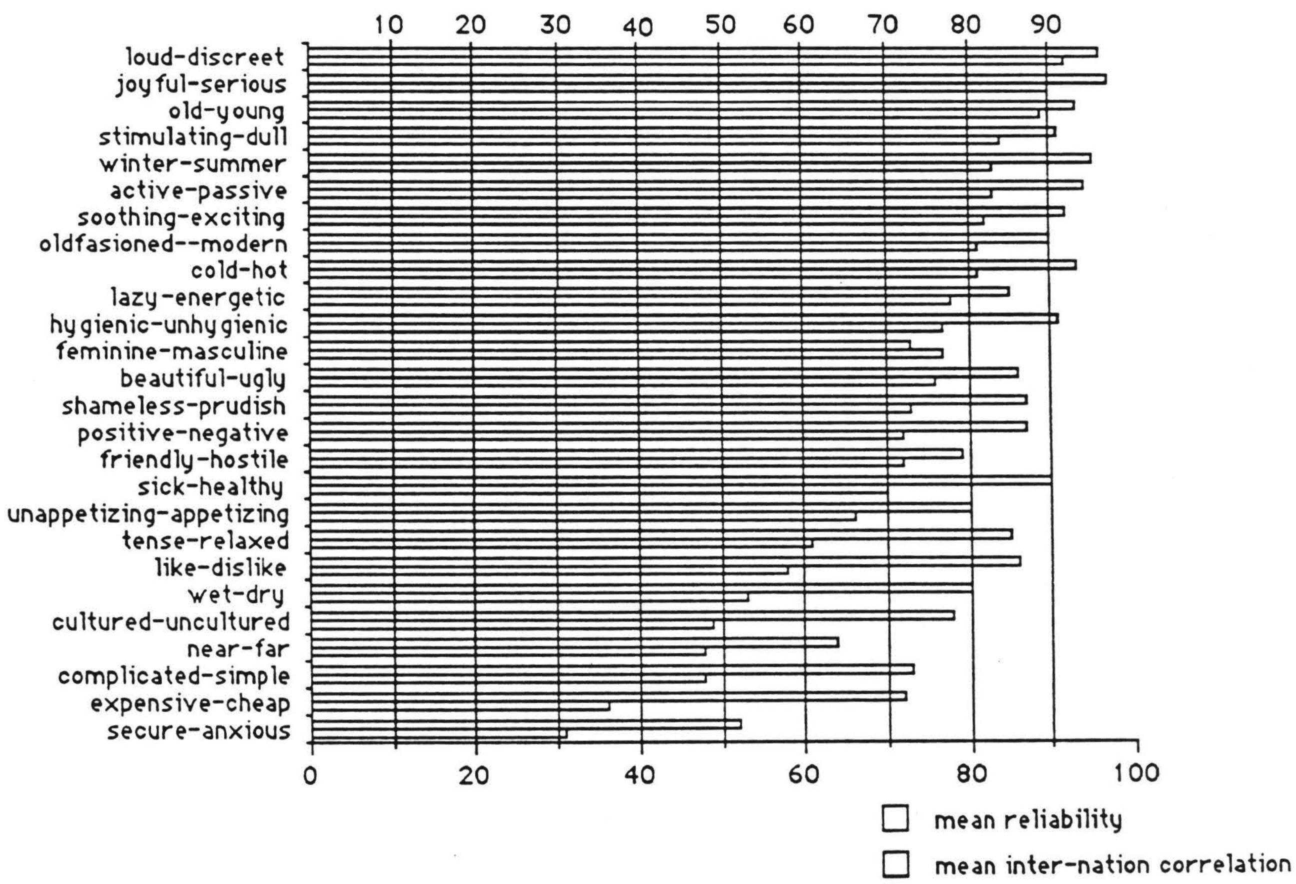
A statistical measure of correlation (Pearson product moment) was used to obtain an estimate of the agreement between groups. The measure can vary from -1.0 to +1.0 and a high positive correlation, close to +1.0, means that the agreement is almost perfect. A coefficient close to zero means that no linear co-variation exists between the opinions. The table below illustrates an **overall** estimate of agreement between all the four participating national groups. The figures are the median values of the correlations between groups across all the scales.

	USA	USSR	Yugoslavia
Sweden	.68	.73	.69
USA		.66	.67
USSR			.75

The differences between the largest and the smallest coefficients are substantial, indicating that the Russians and the Yugoslavians were more similar to each other in their colour connotations than they were to the Americans. This may reflect the close relationship between the two Slavic languages - but the agreement between the Swedes and the Russians was almost as high. Though the figures are statistically significant and the subject samples from the various countries are comparable, we cannot claim that in this study the groups are representative of the countries. But we have shown that it is possible to identify differences of this kind, both on a general level and for specific variables of meaning, which we will now come to.

From the inter-correlations between each of the semantic scales we see firstly, of course, that the semantic scales vary considerably in degree of agreement between the national groups. For some scales all the subject groups have the same opinion about the colours (such as loud-discreet and joyful-

AGREEMENT FOR INDIVIDUAL SCALES.



serious) - while for other scales the agreement was very low (such as secure-anxious) - with all the other scales in between.

In the same figure we have also included a measure of the **reliability** for each scale. It was calculated with a "split-half method", that is, each group of subjects was randomly split into two halves, the ratings of each half were averaged by scale for each colour and the averages were then correlated. The reason for making this within-group comparison with the between-group comparison lies in the closely related hypothesis that the agreement between nations should not be greater than the agreement among subjects of the same nationality.

AGREEMENT BETWEEN NATIONS FOR INDIVIDUAL SCALES.

In some of the colour semantic scales we used the meaning is of an almost objectively descriptive character. The adjectives loud-discreet, for example, are commonly and rather unambiguously used in colour descriptions.

Joyful-serious is another colour descriptive scale which showed high agreement between the groups. Although not astonishing, this result is not necessarily self-evident.

Old-young is given as a third example of scales which seem universal for these groups - it will be interesting, however, to test if this also holds for cultures which are more different from each other than those we have thus far studied.

The three scales mentioned above have between group correlations which are almost as high as the reliabilities.

As seen in the bar chart almost all the other scales have between group correlations which are lower than the reliability - indicating that there is a true national group difference.

There are a number of scales on which the groups were less agreed. This was the case, for example, with most of the **evaluating** scales, such as beautiful-ugly, sick-healthy, like-dislike.

Cultured-uncultured is another evaluating scale for which the agreement between the groups was much lower than within the groups.

Finally, the scale complicated-uncomplicated is an example of a scale on which the groups were least in agreement.

AGREEMENT BETWEEN NATIONS FOR INDIVIDUAL COLOURS.

It seemed probable that the agreement between national groups would vary from one colour to another. In order to investigate this we calculated separate correlations between the groups for each colour across the scales.

It was found that for some national comparisons there were colours that had almost no covariation (e.g. $r=0.08$ between Swe-US for colour #15), and there were others that had correlations over 0.90, indicating almost complete consensus.

The average correlations for each colour between the four national groups (six combinations) ranged from 0.41 to 0.88. The eight colours for which the groups were in highest agreement all seemed to be quite distinct colours, near the focal points of the so-called universal colour categories. They were yellow, red, green, brown, white, orange, blue and gray.

The colours with the lowest average inter-group correlations seemed to be less typical representatives for the common colour names.

This finding - that people and groups of people are more concordant concerning the meaning of focal category colours - can serve as an hypothesis for further investigation.

But the averaged agreement values for the different colours we have just shown conceal information which becomes apparent when we inspect the between group correlations for each colour.

An example of this is the pink colour. Here it was only the Swedes who, for some peculiar reason, had a different opinion. From our earlier studies we know that this colour area has very low preference (seen on a colour sample as in the experiment).

Another colour for which the Swedes seemed to have different meaning was a violet - probably named purple in the English Language.

An example of the colours on which the national groups were in low agreement was a colour which sometimes is called English red, a colour near the borders of orange, red and brown.

In this presentation we have reported the initial studies of a broader project in which we intend to include a larger number of countries, preferably also groups of people which are more different from each other than we have studied to date.

In an earlier report we have, by means of multidimensional scaling, illustrated some general differences between the colour connotation patterns in the different national groups. This has been done, however, only for the comparison between Swedes and Americans.

Further, we have studied the "cultural difference" that occurs within a country between two time periods. The Swedish data used in the present study was compared with corresponding data from 1968 and it was shown that although the agreement between these two Swedish groups was lower than the agreement within each group they were still more concordant than between Swedes and the other national groups from the same time period.

The results up to now have been encouraging. They have shown - in our opinion - that the consensus between the groups is very high (but that evaluation depends on what one had expected) and further that it is possible to identify differences - both for individual scales and for individual colour areas.

The collection of data for this multi-cultural study continues and also includes the meaning of colour combinations.

For references we refer to our original articles which can be sent on request.

COLOUR APPEARANCE AND THE EFFECT OF SIMULTANEOUS CONTRAST

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ABSTRACT

Experiments were carried out to investigate the effect of simultaneous contrast on colour appearance, by varying the lightness, colourfulness, and hue of an induction field surrounding a test colour. A total of 333 test-induction combinations were assessed by a panel of five observers using a magnitude estimation technique. An empirical model was derived to provide a reasonable fit to the data.

BACKGROUND

One of the factors affecting colour appearance is simultaneous contrast, the phenomenon of the change in appearance of a colour caused by the presence of a surrounding stimulus. This effect is usually studied in a centre surround paradigm. Previous studies have shown that the hue, saturation, brightness and spatial parameters of the centre and surround all have an effect on the change in perceived colour of the centre. The apparent change in lightness, known as lightness induction, is well known and has been extensively documented [1].

Less work has been done in the past on chromatic induction, ie. the effects on hue and colourfulness caused by surrounding colour. Jameson and Hurvich [2] have shown that the induced colour in a focal area is inversely proportional to the opponent response of the inducing surround. In separate studies [3,4] the colour purity of a test patch has been shown to increase as the purity of the surround is increased. Other studies [5,6] have concluded that both colour-selective gain attenuation and opponent processing are responsible for chromatic induction.

Only very recently has any work been done in this area on video displays. Tiplitz-Blackwell and Buchsbaum [9] argue that their results suggest the visual system may be removing a portion of the colour signal that is common to both centre and surround. This has also been shown in other studies [6,8,10]. When the centre-surround colour difference is large (as with a yellow centre and a blue surround) the common signal is small; therefore chromatic induction is small. When the centre surround difference is smaller, (such as with a yellow centre and a green surround) the common signal is larger; therefore chromatic induction is larger. Tiplitz-Blackwell and Buchsbaum claim that this indicates a logical link between colour constancy and colour contrast. Hence, although the visual system is unable to determine the portion of the colour signal due to the illuminant, it is able to determine the common part of the colour signal in the surround and centre. Chromatic induction results because part of the common signal is due to the similarity in reflectances and colour constancy results because part of the common signal is due to the illuminant.

METHOD

In order to investigate further the quantification of the simultaneous contrast effect in monitor display conditions we devised an experiment in which five subjects were asked to estimate the magnitude of the lightness, hue and colourfulness of test field colours. Each subject had experience of the magnitude estimation technique, having previously taken part in a much larger scale experiment [11,12]. The display was arranged as shown in Fig. 1 and consisted of a neutral background. In the centre of this background there was a square test field, subtending a visual angle of approximately 2 degrees, completely surrounded by a square induction feld, subtending a visual angle of approximately 6 degrees (from a viewing distance of 60 cm). The reference white colour was an anchoring point used to scale the lightness and had a lightness of 100. A reference colourfulness sample was arbitrarily chosen for scaling colourfulness and had a fixed colourfulness of 40.

A Bentham tele-spectroradiometer was used for colour measurement using the 1931 CIE standard observer. Nine different colours were used for the test field, as set out in Table 1. The Y and L* values for each colour were normalised against those of 100 for the reference white colour. For each test field the same nine colours were used for the induction field, at four levels of lightness which are given in Table 2. The background of the display had the same colour coordinates as the grey test, and each test-induction combination was judged against this background. Hence, each colour was presented under 37 different surround conditions, yielding a total of 333 test-surround presentations.

TABLE 1

Chromaticity and CIE L*a*b* coordinates of the test colours

Test colour	x	y	Y	L*	C*	hue
Red	0.4832	0.3342	18.4	50.0	50.0	30.0
Yellow-red	0.4930	0.3857	18.4	50.0	50.0	53.0
Yellow	0.4467	0.4598	18.4	50.0	50.0	8.0
Green-Yellow	0.3603	0.5024	18.4	50.0	50.0	120.0
Green	0.2865	0.4278	18.4	50.0	40.0	115.0
Blue-Green	0.2342	0.3458	18.4	50.0	30.0	184.0
Blue	0.2090	0.2429	18.4	50.0	30.0	253.0
Red-Blue	0.3355	0.2278	18.4	50.0	50.0	335.0
Grey	0.3052	0.3232	18.4	50.0	0.0	178.0

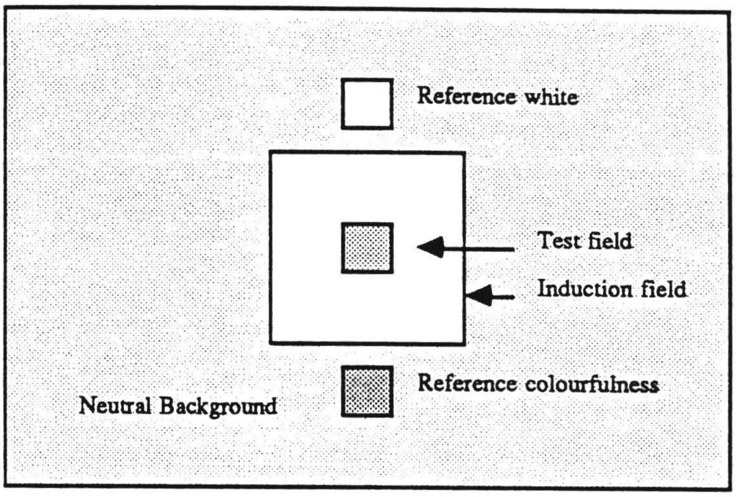

Fig 1. Display layout for simultaneous experiment

RESULTS

The arithmetic mean was taken to represent the mean visual results for both lightness and hue scales. For lightness, a scale from 0 (imaginary ideal black) to 100 (reference white) was used. For hue, a 0 to 400 scale (i.e. 0-100, R-Y; 100-200, Y-G; 200-300, G-B; 300-400, B-R) was used. The geometric mean was used to determine the average colourfulness results for the observers. Any colour perceived as having no hue has a colourfulness of

TABLE 2

CIE L* values of the induction field colours.

Red	30	40	50	70	
Yellow-red	30	40	50	70	
Yellow	50	60	70	80	
Green-yellow	40	50	60	80	
Green	30	40	50	80	
Blue-green	40	50	60	80	
Blue	40	50	60	80	
Red-blue	30	40	50	70	
Grey	1	30	50	70	90

zero. These mean visual results were used to investigate the change of colour appearance due to the variations of induction fields.

In general, the results support and add to the findings of previous studies. The results confirm the hypothesis that the perceived lightness of a colour decreases with increased L* of the induction field, whatever its hue. Our results confirm this fact in over 99% of cases studied. However, previous studies found little or no enhancement of the lightness of the test when the L* of the induction field was below that of the test (Heinemann, [13]; Horeman, [14]; Torii and Uemura, [15]). Our results show that in over 96.8% of cases, perceived lightness increases as the L* of the induction field is decreased below that of the test field. This discrepancy could not be found in the previous studies due to in fact that no chromatic colours were included (our results also indicate that the grey test colour gave the least contrast effect.). Both polynomial and linear functions were used to fit the relationship between L* of induction against perceived lightness of test colour. The shape of these functions indicates that each hue is affected slightly differently.

The effects of hue on hue observed in this study appear opponent in nature, in line with the findings of Jameson and Hurvich [2]. Tiplitz-Blackwell and Buchsbaum [8] have suggested that the magnitude of shift in hue is related to the degree of common signal shared by test and induction colours. Our results support this finding, but suggest that the effect may be more complicated. For example, a reddish-yellow surrounded by blue share no common signal and hence the reddish-yellow should be hardly affected following Tiplitz-Blackwell and Buchsbaum's reasoning. Our results suggest that as well as a shift due to shared signal response, there is shift due to signal response difference. Hence, in the example cited, the reddish-yellow would be expected to shift further towards yellow since the yellow signal will increase with respect to the red signal when surrounded by blue, as compared to the signal ratios when the reddish-yellow is surrounded by grey. Hence, the magnitude of the change in hue is related to the commonality and opposition between the test/induction responses.

The attribute of Colourfulness has not previously been investigated. Our results indicate that the colourfulness of a test field is affected by both the lightness (L*) and hue (h) of an induction field. Increasing or decreasing the lightness of a neutral induction field tends to diminish the colourfullness of a test compared to the colourfulness of the test when viewed against the equal lightness neutral. This appears to be a general effect which applies even in cases where the induction field is chromatic. The decrease in colourfulness is particularly marked when a test patch is surrounded by white. Marked decreases in colourfulness occur when a test is surrounded by an induction field having the same hue but varying in lightness. This suggests that the effects of hue on colourfulness can be explained by the same mechanism that gives rise to the hue (h) on hue effect. Hence, the shift in colourfulness of the test is related to the balance between the common and opposing Red-Green and Blue-Yellow channel responses of the test/induction field combination. In other words, a colour looks least colourful when the induction field shares common response (eg a yellowish-red surrounded by a red), and most colourful when the induction field opposes the test (eg a red surrounded by a green).

DERIVING A MODEL

We have implemented a computer model of simultaneous contrast. Five effects have been independently modelled: 1) L* on Lightness, 2) L* on Hue, 3) L* on Colourfulness, 4) h on Hue, and 5) h on Colourfulness.

The Lightness relations have been modelled by fitting regression curves to the data. For the Hue effects we have implemented a model which assumes colour opponent theory and suppressional interactions between adjacent fields of colour. We have taken the scaled percentage values of the test colour seen against Grey L*=50 (ie equal L* test/induction condition) as indicating the relative responses of the red-green (rg) and blue-yellow (yb) channels when hue interaction between test/induction fields is minimal. The effect of surrounding a test hue by a given induction hue is then computed as follows:

$$rg = (r_t - r_b w_r) - (g_t - g_b\, w_g)$$

$$by = (b_t - h_b\, W_b) - (Y_t - Y_b\, w_y)$$

then

$$rg' = 100\, rg / (|rg| + |by|)$$

$$by' = 100\, by / (|rg| + |by|)$$

where

$$r_t\; g_t\; b_t\; Y_t$$

are the visual responses for the red or green and blue or yellow of the test colour when seen against grey

L*=50;

and

$$r_b\; g_b\; h_b\; Y_b$$

are those for the induction field seen against Grey

L*=50;

and

$$w_r\; w_g\; w_b\; w_y$$

are weighting values for the red, green, blue and yellow responses and effectively determine the maximum amount of suppression that can be applied by an induction field to a test patch.

A red response is indicated by a positive rg' value and a green response by a negative rg' value, similarly for blue and yellow in respect of by'. There is some difficulty in determining the weighting values. By trial and error we have arrived at 0.08, 0.15, .0.8, and 0.20 for red, green, blue, and yellow respectively.

As we have seen from the results, the Hue-Colourfulness effect is related to the Hue-Hue effect such that the Colourfulness of the test decreases (is suppressed) when the induction field shares hue in common the test and increases (is enhanced) when the test and induction field oppose each other. With this in mind the computation of the hue(h) on Colourfulness effect uses the Colourfulness of the test patch seen against grey L*=50 as a reference which is increased or decreased depending on whether the net effect of the Induction field is to suppress or enhance channel responses, hence:

$$c = c_t\, (rg'+by') / (rg+by)$$

where c is the predicted Colourfulness, and ct is the Colourfulness of the test patch seen against grey L*=50

Qualitative analysis of the model performance (by plotting predicted values for lightness, colourfulness and hue against visual data values for lightness, colourfulness and hue respectively) indicates that the model's prediction of lightness and Hue shifts is good. The colourfulness results appear less good, due perhaps to the difficulty of accurately scaling colourfulness or the modelling of the effect of hue on Colourfulness.

CONCIUSION

In summary, our results indicate that colour presented on a computer display are affected by simultaneous contrast in a similar way to surface colours. All three colour appearance parameters studied (ie. lightness, colourfulness, and hue) are affected. These experimental results are to be incorporated into Hunt-Alvey colour appearance model. Further study will also be conducted using a wider range of test/induction combinations.

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ABSTRACT ONLY

COLOURED TRANSPARENCY OVER AN UNDULATED SURFACE

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Impression of transparency requires a clear depth distinction between the transparent surface and what is seen through it. According to most authors such condition is achieved when the background appears unhomogeneous, for instance when figural structures are perceived in it. In this research we wanted to show that a simple sinusoidal grating pattern is a suitable stimulus to produce such disparity. Moreover we have already shown that Metelli's mathematical model of phenomenal transparency also holds for colour situations, provided colours are measured in purely psychological scales. We have also shown that figural and chromatic complexity of the background enhances the degree of perceived transparency, in comparison with the theoretical predictions. Now our aim is to verify that the degree of transparency of a coloured rectangle over a bicoloured grid depends also on the contrast and frequency of the grid. Stimuli were produced by a computerized video display unit. Subjects had to vary the degree of transparency of a rectangle lying over a bicoloured, either horizontal or vertical, grid at different frequency and contrast levels, until it matched with an analogous situation in which frequency and contrast were fixed. Results show that: 1) the perceived transparency of the rectangle is a monotonous function of the grid contrast; 2) and a U-shaped function of the frequency, with a minimum at 2 cycle/deg. Moreover it has been shown that the observed display can appear as a differently illuminated, undulated surface, bent in space: such impression suggests the possibility of extending Metelli's model to transparent surfaces lying over differently illuminated background.

THE ORCHESTRATION OF COLOUR AND LIGHT IN NATURE AND ART

Doris-May Bull

"Sensations of colour do not exist without light. The hues on the sweep of a landscape, in the petals of the most vivid flower, in the pattern of a butterfly's wing owe their different appearance to the same daylight which falls on them all."[1]

This paper is based upon the premise of the writer's acceptance of and belief in the above quote. It is not designed to postulate proven theories or to formulate static ideas. We all come from different colour and light experiences which are tempered by our emotional and learned responses. As a painter, the writer sees grass and trees in terms of multiple colours; another could observe these just green. This paper concerns itself with arousing a heightened sensibility in our responses to the inter-changing quality of light and its subsequent effects on changing colour sensations in nature and art. The equal importance and contribution of both the scientific and creative approach to the harmonious organisation of colour and light in nature and art is emphasised throughout. Of necessity, the confines of this paper dictate that many important considerations be excluded. However, this does not detract from their importance. The common denominator of two art mediums, Impressionist Painting and Creative Stained Glass, namely, the essential presence of light in nature, will facilitate discussion and, as such, will be interpreted in relationship to the orchestration of Colour and Light in Nature and Art.

God said, "Let there be light" and there was light, simple, powerful, effective light. While the physicist can study the nature of the electromagnetic energy vibrations involved in the phenomenon of light, he/she cannot explain creation. Without light there would be no life. Heaven and earth would merge as one and time would be indiscernible without light.[2] Imagine a world without light and you imagine a world without colour. How often do we dismiss the natural light we see as white and, in so doing fail to appreciate the infinite spectrum of colour experience we are offered every day.

Forming a bridge between art and science, the rainbow mystified man for centuries. In 1672 Newton dispersed sunlight into the spectrum.[3] His scientific approach set him apart. To test his hypothesis he placed a second prism in the path of the spectrum formed by the first. He reversed the order of the different effects of refraction by inverting the second prism and so caused the spectral colours to recombine in a shaft of 'White Light'.[4] By joining red at the end of the spectrum to violet at the other Newton produced with a simple colour circle with hues in the same order as the spectrum and rainbow. This was to be the foundation stone upon which many future highly evolved colour systems were formulated. Some sixty-three years after Newton, Goethe decided to look at a pure white wall through a prism. He was dumbfounded to find the wall remained as white as before.[5] Goethe departed from the Newtonian theory that the wave length of light is colour making. Claiming that Newton was merely objective and, only concerned with physical colours and one medium only, he classified colour into three categories. The spectral colours Goethe named physical. These colours we see in or see by means of a soap bubble, oil slick or raindrop. Colours belonging to a particular substance he termed chemical. The fleeting images produced from colour combinations Goethe stated as "those which belong to the eye". These he called physiological [6] His six-colour wheel with its diametric placing of colour opposites can be viewed as a system of colour harmony or interpreted as a system of contrasts. The latter brings focus on Goethe's emphasis on how colour affects the eye and mind of the observer. This revelation presented an exciting colour venture for the Romantic artists who bought into their painting atmosphere and truth to nature.

During the late eighteenth century romantic painters Turner and Constable, made many dedicated scientific studies of nature. It is said that Turner's ideas are similar to Newton's; on the other hand "The Slave Ship" by Turner (1783) bears visual witness to Goethe's pre-occupations with the opacity of the atmosphere. Turner is recorded as saying, "The distant light is darkened to yellows and reds by the intervening atmosphere".

Romanticism lay fertile ground upon which a group of young artists using colour as pure light were to tread. Today we know their legacy as Impressionism (1866-90) - Monet and Renoir were amongst the first to realise that colour was in reality never constant. Shadows were in fact not merely darkened reflections to them, they were coloured. Impressionist painting was linked to the concept of known local colours. That is, a green object was always painted green. Colour variations were achieved through tonal gradation.(7) The Impressionists became increasingly aware that light and atmospheric conditions constantly changed colours and appearances in nature. A fine example of Impressionist innovation with colour and light in nature is "Westminster Palace, London" by Monet (1903). The houses of parliament are not painted the grey they are known to be. Instead, we see the greenish blue of the grey stone buildings against the orange-reddish hues of the sinking sun. Using a mixture of surface colours offset against the predominant hue of the light falling on them, Monet, has produced a visually impressive example of complimentary colour contrasts. (8)

The colour style of the Impressionists clearly reflects Chevreul's colour theories. In 1839 he wrote about the phenomena of simultaneous contrast. He cited that red and blue not complementaries, tended to "incline towards violet" with a noticeable absence of grey. When complementary colours were placed next to each other and viewed at a distance, Chevreul noted they presented a greyish look (9). The Impressionist painters relied on visual mixing. Monet's late water lily series shows bluish green juxtaposed with its true complimentary orange which, when viewed at a distance seems to appear as a dullish purple.(10)

Despite the grand achievement of Monet and his contempories the story is told that, after having seen an exhibition of Impressionist paintings Odgen Rood threw up his hands in horror saying, "If that is all I have done for art I wish I had never written that book.(11) Printed in 1879 Modern Chromatics interpreted the science of colour for artists. For the first time artists and scientists were addressed in equal terms. Rood's book included tables and diagrams that revealed the difference between the primary colours of pigment and those of light. A scale of hues was mixed from six pigments. Other tables showed mixtures of different coloured lights. Rood also wrote of "a quantity of small dots of two colours very near each other and [allow] them to be blended by the eye placed at a proper distance".(12)

The influence of both Rood and Chevreul is strongly evidenced in Neo Impressionism. The juxtaposition of the complementary colours used by Seurat in his painting "The Bathers" (1883-84) is according to the laws laid down by Chevreul. Rood's theory of harmonious triads of colours are used in the colour scheme. He devised a contrast diagram in the form of a circle with each colour separated by precisely calculated angles. Any three equidistant colours orange, green and purple violet, for instance - can be used to contrast harmoniously.(13). The Impressionists painted from nature. It is not mere chance that their subject matter was taken directly from their "Plein Air" approach. Painting the same scene many times over, the Impressionists were interested in colour and atmospheric effects at different times of day and from season to season.

Just as the Impressionists drew inspiration from the revitalizing energy of light in nature, so too can the skilled creative stained glass artist use a vibrant palette of colours to create a work of art equal to that of the most talented Impressionist painter. This claim is clearly demonstrated by Tiffany. His "Four Seasons" window (1905) with its symbolic forms derived from nature and the carefully established relationships of clear light colour, visually brings to life the individual essence of each season. At the same time Tiffany has combined his massive window into a harmonious whole.(14) There are many magnificent buildings in which, supported by sound and aesthetic structural lines, vast expanses of uncoloured glass is used. The full potential of colour and light in nature is tapped by the fleeting subtleties of changing daylight and differing seasonal conditions. One standing testament to this is the Uxbridge shopping centre in Britain.(15)

An intriguing attempt to interpret nature and art through colour and light was made in 1981 by Stanisla Melis.(16) His sculptural coloured glass installation on a South Australian beach brings into existence an animated interplay of man-made, and natural, fantasies of colour and light.

Windows of the world. Early church windows were devoted entirely to religious subject matter. As the churches lost their grip on men's minds, stained glass content increasingly varied. Glass works in Angers Cathedral, France, 15th century, shows an interest in non-religious subject matter.(17) As the result of dedicated scientific investigation, an extensive range of textures, patterns, and varying thicknesses of glass are now at the artists' disposal. Australian artist Andrew Sibley demonstrates the versatility of glass in the seven wall units he installed in The Church of the Holy Trinity, Brisbane (around 1960).(18)

The stained glass artist is responsible for choosing his coloured glass as the painter Is responsible for mixing his colours. Both art forms command a predetermined arrangement of line and tonal graduation to convey the desired mood. Without keen observation of natural light the Impressionist colour technique as we know it could not have evolved. Likewise, light is an essential ingredient in the art of stained glass, which cannot reach Its full potential luminosity without sunlight streaming through it.

The awesome power of colour and light when there is a fusion of the scientific and intuitive approach can be realised on comparative viewing of Seurat's Study for "La Grande Jatte" with his finished painting. It is not only science alone, but the scientific and intuitive in tandem that has reassembled the coloured dots on the working study to give us the majestic aura of the finished masterpiece "La Grand Jatte" Seurat (1884-6) - likewise the powerful expression emanating from a fusion of the scientific and the intuitive would have been experienced by those of us who have basked in the aura of a colour emblazoned stained glass window until we heard the colours singing in the sunlight.

The common denominator of two art mediums, Impressionist Painting and Creative Stained Glass namely, the essential presence of light in nature and the equal importance of the scientific and intuitive Input has been the concern of this paper. If even only a small shift In conscious awareness of the Orchestration of Colour and Light in Nature and Art has been effected, then this presentation will have achieved its purpose.

en quote
"Nature and Natures law lay hidden in Light"

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COLOUR AND PHYSIOLOGICAL AROUSAL

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ABSTRACT

There is more to colour than meets the eye and an account of some of the purported psychophysiological effects is given. The question whether Red is a more activating colour than Blue is discussed by reference to two opposing schools of thought, one based on colour light and measured by physiological changes in the central and autonomic nervous system and the other based on colour pigment applied in interior and exterior spaces while varying the dimensions of hue, chromatic strength and lightness. An experiment is discussed where subjects experience realistic full scale Red and Blue spaces and where both physiological and affective measures are taken.

INTRODUCTION

We need light to see the world around us and colour to add beauty to our aesthetic sensibility. The effects of light and colour on man however go beyond our common sense assumptions and expectations, and writers from poets to evolutionary biologists alike have praised man's good fortune. Indeed Nicholas Humphrey (1976) put forward the proposition that our ability to see colour can only have evolved because it contributes to our biological survival. Rikard Kuller's (1981) mammoth Annotated Bibliography of 1,700 references commissioned by the Commission Internationale de lEclairage (CIE) summarising the psychophysiological literature on activation firmly established the importance of three systems, mediating the non visual effects of light and colour.

1. The cutaneous system activated when ultraviolet and infrared radiation reaches the skin. Skin pigmentation, and the development of vitamin D are some of the main effects,

2. The pineal-hypothalamic-pituitary system. Light affects the pineal gland where it blocks the sleep hormone melatonin which in turn influences the hypothalamus which is involved in our emotions and the pituitary gland which regulates other hormones.

3. The Reticular Activation System whereby visual stimulation passing through the reticular formation activates the central nervous system as a whole.

Both external stimulation through the ARAS and internal activation through the ARAS affect our state of arousal.

BACKGROUND TO THE PROBLEM UNDER INVESTIGATION

In both scientific and introspective accounts, colours have been classified and grouped in various ways depending upon the believed influence or effects of such groupings. One of the most widely held groupings is that of 'warm' and 'cool' colours. Hues such as red, orange and yellow are seen in addition to their warmth, as exciting and stimulating, whereas hues such as blue, turquoise and green are seen in addition to their induced coolness as calming and relaxing. Applications based on these properties of colours are not confined to the work of architects and artists but also to clinicians in an attempt to pacify or calm down aggressive and anxious patients by using blue and green colours, and also to stimulate depressed patients by using red and orange colours. Bayes, K. (1967)

Some researchers have criticized these studies and suggested that the effects of hue on warmth and excitement is an intellectual one involving cognitive processes and not based on physiological processes which affect the whole organism. In an attempt to answer this type of criticism, namely that the effects of these colours are not only based on stereotyped verbal associations but that different colours actually evoke different feelings and emotions affecting the entire organism, Robert Gerard in his classic study in 1958 concluded that the two wavebands of radiant energy at the opposite ends of the visible spectrum, ie Blue and Red, exert a differential biological influence on the organism as measured by general activation in the Central and Autonomic nervous system EEG, blood pressure, palmar conductance level, respiration and heart rate).

Further support to Gerard's work is given by an experiment carried out by Ali, M.R. (1972). Coloured lights (Blue and Red) were projected directly on the eyes of 10 normal subjects for 6 minutes and EEG were recorded throughout the period. The results of this study showed greater cortical arousal following the presentation of Red light and lower cortical arousal following a Blue light.

Parallel to these attempts to validate through physiological measures the purported effects of the warm and cold colours there has been a different approach altogether to establish the meanings people associate with different colours. This approach differs significantly from the above in that:

1. All three dimensions of colours (hue, chromatic strength and lightness) have been systematically manipulated in an attempt to ascertain their relationship to the dimensions of colour meaning and

2. the obtained data were treated by more powerful methods of statistical analysis such as factor and cluster analysis which were not available to the early researchers.

Lars Sivik (1970) demonstrated with a technique of photo-simulation that it was not hue which affects how exciting or calming a colour is but the chromatic strength of each hue. (See Fig 1.) Acking and Kuller (1972) who showed with the use of perspective drawings of interior spaces and later on in full-scale spaces that weak colours give a room an impression of calmness while strong colours make it appear exciting.

The four studies referred to above were well designed by serious researchers in the field of colour psychology. Within their own parameters they show systematic relationships between colour and 'arousal' through physiological measures (Gerard, Ali) and through semantic differential analysis, (Sivik and Kuller).

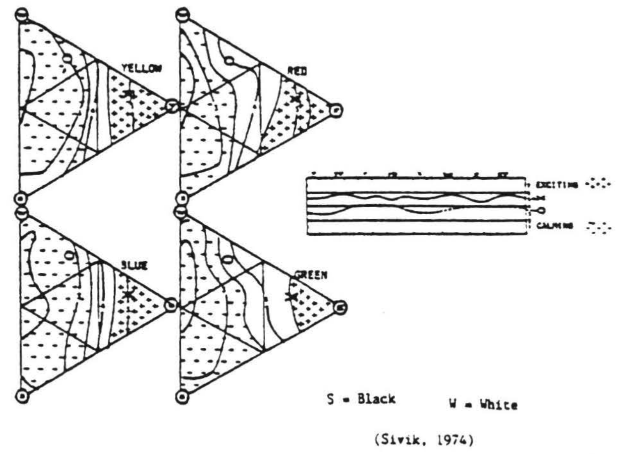

Fig. 1 Compare the points marked 0 and X in each of the four triangles Y, R, B, G (Sivik 1974)

There are however some fundamental differences between the two sets of studies. In the first two studies the content of colour stimulation was coloured light while in the last two studies the content was colour pigment. Furthermore in the first two studies subjects experienced the colour light stimulation in an abstract form in the laboratory, while the last two studies were carried out in the context of interior and exterior spaces.

AIMS OF PRESENT STUDY

The present experiment aims at bridging the gap between these sets of experiments. Why not measure both physiological as well as affective reactions of people? Why use patches of colour light projected on the retina or colour slides or even small drawings and simulated spaces when we can use surface pigments in real life spaces, the sort of spaces we actually experience. Test not only exposure of 60 secs intervals but longer periods when subjects could be experiencing real environments. The main technique used in this experiment in measuring activation is through EEG. J. Empson (1986) suggested that perhaps "the greatest achievement of electrophysiology for psychology, was the identification of the mechanisms subserving the control of activation in the brain, and the use of EEG in assessing level of arousal".

When a person is awake but relaxed, alpha rhythm abounds. This rather slow, high amplitude rhythm has a tendency to disappear when the person is stimulated but returns when the person is relaxed (see figure 2). Too much stimulation results in continuous blocking of alpha, involving the whole nervous system, a state generally referred to as stress. Thus by measuring the proportion of alpha in EEG it is possible to find out whether an environment is understimulating or overstimulating. Changes in Pulse Rate can also be used as an indicator of activation and stress though more difficult to interpret.

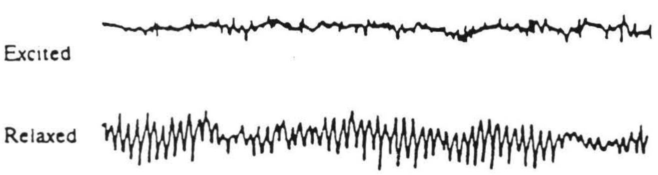

Fig. 2 Typical EEG recordings.

At the 1976 Architectural Psychology Conference in Strasbourg, R Kuller reported that there were differential psychophysiological effects in cortical activation as measured by alpha waves in two very different rooms, one painted grey and the other of a colourful wallpaper design. The results showed that the subjects had considerably more alpha activity in the grey room than in the colourful room supporting the general hypothesis that colour in general has an activating effect (Küller 1976).

EXPERIMENTAL DESIGN AND METHOD

At the Environmental Psychology Unit, School of Architecture of the Lund Institute of Technology a room measuring 3.5 x 4.5m with an adjoining control room where the monitoring equipment was placed, was used for the experiment (see Figure 3 & 4)

One half of the room was painted red (NCS 1674-Y9OR), the other half was painted blue (NCS 1859 B04G). Paint covered the walls, floor, ceiling and fittings. The idea behind this was that the subject, just by moving from one chair to another, would be exposed to four conditions:

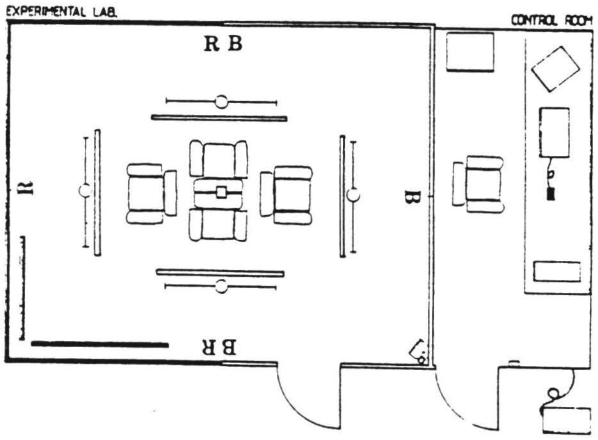

Fig. 3 The experimental room and control room used in the study. Sitting on each of the four chairs at the center of the room would give the subject access to four different fields of vision.

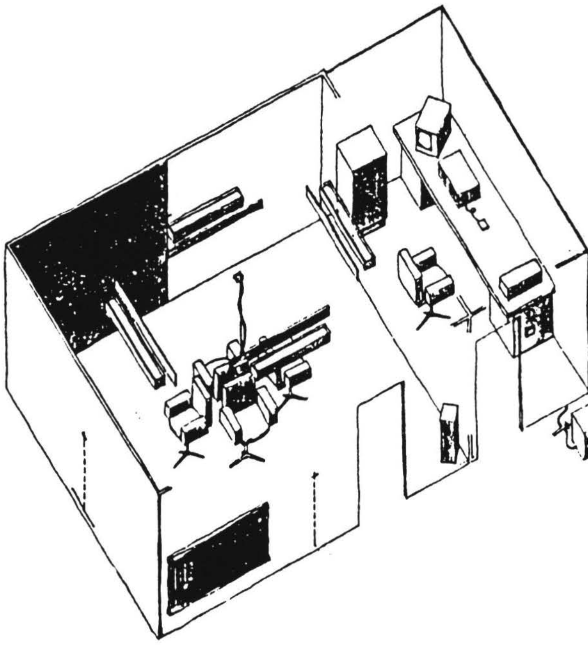

Fig. 4 Axonometric drawing of experimental & control rooms.

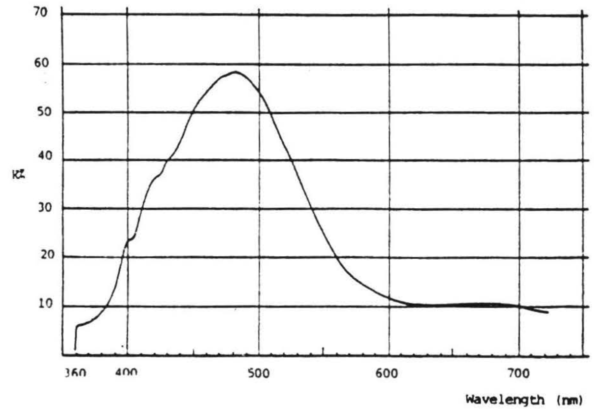

Fig. 5 Reflectance curve for Blue sample. NCS notation 1859 B04G

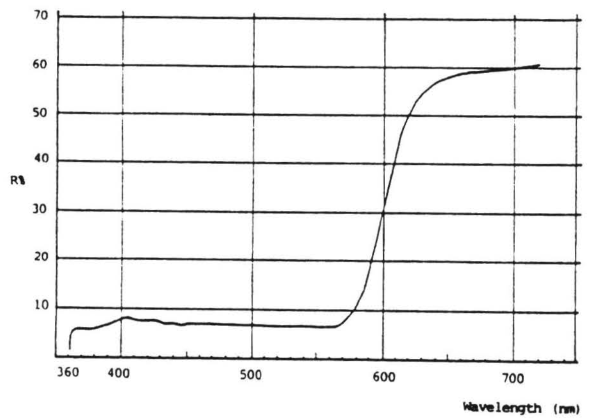

Fig. 6 Reflectance curve for Red sample. NCS notation 1674 Y90R

a) a completely red visual field (R)

b) a completely blue visual field (B)

c) a visual field with its left part red and right part blue (RB)

d) a visual field with its left part blue and right part red (BR)

We chose blue instead of green because the sprectral sensitivity of the eye is about the same in the blue and the red regions, whilst the sensitivity is different in the green region. The general lighting of the room was provided by Luma Colorette, a fluorescent tube which has an even spectral emission and good colour rendering (5400 Kelvin, CRI=91). It was important in this study to use colour samples which would satisfy not only the NCS parameters and colorimetric measurements but also the correct subjective evaluation of colour appearance. This test was satisfactory and the two colour samples conformed with the mapping of colour names in Sweden (L. Sivik and A. Hård, 1984). Temperature was maintained at a constant level through the automatic sensor at 22°C. The participants wore light garments throughout the experiment. In order to measure the EEG, electrodes were placed centrally and parietally, over the left and right hemispheres. A pair of electrodes was also used to record the pulse. In the control room there was a Siemens - Elema amplifier and a frequency analyser supplied with analogous band - pass filters and a pulse meter. The frequencies for the EEG analyses were in accordance with clinical classification. (see Table I)

TABLE I.

Definition of the four frequency ranges used in the present study.

EEG - Frequencies

Delta	2.25 - 3 Hz
Theta	4.5 - 6 Hz
Alpha	9 - 12 Hz
Beta	18 - 24 Hz

Twenty four subjects took part in this study. Each subject spent 20 minutes in each of the four conditions. Each condition was divided into 3 parts, 'reading', 'fixating' and 'closing eyes'. After the experiment electrodes were removed and the subjects introspection was taken. Time estimation and galvanic skin response measures were taken during this period. We had a set of specific hypotheses the main one being that the red visual field should be more activating, which partly should be shown as an attenuation of the alpha rhythm, and maybe even of the delta and theta rhythms. There might even be a differential activation of the two hemispheres when fixating the dot on the margin between the red and blue visual fields. Depending on the outcome, this would possibly enable us to draw conclusions as to which level in the central nervous system the activation is initiated.

EVALUATION AND IMPLICATIONS OF RESULTS

The data from the 24 subjects were treated by means of several analyses of variance for both EEG and EKG recordings. (see Table II below) The most important result of this study was paradoxically that there were no statistically significant differences in the experience of a Red and Blue space at the Central Nervous system. Arousal at the cortical level was the same for Red, Blue, RR and RR conditions. Arousal as measured by reduced alpha, was in fact in the opposite direction from the predicted one: there was more alpha and theta in the Red visual field than in the Blue one. We found in fact more delta activity in the red visual field than in the blue one (p=.03). Concerning differences between the two hemispheres there were only tendencies which were again opposite to the initial hypothesis.

TABLE II

The impact of colour on EEG (delta, theta, alpha, beta) and EKG (pulse and arrhythmia).

DELTA	Red	Blue	THETA	Red	Blue
Male	104	96	Male	106	105
Female	142	135	Female	166	161
Total	123	116	Total	136	133
sex p=.025 colour p=.03			sex p=.005 colour not sign.		

ALPHA	Red	Blue	BETA	Red	Blue
Male	184	187	Male	89	90
Female	300	289	Female	136	134
Total	242	238	Total	112	112
sex p=.05 colour not sign.			sex p=.005 colour not sign.		

PULSE	Red	Blue	ARRHYTHMIA	Red	Blue
Male	67	67	Male	.00466	.00435
Female	74	75	Female	.00951	.00385
Total	71	71	Total	.00709	.00410
sex p=.03 colour not sign.			sex p=.10 colour not sign.		

At the autonomic nervous system level there were no differences in EKG, (pulse rate, Arrhythmia) and Galvanic skin response. Although autonomic measures are not as accurate indicators of arousal and are often more susceptible to individual variation they produced almost identical mean scores for the two conditions. There were differences in all EEG frequencies between the male and female groups but these were not the differences we were looking for. There were no differences between either the male subjects or the female subjects with regard to the Red and Blue space. The fact that we recorded higher EEG levels in the male population in all frequencies may be due to anatomical differences between the two sexes such as the thickness of the cranium, rather than differences in arousal. The differences in pulse rate depend on the fact that women have a slightly faster pulse rate than men. There were also no significant differences in arousal for the left and right hemispheres when exposed to Red and Blue colour respectively and certainly not in the predicted direction.

The results support Sivik's and Küller's findings, that is, provided we control chromatic strength and lightness, there are no differences between the two hues as far as excitement is concerned. Their studies though carried out in a systematic way using the semantic differential technique in the context of interior and exterior spaces lacked support at the physiological level. The results of this experiment give support to their findings.

In his study Gerard suggested also responses and physiological changes; he demonstrated that the "verbal indicants of private experience were in fact correlated with objectively recorded internal physiological events". Reports in Gerard's study that the subjects reported a feeling of arousal and excitement during Red illumination and a feeling of significantly more calmness and peacefulness during Blue illumination has not been the general finding of Sivik (1970) and Acking & Küller (1976), nor were there any differences in the subjects' introspection in this experiment. In a study involving two seminar spaces one painted Red (R8I 04F53) and the other Turquoise (RSI 16F53) both high in chromatic strength by two groups of subjects (architecture students and laymen), they evaluated the two spaces as equally stimulating (Mikellides 1979).

We have already tested the strongest red in the market (1080 490R). Its actual specified strength was 15% more than the blue sample under standardized condition. In our experiment we also judged the two colours used to be subjectively equal in chromatic strength and lightness. Yet we found no differences. As things stand at the moment there is no evidence that a red space is more arousing than a blue one and as such this hypothesis is ahead on points. To use a tennis analogy it has the advantage. But it will be a pity to leave the game unfinished. Why not construct two separate identical spaces painted with colours of lower chromatic colour intensity and still in line with the most adventurous colour schemes at home and work? Include in the design colour curtains, drapes and rugs sympathetic to the constructed spaces; leave the floor and ceilings unpainted and have natural light in the room coming through the windows. Ask participants to stay in each room for 2 hours, introducing a variety of tasks to reduce monotony and boredom. If our hypothesis that there will be no difference in cortical arousal between the two colours of equal chromatic strength, is varified, we would have turned our advantage to winning the match.

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THE PSYCHOLOGICAL AND PHYSIOLOGICAL EFFECT OF COLOUR LIGHT.

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Japan

INTRODUCTION

Generally speaking, among the five senses, the sense of sight gives particularly diversified information and the visual stimuli are expected to have complicated effects on living bodies.

It is obvious that light environment including artificial illumination and natural light through windows plays an important role in comfort of living space.

At present, however, it is difficult to change the space colour of ordinary houses whenever required, for example, by changing wall paper. Coloured lighting will be the way which enables frequent change of the space colour.

In this paper, we conducted an experiment using a miniature room model illuminated with various colour lights as visual stimuli, and we evaluated the effects from psychological and physiological aspects.

METHOD

The subjects were 20 healthy females aged 21 to 45.

The visual stimulus was a miniature of a 16-mat living room (floor space: 1 m^2) on a scale of one fifth with its interior illuminated with one of five colour lights (red, yellow, green, blue and pink). The illuminance of colour lights was adjusted to 40 lux at the center of the floor in the miniature room. The colour lights were produced by an incandescent lamp covered with an applicable gelatine filter.

The room model had only three walls so that the subject could observe the inside of the model from the open side. The miniature model was placed about 30 cm away in front of the subject.

As physiological evaluation indices, blood pressure, pulse rate and skin temperature at the fingertip and brain wave at the front of the head were measured.

For psychological evaluation indices, we prepared a form including 9 measures on mental-physical condition and 21 measures on environmental image. Each measure for mental/physical condition and environmental image had a pair of opposite words on both ends and was provided with seven ranks. Figure 1 shows an experimental procedure. In one experiment taking about 30 minutes, two colour lights were evaluated with a pause between colour light. presentations. Colour lights were presented at random.

For physiological evaluation indidices, the values under colour lights were compared with those under white fluorescent light for calculation of change ratios. For psychological evaluation indices, the contents filled in on the forms were used to make profiles of the colour lights and calculate the scores by a main component analysis.

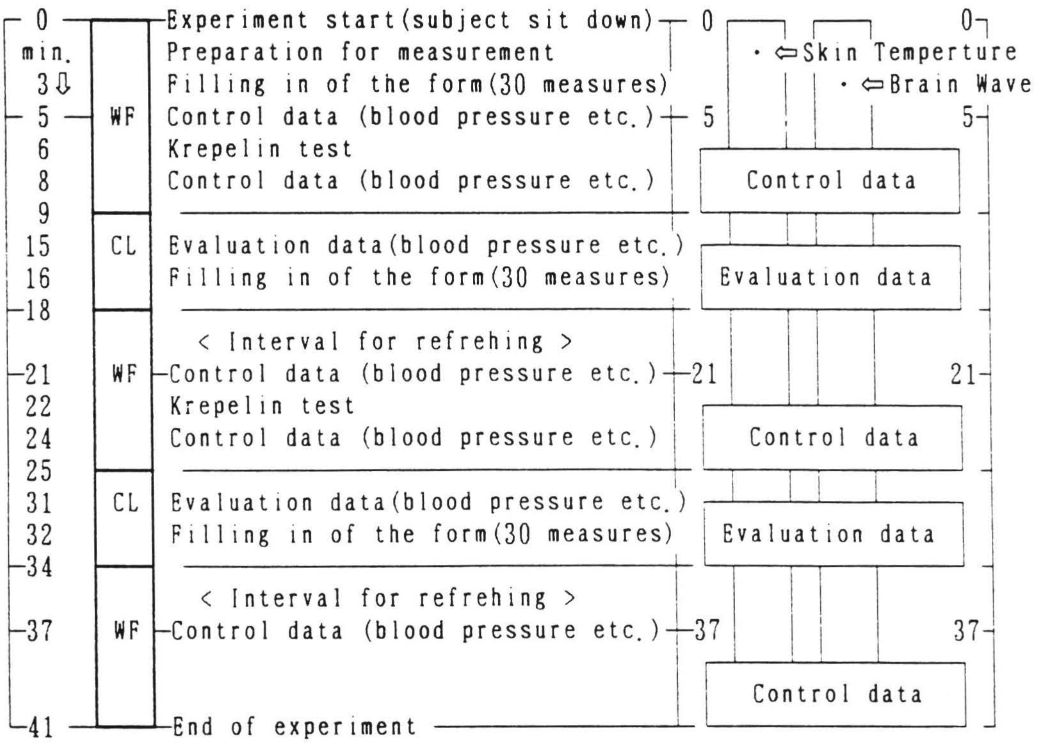

Fig. 1 Experimental procedure
Symbols WI: While fluorescent light
CL: Colour light

RESULTS

(1) Physiological evaluation indices

Fig. 2 shows the mean values of 20 subjects for the physiological indices and the statistical significance levels between the mean values. As the tendency in general, blood pressure and brain wave (alpha wave appearance ratio) became maximum under blue and minimum under red (blue>green>pink>yellow>red); pulse rate and skin temperature became maximum under red and minimum under blue (red>yellow/pink/green/blue).

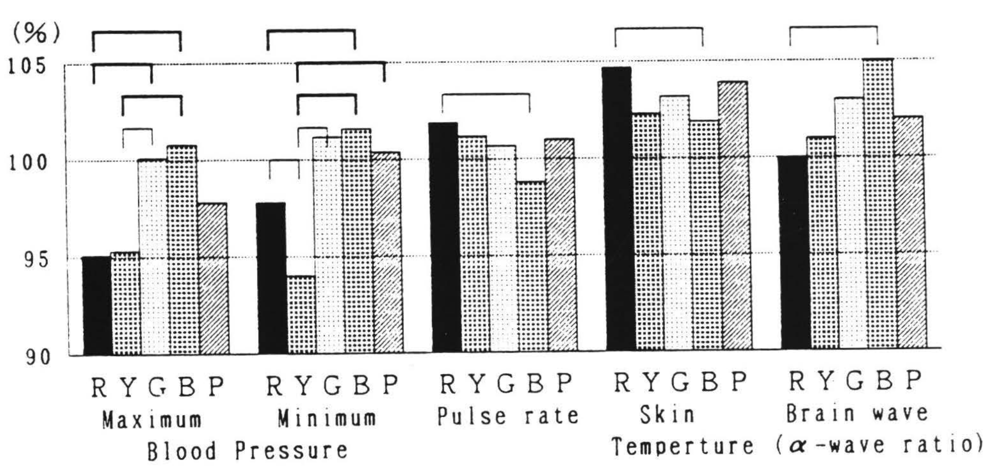

Fig. 2 Physiological Indices (Change ratios)
Symbols R : Red, Y : Yellow, G : Green, B : Blue, P : Pink

Significance $\sqcap$ *: P < 1%* $\sqcap$ *: P < 5%*

(2) Psychological evaluation indices.

Figure 3 shows the profile of the three colour lights (red, green and blue) obtained as average of 20 subjects. A distinct contrast was observed between red and green/blue except measures with "bright - dark", "not. sleepy - sleepy" and "boring - amusing".

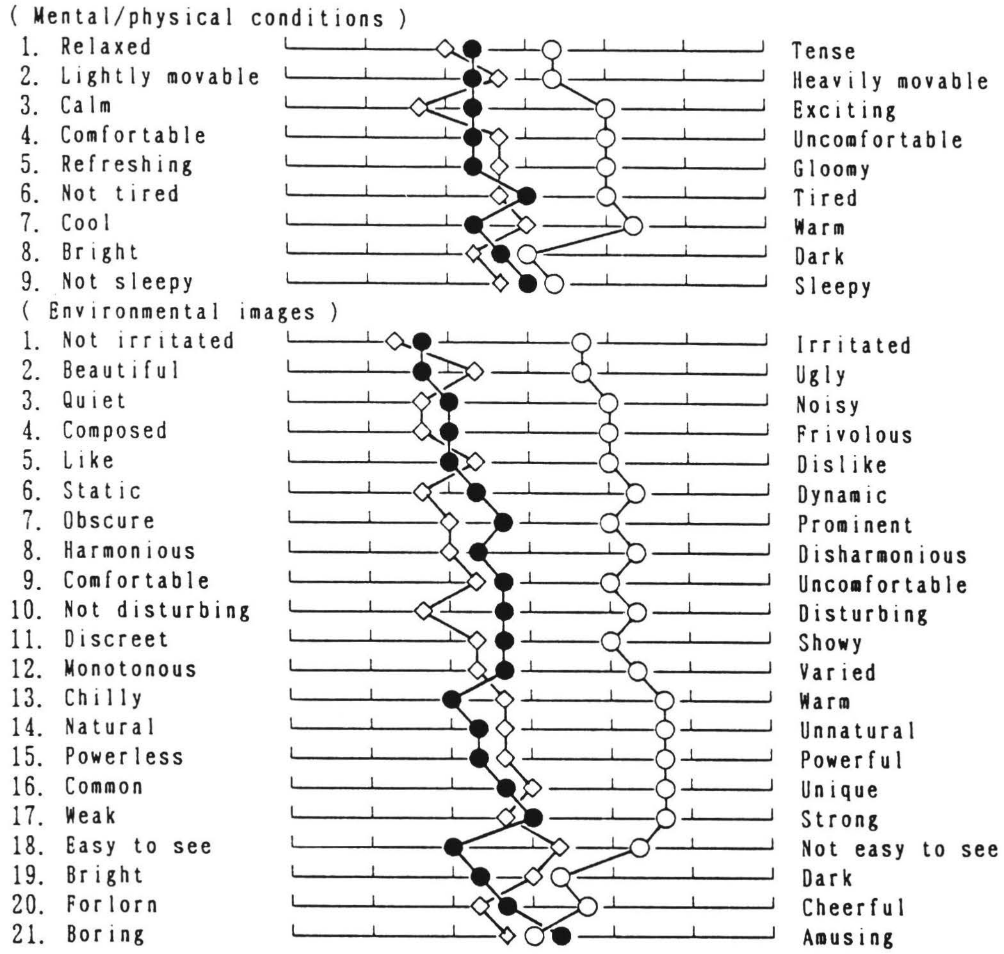

Fig 3 Profile of the colour lights
Plots ◊ : Green • : Blue O : Red

We made a main component analysis for these 30 measures and found that the first main component (contribution ratio: 67.1%) was "Natural comfortableness" and the second main component (contribution ratio: 15.8%) was "awakening feeling". Their accumulated contribution ratio was 82.9%.

Figure 4 shows plotted scores of the color lights for the first and second main components. Red was felt unnatural and uncomfortable, and green and blue were somewhat natural and comfortable. Green and blue were also different in that green was more awakening and blue was more calming. The scores of yellow and pink were almost zero for both first and second main components.

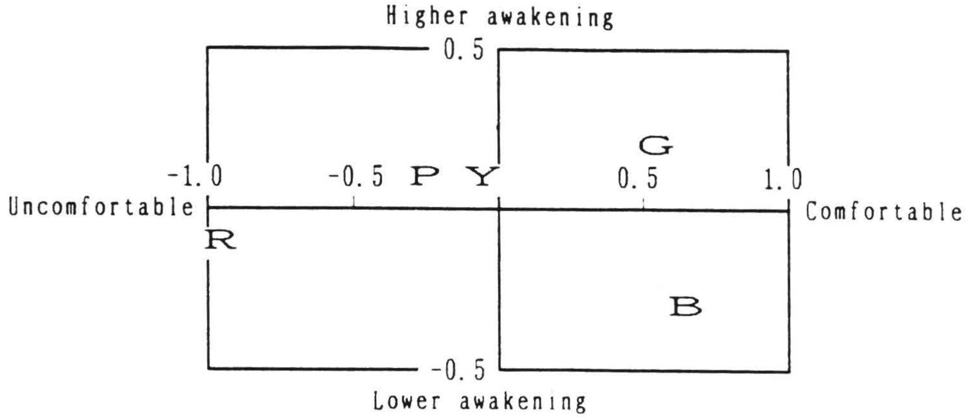

Fig. 4 Main component scores
Symbols R : Red, Y : Yellow, G : Green, B : Blue, P : Pink

CONCLUSION

According to both evaluations from Psychological and physiological aspects, we consider these colour lights have characteristics as follows: Red gives uncomfortable impression resulting in increase of pulse rate and decrease of alpha wave appearance in brain wave, but it gives warm feeling resulting in increase of skin temperature and decrease of blood pressure at the fingertip. Blue gives slightly comfortable and calming image resulting in decrease of pulse rate and increase of alpha wave appearance in brain wave, but it gives cool feeling resulting in decrease of skin temperature and increase of blood pressure at the fingertip. Green gives slightly comfortable and awakening image resulting in physiologically moderate level. Yellow and pink are generally in the center of red, green and blue from psychological aspects, and in the middle of red and blue from physiological aspects.

HARMONY OR DISCORD? THE PARADOX OF DISCORDANT COLOUR RELATIONSHIPS

Carol Arthur

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INTRODUCTION

According to many colour theorists, including the 19th Century American physicist Ogden Rood, there is a natural tonal order of hue, just as musical notes seem to fall naturally into ordered scales. In colour scales, this natural order begins with yellow as the lightest tone and progresses to orange, red, green, blue-green, blue and violet, the darkest tone (Saxton 1982; Varley 1988).

A discord in colour is defined as - *The reversal of the natural tonal order of any two hues.*

If a hue is darkened or lightened so that it is out of its natural order of tone, then used in combination with unmodified colours, the resultant scheme will be discordant (Varley 1988; National Art School, 1961; The School of Colour & Design 1988; Saxton 1982).

Discordant colour relationships can be created by adding:

1. WHITE (TINT) -TO LIGHTEN A COLOUR.
2. BLACK (SHADE) - TO DARKEN A COLOUR.
3. CONTRAST/COMPLEMENTARY - TO DARKEN A COLOUR.
4. GREY - TO REDUCE CHROMA.

The optimum effect is achieved when the tonal interval of the discorded colours is kept close.

Such reversed or inverted tonal colour combinations can attract attention, give emphasis and create extremely vibrant effects, but, in large masses can be very overpowering and disturbing especially where the tones of both colours are close and/or they are contrasting combinations (Nat. Art School, 1961). To the majority of colourists, discordant, or extreme clashing colour combinations are best used in small and/or unequal proportions to other colours when vibrant accents are required.

However, many 'discordant' relationships can be very exciting, with beautiful and even 'harmonious' effects, particularly if the proportions of the hues are well balanced.

Some examples of 'Discord' applications:

Fine Art:
Monet, Gauguin and Bonnard were artists who explored 'Discord' colour relationships.

Craft/Arts:
Contemporary Designer/Makers e.g. Robyn Gordon.

Post-Modern furniture design e.g. Ettore Sottsass & the Memphis Furniture Group.

Design:
Textiles; Packaging; Advertising graphics; Product design; Theatre design etc.

Natural/Environmental:
Blue sky and green foliage.

Marine animals - particularly tropical fish; Nudibranchs (sea slugs):

Wrasse - (pink & yellow); Botrylloides -Ascidians - (purple tint & orange; blue tint & yellow).

Blue-angel fish - (khaki - yellow reduction & blue tint). Coral cod - (violet/purple tint & red-orange).

Plants and flowers:
Pyrethrums and Waterlilies - (pink & yellow); etc.

The initial purpose of this project was simply to explore these ' discordant relationships' and to create a systematic study of all the combinations which could be achieved from a selected hue wheel.

It is a self-initiated project being undertaken as part of my Post-Graduate Exhibition year at the School of Colour & Design and it was intended that the resultant charts be used as visual aids to the selection of colour combinations for various design and fine art works for the exhibition.

However, research soon led to a number of questions relating to the nature and definition of 'Discords' and to a discussion centred around a jig-saw puzzle of terminology.

The premise that the technique used to obtain 'Discords' *usually* produced clashing combinations and negative emotional responses in the viewer needed to be addressed and is therefore examined here.

SYSTEMATIC STUDY - *BASIC CRITERIA*

Reference sources researched pre-AIC 'Colour & Light' Conference provided very little information due to the confusion surrounding the concept of 'Discord' and its use in colour theory and practice in Australia. Consequently, the following questions were considered for further investigation:

- What is a 'Discordant' colour relationship?
- Can we still describe many of these combinations as 'Discordant' i.e. unpleasant, clashing, out of harmony?
- Which combinations are considered 'Discordant' and which 'Harmonious'? By whom?

A systematic study of this size is potentially an on-going project which could take considerable time to complete. Therefore, this initial exploration can only serve as an introduction to the topic.

METHODS & MATERIALS

The basis of this analysis centres around the selection and application of hand mixed paints listed below:

Paints: Artists Designer Gouache paints were chosen as the initial pigment medium. 12 standard Art Spectrum hues were selected to represent a colour wheel incorporating primary, secondary and intermediate mixes. These were - Primary Yellow; Light Green; Middle Green; Turquoise; Primary Blue; Ultramarine; Violet; Magenta; Rose; Vermilion; Orange; Deep Yellow; (Jet Black and White). The hues were numbered clockwise and remained constant throughout the study.

Watercolour papers selected for Artwork:: • W & N CP/ NOT 300 gsm - Medium. • Arches Cold Pressed 300 gsm - Medium.

Mounting paper selected for A3 Folio Charts: • The Paper House - "Origin" - 100% Re-cycled cover weight 220gsm - colour "Tinsel".

Mat for Posters: • Bainbridge Black Core - "Polar White".

The study included 3 initial reference charts followed by a poster displaying all combinations of discordant relations.

A. COLOUR WHEEL: A 12 segment wheel was selected as the reference point for the study.

The centre shows the matching grey tonal value to each hue. An outer band shows corresponding complementary colours.

B. TONAL SCALES: A scale showing the hues matched with their corresponding tonal value (grey scale). The twelve hues were analysed for their tonal value using a Densitometer and visual judgment, then arranged alongside a corresponding grey scale to show their order of descent from light to dark. This set the 'natural order' from which discords were created.

C. GRID SYSTEM: A grid was produced, showing each single colour-wheel hue in a row, with all of its 'discords ' derived by lightening or darkening the 11 remaining colours. This gave a total of 132 discord combinations. (See Chart)

D. COMBINATION STUDIES: Many approaches to discordant colour combinations are possible. For example, related colours, contrasting colours, colours tonally close or far apart, reduced chroma or pure hues. In this study, small motif designs were arranged to illustrate all the combinations possible using the hue wheel and included:

1. *Chart Series* - A separate sheet for each colour illustrates light and dark combinations in detail.

2. *Pattern Strips* - A pattern strip of each grid row shows the total discord combination of one colour all together (Poster 2).

3. *Pattern Strip Format for Complementary Hue Rows & Chroma Grid*

The following formats developed as further studies to show:

Discords within rows - A pair of Complementary hues (Blue & Orange) were chosen to illustrate 'Discordant' combinations within their own rows. The first 6 pairs were complementary combinations, and the second 6 related hue combinations. These combinations were presented as a poster (Poster 3).

Chroma Grid - The chroma of the twelve Wheel hues were reduced in three stages by adding grey. Six complementary pairs and 6 related hue pairs were then arranged into pattern strips for comparison (Poster 1).

E. PRESENTATION: AIC "Colour & Light 91" *International Colour Conference - Powerhouse Museum 25 - 28 June.*

POSTERS Three posters were presented at the AIC Conference:

1. Basis of Study - Colour Wheel; Grid System; Grey Scales; Chroma Grid and Text .
2. Small Design Motif Discord Combinations - Pattern Strips and Explanatory Text.
3. Larger Design Images - 'Discordant' and 'Harmonious' examples; Complementary Hue Row Pattern Strips and Text.

G. QUESTIONNAIRE: (See Appendix). A simple questionnaire was prepared to assess the emotional responses of viewers and their colour combination preferences. This required participants to grade the discordant combinations according to how pleasant or disturbing they judged them.

RESULTS AND DISCUSSION

Detailed observations concerning the problems associated with the setting up of the project are not discussed here, however, they are recorded in a journal elsewhere.

Questionnaire

The primary aim of this study was to create a systematic chart series of specific colour combinations and to consider the question as to whether there is a paradox of 'Discordant 'colour relationships.

The results of the Questionnaire indicated that most people who participated were fascinated and stimulated by the vibrant colour combinations produced.

It should be noted that the number of responses obtained at the Conference was low (23), predominantly female, Australian born and all were familiar with colour. Further surveys would require a greater range of more specific questions and provision for more detailed analysis.

The majority of general comments concerning 'Discordant ' combinations were very positive and were in agreement that most could not be regarded as 'inharmonious', which tends to supports my statement.

This brings us to the question as to whether these combinations should still be generally described as 'Discordant', and this required further research into their history.

As already mentioned in the Introduction, this aspect has been very difficult to establish. However, in discussing the problem with several colourists at the Conference more information has been added.

Peter Travis (personal communication) related the story of how Phyllis Shillito, an artist who arrived in Australia during the 1920's, was invited to initiate a course in Design at the National Art School, Sydney in 1932. She introduced and taught Colour Discords there for many years before founding her own School of Design with Travis. At that time the only source book available for students refers to discords as being "the opposite extreme to complete repetition, and harmony is between and combines the character of both.......Discord concerns all dimensions. Discord is maximum interval of shape, size, value and colour. It is extreme contrast of difference" (Graves, 1951).

Graves (1951) goes on to describe how discords can co-exist in a composition if the principle of dominance is enforced and when controlled and organized. It is a matter of personal preference as to whether one likes discord or not.

However, this view was not always supported. In earlier work on the subject, mainly by Aemilius

Müller, who, continuing the research of Wilhelm Ostwald, stated in 1946 that "hue deviation" can produce ugly colour combinations, in the event of so-called "inversions" and that colour combinations can only be harmonious if their lightness ratios follows the natural order of the corresponding full colour. The inversion of natural lightness ratios of different hues was for Müller a definition of colour disharmony. He produced many colour scales based on systematic hue deviation and even used the phenomenon of colour inversion to measure colour taste (Spillman 1985, and personal communication; Luescher 1991, and personal communication).

Whether the concept and the use of the word 'Discord' in describing the combination relationship of colour inversion as being concordant or discordant is adequate or misleading requires a review of our terminology and is therefore open to discussion.

In conclusion, several suggestions for further research have been made and additional questions have been raised e.g :

- What effects do colour inversions have on our visual perception and our emotions?
- Which combinations give the maximum effects, i.e. visual vibrations and emotional impact?
- What effect does proportion have on combinations, i.e. large field areas and/or accents?
- What relationship exists with "fashion trends"?
- What occurrences in the natural environment and in the man-made environment?

As mentioned in the Questionnaire, I would be most grateful for any feed-back or information related to this on-going study.

SPONSORSHIP:

Art Stretchers Co. - For the supply of Art Spectrum Designers Gouache paints used throughout the artwork of this study.

ACKNOWLEDGMENTS:

The School of Colour & Design - Eva Fay, Prue Leith and the Post-Graduate Art Design Studio Group.

My son, Julian Seddon, BSc. - Paper format and constant ear-bashing for feed-back !

Dr. Penelope Farrant - Royal Botanic Gardens, Sydney - Data on colours in the Natural Environment.

Dr. Peter van Sommers - Dept of Psychology, Macquarie University - advice on Questionnaire format.

Jenni Walsh - Poster Graphics advice.

Bryan Powell - ABC TV - Densitometer readings, computer operating assistance and tuition.

Professor Werner Spillman, Max Luescher and Peter Travis for their information re: historic research .

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GRID SYSTEM													
The Grid showing each single pure hue in a horizontal row with all of its "Discordant" colour combinations													
TONE	NO.	HUE	Y-GREEN	GREEN	B-GREEN	BLUE	B-VIOLET	PURPLE	R-PURPLE	RED	R-ORANGE	ORANGE	Y-ORANGE
B	1	YELLOW	2 T	3 T	4 T	5 T	6 T	7 T	8 T	9 T	10 T	11 T	12 T
D	2	YELLOW-GREEN	3 T	4 T	5 T	6 T	7 T	8 T	9 T	10 T	11 T	12	1
F	3	GREEN	4 T	5 T	6 T	7 T	8 T	9 T	10 T	11	12	1	2
G	4	BLUE-GREEN	5 T	6 T	7 T	8 T	9 T	*10 T	11	12	1	2	3
H	5	BLUE	6 T	7 T	8 T	*9 T	10	11	12	1	2	3	4
K	6	BLUE-VIOLET	7	8	9	10	11	12	1	2	3	4	5
J	7	PURPLE	8	9	10	11	12	1	2	3	4	5	6 T
I	8	RED-PURPLE	9	10	11	12	1	2	3	4	5	6 T	7 T
H	9	RED	10	11	12	1	2	3	4	* 5 T	6 T	7 T	8 T
G	10	RED-ORANGE	11	12	1	2	3	*4	5 T	6 T	7 T	8 T	9 T
E	11	ORANGE	12	1	2	3 T	4 T	5 T	6 T	7 T	8 T	9 T	10 T
C	12	YELLOW-ORANGE	1	2 T	3 T	4 T	5 T	6 T	7 T	8 T	9 T	10 T	11 T

* Denotes where the hue is the same tone as the hue being 'discorded'. This can be achieved by tinting or shading one of the two slightly

T	The hue is tinted with white to be slightly lighter than the row hue
	The hue is darkened by adding black (Shade) or its Complementary to be slightly darker than the row hue

APPENDIX

HARMONY OR DISCORD ? THE PARADOX OF DISCORDANT COLOUR RELATIONSHIPS.

QUESTIONNAIRE.

As well as attempting to answer the question posed by a specific Visual Arts theory, there are many aspects concerning the study of Discordant Colour Relationships which I am interested in exploring. The more deeply one becomes involved in the subject, the more complex the questions become !

I would appreciate it if you could take a few minutes to answer this simple questionnaire and would be especially grateful for any feed-back, additional information &/or material relating to this study.

I shall be available during the entire time at the Conference for comment, but may also be contacted at the address and phone number below.

The results of this initial study will be published in the Book of Proceedings following the Conference. However as this is the beginning of an on-going project I anticipate that the findings will require a great deal of further investigation and analysis in collaboration with specific experts in various fields e.g. Psychology; Optometry; Biology etc.

You will find the Poster Display on Level 5. Please refer to the Posters with the above title to answer the following questions.

QUESTIONS:

1. Are you Male ☐ Female ☐

2. Are you under 25 ☐ 25-35 ☐ 35-45 ☐ over 45 ☐

3. What country do you come from ?..

4. Poster no. 2 is made up of 12 horizontal patterned strips. Each is a separate base colour taken from the hue wheel on poster 1. They show a series of 'discordant' colour combinations arranged in decorative rectangles across each strip. The vertical and horizontal numbers refer to the colour, that is, number 1 is yellow; number 2 is yellow-green etc.

   Identify the horizontal row which you like best ....

5. Identify the horizontal row which you like the least..

6. Within the best row identify the <u>colour combination</u> you like best..

   (the patterns are vertically numbered at the bottom of the poster)

   Comments..

   ....

7. Within the most disliked row identify the combination you think is the most unpleasant

   ....

   Comments..

   ....

8. On poster 1 is a chart of reduced chroma colour combinations.

Do you prefer either of the 2 rows ? Which one ? Row 1 ☐ row 2 ☐

9. On poster 3 is a pair of complementary colour discord rows.

Which row do you like best: orange ☐ or blue ☐

10. Comments on your reactions to discords..

....

....

COLOROID COLOUR HARMONIES AT THE BUDAPEST UNDERGROUND RAILWAYS

Antal Nemcsics

Technical University of Budapest, HUNGARY

Colour design of the Budapest underground railways (Metro) relying on relationships or the COLOROID colour system developed by the Author in Hungary.

Colour space of the COLOROID colour system relies on harmony threshold measurement tests involving votes of thousands of test subjects. A harmony interval corresponds to different perception threshold spacings at different locations of the colour space. In the COLOROID colour system, every colour has been indicated by three correlated numbers. Those marked A,T and V refer to hue, saturation, and lightness, respectively, such as:

A - T - V
22 - 30 - 70.

Colours in axial sections of the COLOROID colour space have identical hues. Axial sections are included between the achromatic axis and two boundary curves each. Spectrum colours at boundary curve intersections are at different heights of the cylinder generatrix opposite to the achromatic axis, depending on their brightness. In colorimetry the "intensity" sensation of a light stimulus is termed "brightness". For surfaces, if the brightness sensation is evaluated in its proportion to the equally illuminated absolute white surface, the term "lightness" is used. As the COLOROID system is used mainly for surface colours, throughout this work the term "lightness" will be used, even for luminous colours the luminance of which is arbitrarily defined, based on the spectral tristimulus (colour matching) functions of the spectrum colours. Every colour in an axial section has the same characteristic wavelength. The COLOROID colour system has very many axial sections containing colours of the same hue. 48 among them have been selected, named basic hues, and indicated by two-digit integers. Indices of axial sections belonging to different colour domains are:

yellow:	10,11,12,13,14,15,16;
orange:	20,21,22,23,24,25,26;
red:	30,31,32,33,34,35;
purple and violet:	40,41,42,43,44,45, 46;
blue:	50,51,52,53,54,55,56;
cold green:	60,61,62,63,64, 65,66;
warm green:	70,71,72,73,74,75,76.

Deflections between hue planes are directly proportional to the numbers of harmony thresholds between them. There is throughout the same number of harmony thresholds between neighbouring basic hues. Every hue plane contains luminous colours and surface colours in different proportions. Surface colours lie near the achromatic axis, and luminous colours near the boundary curves.

In the COLOROID colour space, colours of the same saturation are on coaxial cylindrical surfaces. Each colour in such a cylindrical surface typically needs the same quantity of spectrum colour to be produced by additive colour mixing from gray and the spectrum colour. Grays reside on the common axis of the cylinders where saturation is zero, and spectrum colours do on the cylindrical surface the farthest from the axis where saturation is 100. Between the achromatic axis of the cylinders and the cylindrical surface for spectrum colours there are very many cylindrical surfaces of uniform COLOROID saturations. In the COLOROID colour system, saturations of 99 consecutive ones are denoted by integers beginning with 1. Reckoned either from inside or from outside, colour saturations on consecutive cylindrical surfaces differ by the same number of harmony thresholds throughout. Some of these cylindrical surfaces contain only luminous colours, but most of them contain both luminous colours and surface colours.

In the COLOROID colour space, colours of the same lightness lie in planes normal to the achromatic axis. Numerical value of the lightness of every colour in such a plane is ten times the square root of the CIE Y tristimulus value of the colour stimulus raising the colour sensation. There are very many such planes containing colours of equal COLOROID lightness. Lightnesses of 99 such lightness planes have been indicated by integers beginning with 1. Colour lightnesses in neighbouring planes are separated by the same number of harmony thresholds throughout. The numerical value of the lightness of absolute black is 0, and that of absolute white is 100. Marginal parts of planes with colours of equal COLOROID lightnesses comprise luminous colours, and inner parts, where the plane intersects the COLOROID colour solid, comprise surface colours. Colours of the same lightness and the same hue are aligned along a radius each. Geometrical loci of those of the same saturation are concentric circles, centred around a gray of the same lightness as the other colours. Every colour in this figure has a lightness of 65. Numbers indicating the radii refer to the hue of the colour on the radius, those joining the concentric circles refer to saturations of colours along the circle.

Harmonic colour groups within the aesthetically uniform COLOROID colour space can be determined by simple mathematical and geometrical relationships.

Colours with COLOROID coordinates forming arithmetical or geometrical series meet essential fundamental condition of the colour harmony sensation to arise.

In selecting the colours for the new Budapest Metro stations, both fundamental and accessory conditions of the arise of colour harmony have been reckoned with.

The set of station symbols of a line offers the passenger line information not only whence the trains stopping at the platform started, what stations they touched, where they were stop, and where arrive to, but also, whether the train runs toward the centre or the outskirts. Also change possibilities are imparted.

Station symbols and symbol groups of line information rhythmically divide platform and exit wall surfaces, - rather than to function as an information alone -, but interaction with wall and ceiling colours helps space sensation, artistic appearance of the given space.

Coloration of every station has an emotional message, too. For instance, coloration of the Forgách Street station features combination of light Naples yellow and golden grey. This pair of colours expresses deep contrast between daylight and shadow on platform walls and ceilings. Steel structures of benches, wall surfaces behind benches, rails, handholds, and any functional unit are Coventry blue, complementary of Naples yellow, colour symbol of the station.

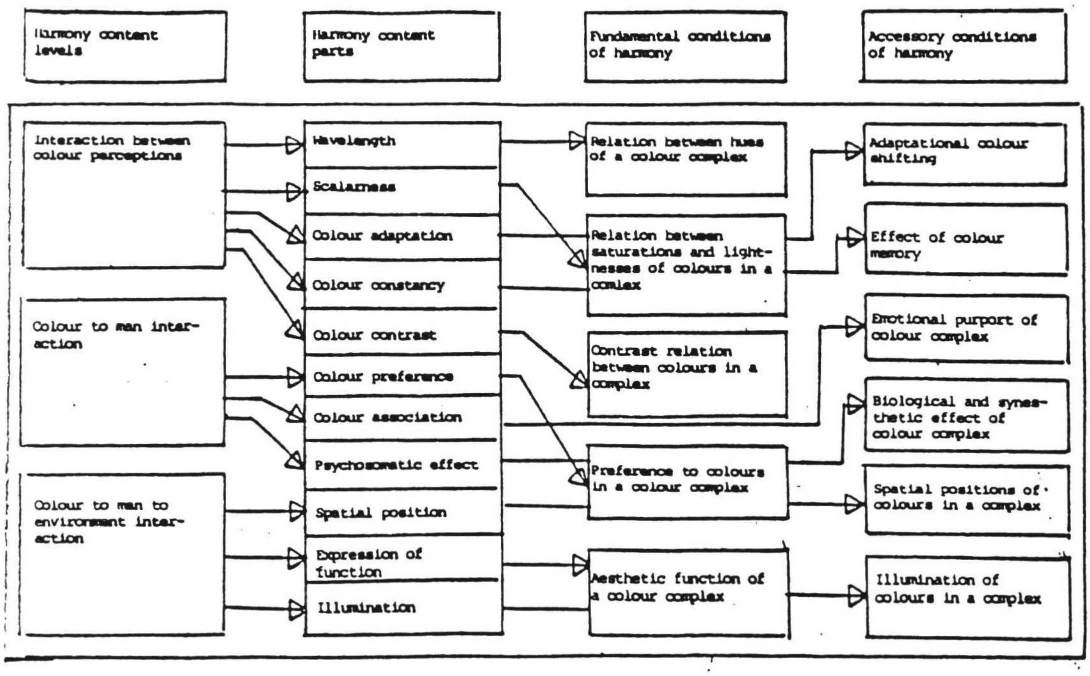
Station symbols accompany the passenger across exits to the ground. Underground information tables are always of the line colour, but ground traffic information tables have always a different colour.

Enamel surfaces (murals) at station exits are integer parts of space sensation but have a message of their own. In the enamel mural entitled Ground and Depth in the SE exit of the Forgách Street station, black increases logarithmically along the subway.

The mural in the NE exit of the station at Gyöngyösi Street consists or squares where the ratio between white, black and blue surfaces changes in conformity with COLOROID colour harmony rules. Additively mixing colours in a square would yield colours of that section of the COLOROID colour space forming harmony scales with the station colour symbol.

Every underground line obtained a symbol consisting of a colour and a configuration. The new stations are those of the N-S line, given symbols being circle as a configuration, and cobalt blue as colour.

The Budapest region has been divided to a north sector given cold colours, and a south sector given warm colours of the COLOROID colour circle, as well as to zones outwards from the yellow-tinted town core. Within boundaries of a zone, hue of the colour symbol is the same at every station of the zone, though saturations and lightnesses go increasing toward the town centre.



Symbol of the station consist of the line symbol and the station colour symbol. Arrows above the station symbols point to exits. Colour of the line tunnel between platforms is always the line colour symbol.

Station colours are mostly in a dichromous complementary harmony, though often corresponding to a dichromous truncate triadic relation in the COLOROID colour space.

ABSTRACT ONLY

EDDIES ROOM - A SPECIAL ROOM FOR A SPECIAL CHILD

Magenta Yglesias, ASID

Chair, Special Interest Group III
Inter-Society Color Council

MISSION: Eddie is a 5 1/2 year old little boy with cerebral palsy. He is severely visually impaired and is unable to walk;. Eddie has movement only in his left arm and hand. Eddie can hear, touch and is beginning to speak.

SYNTAX: Relationships in the room are singular and are plural with the caregivers.

PRAGMATIC: Think about the effects of the furnishings for Eddies' capabilities and the causes of stimulation and pleasure.

FUNCTION: Movement, texture and sound.

BEAUTY: Approach the spirit with tactile adventures and experiences and approach the senses with simplicity and calm.

COLOR HARMONIES: Soft greys, whites, chroma blue and small quantities of oranges. Contrast is important.

COLOR INTERACTION: Dark outlines for doors, windows and passages to identify functions by contrast.

TEXTURE AND MATERIALS: Texture is the strongest tool. Soft, rounded grooved edges are easier in wood than in laminates and the color gained by plastic is not useful because Eddie can not perceive it.

ORNAMENT AND PATTERN: Very simple and full of meaning and information. Ornament should be a function not an application.

THEME: Outer space and special concepts as decoration and theme can give a sensation of "no limits" and/or no confinement to Eddies' potential development.

Colour Education

COLOR SCIENCE EDUCATION IN THE 1990'S

Roy S. Berns

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OVERVIEW

Today as never before, color science education requires a more interdisciplinary approach. Many of us learned color science for a specific application. My introduction to the field was to understand how to effectively formulate and control the color of continuous dyed carpet. Having this narrow perspective initially hampered my teaching effectiveness; upon entering academia, my first responsibility was to teach colorimetry to photographic science students. I found I needed a more global approach to the study of color science. Today, this need is even greater due to the emergence of technologies where color is transferred between different media.

HISTORICAL PERSPECTIVE

Here is an example of the danger of teaching color science with too narrow of a perspective. An educational need arose in 1931 with the promulgation of the CIE recommendations for calculating colorimetric parameters for an average, standard observer. As the years progressed, educators approached teaching colorimetry from one of two perspectives: metamerism was "evil" and should be avoided at all costs or metamerism was not even an issue except for a few rare occurrences. This dichotomy resulted from applying colorimetry to two general applications. The first is the coloration of materials where the goal is to match the spectral properties of a standard. When the spectral properties cannot be matched, metamerism occurs. Strongly metameric matches have lower quality than non-metameric (spectral) matches. The introductory textbook, *Principles of Color Technology*, written by Billmeyer and Saltzman,[1] approaches the education of colorimetry from this perspective. Nearly 13% of the text revolves around the word "metamerism".

The second application is color reproduction where the goal is to achieve a metameric match. By varying the amount of three or four colored primaries, one tries to match metamerically all natural and man-made colored stimuli. Quality corresponds to achieving a metameric match. This is known as trichromatic color reproduction. Another introductory textbook, Measuring Colour, written by Hunt,[2] devotes less than 1% of the text to the word "metamerism". Billmeyer[3] in his review of *Measuring Colour* stated that, "But I cannot help adding the comment that I don't see how one can write a whole book on colorimetry without mentioning metamerism except for a one-page treatment under 'Miscellaneous Topics' two-thirds of the way through." I might argue that a color text designed for a color reproduction audience devotes most of the text to metamerism, except it is disguised as trichromatic color reproduction.

Certainly Billmeyer and Hunt are both eminent in color science. Yet imagine a novice colorimetrist reading both texts to become better educated. How can they possibly have the experience and perspective to understand why each author has treated metamerism differently, particularly when metamerism is the theoretical basis for colorimetry? This dichotomy has existed for decades where both orientations have coexisted seemingly in complete contradiction without undue alarm or agitation. As the 1990's progress, this historical dichotomy is becoming problematic. Suddenly, there is a need to understand both applications, and as a consequence, understand both perspectives. This need has arisen with the emergence of computer color imaging where color is represented and transferred between media with very different properties. As educators, we must insure that the theoretical principles are understood so that our students can apply their knowledge to any color device. By stressing the commonalities, confusion exemplified by the metamerism example should be minimized.

Color scientists and engineers are not the only colorists in need of a more global approach to color education. Graphic designers and artists also require a knowledge of colorimetry as applied to computer color imaging. For example, the design-oriented publication *Step-By-Step Graphics*[4] contains articles where colorimetry is used for device characterization and the standardization of lighting.

As an educator, I have found myself in the midst of the collision between what I will label the formulation technologies, the imaging technologies, and the design technologies. As the Richard S. Hunter Professor in Color Science, Appearance, and Technology, the Director of the Munsell Color Science Laboratory, and Coordinator of the Master of Science degree program in Color Science, it is my responsibility to first understand these different perspectives, and second, to educate for academia and industry the theory and application of color science in view of the explosion of color imaging.

THE NEED FOR A GLOBAL APPROACH

Why does the formulation technologies require an understanding of trichromatic color reproduction? Why is the Principles of Color Technology text insufficient? Color scanners, electronic cameras, CRT displays, and non-impact printers are being used to simulate the material world for purposes of design, quality control, and computer colorant formulation. Many formulation systems offer on-screen display of the proposed formulation relative to the standard for a variety of illuminants. I am often asked whether this is accurate and whether this has any engineering value. In order to answer these questions, a greater understanding of colorimetry is required than often presented when the primary application is the coloration of materials. To understand how to colorimetrically characterize a CRT display, one needs to know how to perform primary transformations. To adequately use CIELAB for quality assurance, one does not.

In color reproduction, an understanding of computer colorant formulation is very useful in colorimetrically characterizing a color printer. Recently,[5] Kubelka-Munk theory was applied to the color modeling of an ink-jet color printer. Nearly all the references were from the coatings and polymer industries. A master's thesis is underway in our laboratory where we are doing similar research. My background in the formulation of carpet color has been very beneficial in the modeling of color printers.

To effectively design on a CRT, it is useful to understand how color is formed on both a CRT and a printer and to understand differences in color gamuts. This requires knowledge resident in both the formulation the imaging technologies.

Suddenly, students interested in studying color science at the graduate level need to understand color at a greater depth and scope. This need is magnified within our programs. Our historical constituency has been the formulation technologies. The Munsell system has been embodied in paint and textiles. Color measurement instrumentation is usually designed for the quality control and formulation of colored materials. Most of the members of the Munsell Foundation Advisory Board were formulation oriented. (The Munsell Foundation was dissolved in 1983 to establish the RIT Munsell Color Science Laboratory.) Richard Hunter had the greatest impact in applying colorimetry and glossimetry to the coloration of materials. Today, our constituency also includes color imaging technologies. Our program is within the RIT Center for Imaging Science. Most of our research uses imaging devices and many of our findings are of greatest applicability to imaging companies. This fortunate, albeit sometimes frustrating, synthesis of technologies has placed us in an excellent position to provide education that will well serve students studying with us into the next century.

MASTER OF SCIENCE IN COLOR SCIENCE

Obviously, we cannot teach every topic encompassing color science. We have focussed our curriculum to insure our students have the necessary theoretical framework and practical experience to deal with emerging color technologies as well as traditional technologies. Our facility supports this focus with traditional colorimetric instrumentation and a variety of computer color imaging systems. Six color science courses are offered. These courses assume undergraduate knowledge of calculus, physics, statistics, C programming, and the ability to write technically and orally communicate. In addition to color science courses, electives are taken; specifics depend on the student's interests and long term objectives. The majority of course work is completed during the first year of study. During the second year, a research thesis is performed.

COLOR SCIENCE COURSEWORK:

Vision and Psychophysics: An overview of the human visual system and psychophysical techniques used to investigate it. Topics include: the optical design of the eye; mechanisms of photoreception; neural coding; processing of visual information; and experimental techniques. (Includes laboratory.)

Applied Colorimetry: The CIE system of colorimetry is presented with an emphasis on its practical application to common problems in quality control, color reproduction, and electronic imaging. Topics include spectroradiometry, spectrophotometry, colorimetry, colorimetric transformations, color appearance specifications, and device independent colorimetric characterization. (Includes laboratory.)

Theory of Color Measurement: Fundamental research leading to modern color measurement techniques is presented. Topics include principal component analysis of daylight, instrumental geometries, measurement and derivation of color matching functions, color appearance, color difference, metamerism, and computer colorant formulation. (Includes laboratory.)

Color Science Seminar: A seminar course in which the students will study the literature in particular areas of color science and lead in-depth discussions.

Optical Radiation Measurements: An in-depth treatment of the instrumentation and standardization required for accurate and precise measurements of optical radiation. Topics include optical properties of objects and radiation sources and optical and electronic design of spectroradiometric and spectrophotometric instrumentation. The laboratory is heavily stressed with students fully analyzing the design and performance of various instruments.

Color Modeling: Mathematical techniques for predicting the coloring of various imaging systems including self-luminous displays, non-impact continuous-tone color printers, and color scanners. Emphasis is placed on both analytical-physical and empirical-phenomelogical approaches. Statistical techniques include multiple-linear regression, non-linear optimization, and three dimensional interpolation. Accompanying laboratory stresses the characterization, calibration, and prediction of various imaging devices in a systems approach.

CONCLUSIONS

I believe that to effectively contribute to the science of color with today's emerging color devices, we need to insure that our students have an outstanding theoretical framework from which to draw upon. Students also need to experience applying theory to a variety of color technologies. Ultimately, our success in color science education depends on a dynamic and intensive interaction between academics and industrialists.

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CREATIVE COLOUR COMMUNICATION

Eva Fay and Prue Leith

School of Colour and Design, Sydney

INTRODUCTION

We would like to take this opportunity to say how pleased we are to present our "Creative Colour Communication" from the School of Colour and Design.

"We are not here today to talk in great detail about Colour Education as such, but rather to illustrate and describe the uniqueness of our School of Colour and Design. Naturally enough, we do follow a very organised, systematic structure in our colour teaching based on the three dimensions of colour - namely Hue, Tone and Chroma.

As we are "preaching to the converted" in a lot of respects, we do not intend to describe our syllabus in great detail. However, we would like to explain our philosophy in regard to our subject today - "Creative Colour Communication".

Our major task is to teach, both amateurs and professionals, to gain a complete understanding of colour mixing, analysis and organisation. To solve problems with colour effectively and to use colour creatively in a wide range of media and applied to as many different disciplines as possible.

We are quite different from other schools in Australia in that we specialise in teaching Colour and Design. But within the specialisation, the key to our success is the widespread application of our teaching to many different skills, technical usage and subject areas

In our certificate course, the initial period of learning about colour is done with pigment, as paint is the easiest and most accessible media at that stage. Once students are confident using subtractive colour mixing, they are then exposed to additive or light colour mixing.

As you will see in the slide presentation to follow, the students are taught to experiment fully with a wide range of media, including new man-made fibres, paper, board, clay, fabric, acrylic, plastics and natural materials.

Our course covers all disciplines of design as the basic elements and principles in our syllabus can be adapted to all areas of art, craft and design.

Colour is applied to projects including textiles, furniture, jewellery, painting, interior and graphic design.

In this way, our school follows the multi-discipline theme of the Bauhaus school established in Germany in 1919.

Our students are prepared for the real word of colour - commercially and in fine art, in that they are exposed to all aspects of colour usage.

Advanced projects include the design and colour work for theatrical stage sets and the construction of three dimensional sculptural forms such as furniture. In these projects, the problems of different colour surfaces and the impact of lighting are tackled.

Market Research into current trends in colour as well as the psychology and symbolism of colour are included in our course.

We bridge the gap between industry and education with our annual Design Awards sponsored by leading design companies in Australia.

Our aim is to produce independent colourists and designers with an individual style of their own - we do not encourage a "School of Colour & Design" Style - unless it is of a contemporary image which, after all, should be in a state of change to be healthy!

The fact that our course is part time comes as a surprise to some people. But our school depends on the dedication and self discipline of the individual.

Students in other schools studying, say, interior design, receive as little as 24 hours of colour work in their entire curriculum. Our specialisation enables us to concentrate an intensive and extensive colour mixing and experimentation in over 1,000 hours of colour classes per year. This means that our students build up a vast knowledge and large portfolio of colour work in their first year alone, dealing with a variety of colour systems including the Swedish Natural Colour System.

Throughout our 2 and 3 year certificate courses, we have a careful balance between an analytical and an emotive approach in our teaching.

The cross-referencing of Left and Right Brain functioning is very important to us.

Students are encouraged to work conceptually in most unusual (and sometimes strange!) ways, but to document all their ideas and processes to form a cohesive understanding of each project and to achieve successful, high standard results and design solutions.

We would now like to present to you an overview of work done at our schools and we welcome comments and questions later in the session.

NORDIC INTEREST IN COLOUR - RESEARCH AND EDUCATION

Lars Sivik

Dept. of Psychology, University of Goteborg, Sweden

In an historic retrospect for sketching a background to my paper, Nordic colour research, it is very appropriate to begin with the Finnish-Swedish priest Sigfried Aron Forsius, whose great interest, besides his profession (I suppose), was colour. His colour order system from 1611 was perceptually based, for the simple reason that there was no other way to "see" colour at that time. This was before the discovery of wavelengths and energy quanta which, when it came, was to confuse the psychological science of colour for such a long time - and the fact that colour is what we see.

But actually it was not Forsius who was the impetus to interest in colour in Sweden but rather a physicist from this century, Tryggve Johansson. In the fifties, Johansson came across Ewald Hering's books from 1878 on the yet unaccepted opponent-colour theory and Natürliches Farbensystem. With Hering's model as a basis, Tryggve Johansson formed the first Swedish version of The Natural Colour System - but for some obscure reasons he abandoned Hering's concept of blackness and whiteness as constituent colour parameters and yielded to Munsell's and other's concept of lightness.

Johansson also wrote a number of books on the subject of colour systematization. Before his early death in 1960, the Natural Colour System was already being taught in schools at all levels. Since that time a variety of colour interest organizations have regularly arranged colour courses. Today they are offered primarily by the Scandinavian Colour Institute.

An architect friend of his, Professor Sven Hesselgren, realized the value that a universal colour atlas would be to architects and designers of all kinds in their creative work. Using Tryggve Johansson's version of Hering he produced the Hesselgren Colour Atlas which was soon employed by all architects and designers in Sweden.

Hesselgrens Colour Atlas was an admirable work, accomplished by Sven Hesselgren almost single-handedly, but the number of colour samples contained in the atlas was soon considered insufficient. With grants from industry and government an institute was set up in 1965 for the exclusive purpose of updating Hesselgren's atlas by increasing the number of samples. During this work the head of the institute, Anders Hård, and his collaborators encountered difficulties and found some theoretical contradictions. These problems were found to stem from Johansson's violations of Hering's parameters. It was decided that a return to the original theory (with the whiteness- and blackness-parameters instead of lightness) was required - and in 1969 the prototype of the current NCS Atlas was ready.

Today NCS is the national standard in Sweden and is used for colour appearance notation in an increasing number of major companies and countries.

The NCS Atlas is published by the Swedish Standards Organization and sold through The Scandinavian Colour Institute. The Scandinavian Colour Institute also provides, for instructional purposes, sets of colour samples and colour exercises dealing with the perceptual colour space, colour combination theory and practical applications for environmental colour design.

Since 1970, the year that the initial development of the NCS Atlas was completed, the Swedish government, and in particular the Swedish Building Research Council, has provided financial support for further research on problems of colour appearance - both general and applied in architecture and design. In addition to the continual revision and control of the atlas, this work has involved a variety of colour problems, some of which derive directly from the development of the NCS colour assessment and reference system.

The NCS is, in addition to being a colour reference notation system with an exemplifying atlas, principally a colour assessment system based on the six unique colours, or as they are called in the NCS, elementary colours. This assessment method is applicable in a variety of colour problems which cannot be solved in any other way than direct assessment of colour appearance.

One of these problems concerns the colour rendering properties of different light sources. In a series of experiments by Anders Hård and the present author the NCS colour assessment method was tested and found valid. The method is quite straightforward: each colour is judged by a number of subjects under each lighting condition, the ratings are averaged, and the averages are then plotted in the colour triangle. The changes in colour appearance can easily be illustrated in a graphical colour model (these experiments are discussed elsewhere at this conference).

The same kind of experimental design can also be applied in experiments dealing with other kinds of colour changes resulting from variations in viewing conditions, such as viewing distance.

We have also used this colour assessment and reference system to see how colour surfaces change appearance as a function of area size. We have found that the common belief, that the apparent strength of chromaticness increases with size, is not generally true.

Colours never appear alone, but always in combination. It is for this reason that one of our principal interests has concerned colour combinations. As the number of possible combinations is countless a first step in approaching this area of research must be to establish a language, or a model, for describing a colour gestalt composed of many colours. Again Anders Hård has been the primus motor in this work and the tentative model we presented in 1975 had the following dimensions and sub-dimensions:

- Interval
  - Distinctness of border
  - Kind
  - Size
- Colour chord
  - Complexity
  - Content
  - Type
- Tuning
  - Colour similarities
  - Area relations
  - Rhythm

Since that time the colour combination model has been used extensively in the Nordic countries in schools of design and architecture and in colour courses arranged by the Scandinavian Colour Institute. One of the sub-dimensions represents an area which has received a good deal of research interest, namely the phenomenon of colour contrast or colour difference.

Our approach has been to investigate the phenomenological multi-dimensionality of colour contrast and to relate the relative weights of the various difference parameters to the phenomenon of distinctness of border, which is one of the subdimensions of contrast. We have also studied the role of colour contrasts in the perception of complex colour gestalts and colour chords.

The NCS is one of many possible ways to describe colours. Ewald Hering called it "natural", probably because he noticed that people around him used the six elementary colours as a common denominator to describe all colours. But there are also other generic colour names and terms beside these six. The common colour names, which Berlin and Kay and others before and after them have identified are around a dozen and they are thought to represent specific cognitive categories. A number of studies claim that they are universal, that is, that their corresponding lexical terms in different languages represent the same colour areas in a colour space. This has not yet, however, been investigated properly from the view-point of colour research (Berlin and Kay's study is an excellent linguistic study but it is too vaguely anchored in a colour reference system).

Already in the seventies we mapped out the borders and focal areas of the most common colour categories and illustrated the results in the NCS colour space.

We have recently received grants for comparative studies to further investigate the universality of the common colour categories (and we hope to find collaborators during this conference). Our aim is to make corresponding mappings in the NCS for a number of languages in order to compare the focal areas and borders of the colour category terms. We are convinced that we will find considerable concordance among the various cultures - but we also expect deviations. Some languages, for example, have two or more names for a colour area while others have only one for the same area.

Now a few words about my own main interest, namely the meaning and semantics of colours and colour combinations. We made our first data collections over twenty years ago. The methods we used then, derivatives of the semantic differential, were not new nor was our use of factor analysis, a statistical means for reducing the number of possible dimensions of meaning. However, what was new with our first studies was firstly, that we had better control over colour appearance parameters and secondly, our use of the iso-semantic maps of meanings, which have been presented at many AIC conferences since that time, by both myself and others.

As our main source for research grants is the Swedish Building Research Council, we have also studied actual colour environments for comparison with laboratory data on the perception of and attitudes to colours. The question of generality in people's cognitive and emotional colour meaning structures is a very complex one and constitutes in itself a whole area for scientific research. As a general conclusion from our investigations it can be pointed out that some variables of colour meaning are rather general and the same for all contexts, while others change dramatically depending on the context. An orange colour appears warm regardless of whether it is on a house or a piece of paper - but it can be ugly in one place and pretty in another. But context in itself is multidimensional - one kind of colour context is the colour or surface material, which of course influences the psychological correlates of colour meaning and preference. There is obviously no risk for a colour researcher in this field to run out of problems.

In Lund, Sweden's oldest university city, Rikard Kuller leads another environmental research unit which is also involved in the study of colour. In particular their interest has centered on the controversial question of whether coloured environments influence physiological activities such as blood pressure, skin sensitivity, heart rate and so on. A Swedish/British collaboration project is presented by Byron Mikellides at this conference.

Another area of applied research which has been probed rather extensively in Sweden is that of colour on the computer screen. Gunilla Derfeldt and her co-workers at the National Defence Research Institute have, during the course of many years, studied visual ergonomic aspects of the use of colour in this medium. They have also developed a computerized colour atlas based on the NCS, CIELUV and CIELAB colour order systems.

While Derefeldt's system is derived from the physical measurements of colour, i.e. transformations RGB values, Gunnar Tonnquist, at the Royal Institute of Technology in Stockholm, has developed a perceptually based computerized NCS atlas. The atlas consists of display colours which were perceptively matched against NCS colour samples.

Another aspect of colour meaning that we have begun to look at concerns the question of how similar people from different countries are in their associations to colour. Are the same colours considered warm and cold in all nations? Is a colour which is considered cultured in Sweden also cultured here? Tomorrow I will go into greater detail on this matter and present some preliminary results from a cross-national comparison study of colour meaning.

Still another aspect of colour meaning, and what we consider the most interesting, concerns colour combinations. Not only are there an almost infinite number of possible combinations, but there are also a large number of different meanings. We started therefore to study if there is any general semantic space associated to colour combinations. We factor analyzed data on 130 semantic variables like cold-warm, active-passive and so on that we had collected and were able to identify a smaller number of semantic dimensions. This is virtually a semantic space for colour combinations, a space composed of six dimensions. But without violating its structure too much the space can be represented in two dimensions as in this figure. In the picture we have also illustrated which colour combinations are associated with the various parts of the space.

In comparison to colour researchers in many other countries, I think that Swedish colour researchers have been unusually lucky in that we have had very understanding and interested financial backing. Besides the Building Research Foundation, the Work Environment Fund has provided research grants to study the effects of colour and light in industrial environments and, as late as last month, it was decided that the paint manufacturers and the painting contractors in Sweden would support colour research - particularly research concerning the visual and appearance properties of colour materials in various environments. The only problem that we see now is how to recruit new and more colour researchers. The multidisciplinary field of colour is, after all, quite difficult- and yet so self-evident and easy.

For references we refer to our original articles which can be sent on request.

ABSTRACT ONLY

THE TEACHING OF LIGHT AND COLOUR IN SCHOOLS OF ARCHITECTURE

Marla L F. de Mattiello
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The experience made in four consecutive years teaching the subject and the observed difficulties, specially due to the progressive disminution of the perceptive attitude of the student, are commented. Trying to solve these difficulties, the strategy put into practice to help the students pass from the rational comprehension of objects to their subjective comprehension is discussed. We place special emphasis on the subjective comprehension because it allows to put the student into contact with his personal imagery, in other words, with fantasies and illusions. These fantasies and illusions allow him to communicate with the objects and in this way create new experiences and observations. The subject is illustrated by students' pieces of work where it can be observed the development followed from the formulation of the subject of study to its conclusion in a concrete proposal.

COLOUR NAVIGATION

E. Maxwell-Smith

INTRODUCTION

Artists usually restrict themselves to a limited palette from which all other required colours are mixed. Knowing the appropriate position of these colours in a colour space based on measurable units of chromaticities, makes the mixing of paints a process of common sense rather than the hit and miss approach practiced by many.

In a paint, the colour of pigment is influenced by the binder used in the system. To stay as close to the true colour of pigments as posible, a gouache style paint was prepared for all the experiments described in this paper. Gouache is a paint system that after drying, resembles the original pigment colour. The evaluation of colour is also subject to the type of illumination used in the test. Subjective colour assessments were made under standard daylight conditions, while all colorimeter readings were taken with D_{65} as the nominated illuminant.

The design of a mixing guide for typical artists' colours has to take into account that colours are seen in three dimensions. The mixing process of colours is not easily plotted on a flat projection like paper.

GREY SCALE

To see a Euclidean colour space in the right context, the core, or the neutral mid grey has to be established first.

Using the CIE-LAB mode of colour measurement, the test white paint had a L* factor of - 98 and the carbon black - 18. The grey scale based on perceived regular intervals, will have the following L* readings: 98-90-82-74-66-58-50-42-34-26-18.

TABLE FOR OPTICAL MIXING DISK - GREY SCALE

A	B	C	D	E
Grey scale	L* value	Y factor	Black %	Degrees
White	98	95.28	0	0
Grey - 9	90	76.40	20	18
Grey - 8	82	60.80	37	33
Grey - 7	74	47.00	52	47
Grey - 6	66	35.52	64	58
Mid grey	58	26.26	74	67
Grey - 4	50	18.50	83	75
Grey - 3	42	12.66	89	80
Grey - 2	34	8.26	94	85
Grey - 1	26	4.94	97	87
Black	18	2.54	100	90

Column B indicates the metric L* value. Column C indicates the actual reflectance from which the percentage of black was calculated in column D. Column E shows the degrees of black (L* 18) paint for each quarter circle painted on a white (L* 98) cardboard disk.

Taking a leaf out of Ostwald's book, a flat circular cardboard disk can be designed which, on rotation, will optically mix the black and white sectors painted on the disk, into greys with values coinciding with the L* readings from the grey scale schedule.

COLOUR NAVIGATION CHART

The colour space can be presented as a extended polar gnomonic projection. The space is flattened with the south pole (black) placed in the centre of the chart and the parallels of latitude (grey scale) represented by ever increasing size circles. The opposite pole (white) is represented by the largest outer circle. This flat earth approach allows the placement of the palette colours on the respective meridians (hue) and latitudes (value).

HUE

By using the CIE-LAB co-ordinates, it is possible to locate the appropriate position for any colour on the radials of of the circle. Finding the correct positions of the palette colours makes more sense than mixing colours to fit a set of so-called "ideal" positions, as is usually the case with the conventional colour wheel.

With the assistance of a plotting chart (a standard graph paper) the horizontal and vertical lines become the a and b axes of the CIE-LAB coordinates. The radials, drawn centre of the chart at 10° intervals, will convert the a* b* co-ordinates to the designated hue radial.

At this stage it may become obvious whether the selected palette presents unwelcome gaps or duplicates colours unnecessarily.

Although more exact specifications are necessary for paint matching purposes, artists generally only need a reliable guide to the chromaticity tendencies in the range of colours for mixing purposes.

VALUE

The lightness of a colour is determined by the total reflectance of light coming from the surface of that colour and is referred to as the colour's value.

After the value or the light reflectance of a colour is matched to a comparable value of one of the greys in the ntioned grey scale, a spot of this colour placed on the respective radial and value ring of the colour navigation chart.

White or black paint can be mixed with the full strength sample colour in order to come up with a range of colour values identical to the values of the remaining greys. Although colours mixed with black or white will not necessarily be perceived as the same colour, they could be placed on the same radial.

A true monochromatic scale of values can be simulated by means of an optical mixing disk like the one grey scale.

The relevant proportion of white, black and coloured areas are painted on the disk. Each completed disk will on rotation optically mix a complete monochromatic scale of values identical to the values of the greyscale.

SATURATION

The CIE-LAB colour coordinates also determine the position colour related to the central shaft of the space. The distance measured from the neutral centre indicates the colourfulness or saturation.

The saturation of a paint is bound by its lightness. A colour can be desaturated without altering its value (by adding a grey or complimentary colour of the same value), but we can not change the value without changing the saturation.

The whole question of specifying the saturation level of a colour is rather academic. The maximum saturation of a paint, so far as artists are concerned, is equal to the saturation of that colour as it is squeezed out of the tube. Any admixtures of other colours will effect the hue and most likely reduce the saturation.

When a paint is made lighter with the addition of white it becomes less saturated. However, the mixed colour is still the maximum saturation possible for that paint at that value. Therefore, the tube colours, adjusted with white and black to complete the value scale, become the outer limit of the colour chart.

To represent the movement of colour from this outer limit towards the neutral grey of the diminishing dots of the gradual desaturating colour are placed within the larger spot of the full colour.

The gradual desaturation of a colour towards the neutral grey of the same value can be demonstrated with another optical mixing disk. The design of the disk follows the principles of the Oswald monochromatic triangle which takes into account a diminishing chromatic component in equal steps.

The colour chart, once fully developed, will principle of seeing colour in three dimensions. It will also clearly show which tube colours should be mixed to reach the unoccupied spaces.

LOCALISED ENVIRONMENTAL COLOUR PALETTE

Peter Day

PART A

1. INTRODUCTION

I've been an artist for 25 years, in the last 12 or so I've mainly worked with Communities ie. Schools, Universities, Local Councils, Government Departments etc. to create Public Works of Art. Some of these have had a large community participation component yielding projects like sculptures playgrounds and murals. I often have to teach skills within the communities to get the results that they want.

As such an Artist I was invited to be the inaugural scholar in residence at Eltham College in Victoria, a private school in semi rural surrounds.

Part of my initial research within the college yielded the information that the kids didn't know much about colour, and didn't appreciate the concept of environmental colour harmony. Also the school Administration didn't consider the students colour preferences at all in the design of the school.

The "Eltham palette" or the localised environmental colour palette project came out of the idea of bringing the views of the school administration and pupils closer together, and finding a consensus about school colour schemes. The kids said 'school needs colour'. From talking to the students it was obvious that they didn't have an awareness of the subtlety of colours especially those that occurred naturally. The local bush to them was just all green - not even grey green. They didn't seem to have a sense of the beautiful array of colours and colour schemes that occurred in the bush probably because in Australia non-tertiary colours often only occur in very small spots and quantities - like flowers etc. It seemed valuable to design a project that would encourage students to view the bush in a way that would yield the subtlety and beautiful array of colour that did exist. It also seemed valuable to take this proposed new view further by using it in an 'environmental sense', by creating a tool to help provide an harmonious visual environment in Eltham.

2. BACKGROUND

There are cities such as Venice that legislate for colour control so that unthinking residents can't paint facades in just any colour, but only in a prescribed range of colours that relate to Venice in an historical, geological, geographic and cultural sense.

There are lots of other examples of legislation and advisory groups throughout Europe eg. Turin Italy and Salem Mass. in the USA. This type of work has been occurring since the early 1800's. I certainly wouldn't be one for advocating legislation in Australia, but the provision of a free a given area is a powerful tool for the development of an idea, that of harmonious colour schemes in our environment, and providing an alternative to Heritage colours or post-modern pastels.

3. PROCESS

At Eltham College the schools founder is also the schools architect. He is very well respected and successful, his use of colour in the school is very restrained. The students thought that he needed a 'colour sense transplant' and they would donate their colour schemes. The Eltham Shire Council became interested in this project and decided to put the final details of the "Eltham palette" in a new residents kit.

The process of the project was:- (I won't apologise for my lack of scientific method here - we were having fun) hundreds of samples of naturally occurring coloured objects were collected by sending groups of junior school pupils out on forays into the local bush to find 'Reds" or Blue-Greens etc. The groups were given specific colours to look for. The samples were sorted into 14 colour groups. The collected samples comprised of tree bark, earth, sand, rocks, leaves, flowers, mosses, timbers, nuts and seeds, grasses, paint samples from an old house (that a well known environmentalist and artist used to live in), a dead yabbie and other naturally occurring coloured objects like coke cans, chip packets and reflector lenses from car tail lights. 120 different colours were isolated and colour matches with international standards were found for 96 of these colours. The colour standards used were the Munsell Colour System colours for plant tissues and soils, the Australian Standard and the British Standard

Of these 96 colours 65 were matched with colours available through Taubmans Spectrum Paint Handbook, 31 colours were not able to be matched.

Of the 65 available through Taubmans 34 were found to have an existing standard code and were readily available with colour swatches.

The other 31 colours were available (having a ready formula) but had to be mixed to obtain a brush out or colour swatch, which Taubman did for us.

As there appeared to be a relatively even distribution of numbers of hues through most of the 14 colour groups I decided to limit the palette to what was available through Taubmans at the time. So the Eltham palette comprised 65 naturally occurring colours from which to choose colour schemes.

These were: 7 reds, 5 oranges, 5 pinks, 3 ochres, 4 yellows, 1 yellow green, 5 greens, 4 blue greens, 10 browns, 1 black, 3 whites, 2 violets, 7 blues and 8 greys.

As you can see the palette is a bit light on in yellow greens and violets. Interestingly enough in examining those 31 colours not readily available through Taubmans there were 6 yellow greens and 6 violets - (maybe Taubmans don't have many yellow greens or violets in their range).

4. RESULTS

On my second visit to the school, I organised to take the project further and get the students to arrange some colour schemes from the 'Eltham palette'.

I deliberately didn't say much about my views on colour schemes to the students except for that we talked about the harmony of colours with the natural and the school environment. I was interested to see what they would come up with on their own. However I did encourage them to 'feel' if the colours were right and to go outside to see if the colours worked in the environment.

Obviously there would be a lot of forces already at play in their choice of colour schemes. The students were asked to create one exterior and one interior colour scheme for the school, a suggested approach which was not mandatory, was to choose 3 colours - a major colour, a minor colour and an accent. About 66 individual colour schemes were created 33, interior and 33 exterior.

The colour schemes were displayed in the school and voted upon - the most popular were these ones shown:

Exterior #s	1, 2, 7, 15, 16, 22, 32, 35, 40.
Interior #s	50, 57, 60, 64, 67, 68, 69, 70, 77, 81.

I'm not sure if I know what the above means. Obviously in the hands of a professional colourist different results would occur. However by offering students a finite set of colours for selection with colour swatches readily available to mix and match, chop up and play with. I would like to believe that some extension of their existing colour sense must result.

The real value of the project is, apart from a heightened colour awareness amongst the students, is in that there now exists an 'Eltham palette', a range of colours that belongs to the immediate environment. It is an informed basis on which companies and individuals can be creative in bounds provided by a 'researched' (?????) environmental context.

PART B

FURTHER WORK

If I have time I would like to tell you about an extension of this project which has been taking place in Wollongong where I have undertaken the development of a new colour scheme for the City Mall. The colour scheme is based upon the colours that occur naturally in the various geographical zones that make up the area from the escarpment to the sea.

This area has been broken up into 5 different zones:

1. The escarpment
2. Rainforest
3. Woodland
4. Parkland and heritage
5. Coastal

The mall also has been divided into 5 different zones and colours are being chosen from each zone according to native flora. Spectacular examples of natural flora like the Illawarra Flame tree naturally command a leading role.

Here, I am working in a reverse manner compared to Eltham, establishing a theoretical context for a colour scheme and environment to fit. Here is the context of the colour schemes.

Instrumentation for Colour Measurement

ABSTRACT ONLY

KEYNOTE ADDRESS: INSTRUMENTATION FOR COLOUR MEASUREMENT

MAKING MEANINGFUL COLO(U)R MEASUREMENTS

Frederick T. Simon

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The marvel of modern technology that undergirds color measuremen~ is a development over the past 25 years that is almost beyond belief. Those of us who had suffered through the early days of colour science and have watched and sometimes participated in developments allowing us to handle color in ways what could hardly be imagined in the past. To my vlew five things have provided the plailorm for far better applications of color measurement in todays environment.

- increased knowledge about color science gained from research
- the economical microprocessor or personal computer
- much better color measurement instrumentation
- better computer programs for inlerpretalion of data
- graphical presenfation of color information

Today there are tools available to anyone who has the price to pay for them. Unfortunately such tools are sometimes sold for their glamorous superficialities to those who see them as an answer to immediate problems without realizing that they are <u>only</u> tools that can be misused. What is most needed to benefit from this elegant equipment is adequate training of the operating personnel and thoughtful understanding of its limitations on the part of those who must take aciion based on the reported data. At the center of any application of technology is the training and dedication of the key people who use the equipment and evaluate the data. Once this need is properly satisfied to gain continued advantage from color measurements one musl take pains wilh certain deiails. Several relatively simple things must be done to provide the foundation for reliability

- know the repeatability of any instrument and its supporting system
- have regular calibration checks of the instnuments involved
- back and review old color measurements for long term behaviour
- perform regular and thorough maintenance on inslruments
- use color video displays of sample measurements to monitor data
- understand and use spectrophotometric curves
- <u>look at samples</u> not iust data

Some of these recommendalions are simple commonsense. However unless a commitment is made to pay attention to details and rigourously follow procedures any investrnenl in time or money can be wasted. What is even worse decision made on the basis of erroneous data can be very costly.

THE SENSITIVITY OF VARIOUS INSTRUMENTS IN THE MEASUREMENT OF SMALL COLOUR DIFFERENCES: A COMPARISON

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During the last two decades colour quality control has become more and more important for many industrial products; indeed, technological advances in electronics have made available quicker and easier-to-use colour measuring instruments, which are suitable for uses outside the laboratory.

Several models of spectrophotometers and colorimeters, each with its own characteristics and design, have become widespread in many productive sectors other than those traditionally concerned with colour control.

The fixing and respect of colour tolerances will undoubtedly become a relevant factor for the qualification and standardization of industrial products. The latest advances in the definition of a more uniform colour space will probably make this process easier, however, such a variety of available instruments and the shortage of standardization among them might, somehow, be an obstacle.

The purpose of this work was to find out to what extent the measurements made with different available instruments are comparable and correlated, particularly for small and medium colour differences.

With this aim, we planned to prepare painted samples by using paints of some basic hues which would be gradually modified by adding white or black paint; these panels would be measured with various colour measuring instruments.

The first step was the identification of the most adequate painting products; we decided to utilize saturated hues with the highest possible excitation purity and this search was very time-consuming, as we had to check many products on the market before finding those that were satisfactory and, at the same time, easy-to-apply.

Finally we chose acrylic colours of four different hues - permanent green light (Maimeri 991; pigments: phthalocyanine green, cadmium yellow light), cobalt blue (Liquitex 170; pigments: cobalt and aluminium oxides), cadmium yellow medium (Maimeri 967; pigment: cadmium yellow medium), naphtol red light (Maimeri 977; pigment: naphtol AS-OL) - to be cut with titanium white and ivory black.

We prepared, for each hue, seven cuttings by mixing white at geometrically progressive percentages from 0.125 to 8%. The same was done with black.

The cuttings obtained, as well as the original hue colours, were applied on metallic test panels by means of a film applicator, whose gap depth was 0.8 mm. After drying. the samples were kept in a dark place.

Measurements were made with the following spectrophotometers:

Gardner TCM and TCS; Hunterlab Colorquest 1400. Macbeth Color-eye 7000; Max-Meyer Duco Delta-E Crom. Minolta CM-1000. MTS SD Compact: Optronil. ColorDash and Perkin-Elmer Lambda 15 (equipped with a Perkin-Elmer integrating sphere).

The main features and operating conditions of these instruments are listed in Table 1. As can be seen two of them have a 45 (circumferential)/0 illuminating viewing geometry, while all the others are endowed with an integrating sphere for diffuse illumination or viewing (where possible the specular component was included). The other parameters present a certain variability, even though the prevailing values are 400 to 700 nm for wavelength range and 25 mm for measuring area diameter.

When the instrument's software comprised an averaging function, measurements were taken on three different points of each sample's surface and the mean values were used (this was the case for all the instruments, except Delta-E Crom and Lambda 15). Measurements were repeated on some samples in order to verify measurement repeatability and the reliability of the samples.

For each hue, colour differences (ΔE_{ab}^*) were calculated, by means of each instrument's software, between the original colour as a standard and the various white or black cuttings.

For reasons of space, in this paper we will display and analyze the data concerning green and blue.

Table 2 and 3 show colour differences between standard green and blue, and their white or black cuttings, measured with the various instruments. Sample codes are made up of one letter representing the initial of the color used, an eventual second letter indicating whether white or black was mired and a number of one or more figures indicating the percentage of white or black added In order to avoid identification of the instruments, they have been randomly named with a letter from A to I.

Generally, these differences showed a good repeatability, as calculated standard deviations were mostly under 0.05 ΔE_{ab}^* units and only in few cases were they higher than 0.1

At a first general look, colour difference values obtained by different instruments appear to be closer when the differences are smaller; indeed the absolute standard deviation rises with an increase in the mean differences (see Tab. 6). If we consider the more significant percentage deviation from the mean, we see that the most concordant results are obtained with medium and large differences. In general, it can be observed that, for similar difference values, green samples have higher percentage standard deviations than blue ones. Moreover, within the same hue, white cuttings present lower standard deviations than black ones - always referring to similar difference values.

We would also like to point out that, for three of the four sample sets, the decreasing trend of the percentage deviation seems to invert in relation to the highest differences. This might be confirmed if we reach higher percentages of white or black in our samples, and it could be the subject of further research.

In order to find out the degree of correlation of the data sets, linear correlation coefficients between the various instruments were calculated for green and blue samples (see Tables 4 and 5).

As can be seen, the degree of correlation is very high, and only one or two instruments present slightly lower coefficients. Best correlation coefficients are obtained for blue sample measurements.

It would be appropriate, in the future, to use more sophisticated statistical analysis, as well as to extend this research to include other hues. in order to systematically cover different colour space regions, and to take into consideration the comparison of instrumental measurements with visual evaluation.

TABLE 1

Main features and operating conditions of the examined instruments.

Intruments	Measuring geometry	Wavelength range (nm)	Measuring area diameter (mm)	Specular component
GARDNER TCM	45(circ.)/0	380-720	30	-
GARDNER TCS	d/0	380-720	25	included
HUNTERLAB Colorquest 1400	45(circ.)/0	400-700	25	-
MACBETH Coloreye 7000	d/0	360-750	25	included
MAX MEYER-DUCO Delta-E Crom	d/0	400-700	9	included
MINOLTA CM-1000	d/0	400-700	8	excluded
MTS SD Compact	d/0	400-710	25	included
OPTRONIK Colorflash	d/0	400-700	20	included
PERKIN-ELMER Lambda 15	0/d	380-780	1 x 10 (a)	included

(a) rectangular measuring area.

TABLE 2

Colour differences (ΔE_{ab}^*) between standard green (G0), green + white (GWxx), green + black (GBxx) cuttings, measured with various instruments.

	Instruments								
Pairs of samples	A	B*	C*	D	E	F	G	H	I
G0-GW0125	0.27	0.33	0.64	0.36	0.30	0.45	0.38	0.42	0.15
G0-GW025	0.31	0.36	0.74	0.38	0.29	0.46	0.59	0.69	0.32
G0-GW05	0.48	0.67	0.98	0.57	0.67	0.78	0.74	0.75	0.38
G0-GW1	0.98	1.12	1.29	1.09	1.08	1.14	1.13	1.34	0.72
G0-GW2	1.69	1.83	2.05	1.94	1.81	1.91	2.03	2.15	1.53
G0-GW4	3.04	3.37	3.61	3.46	3.16	3.31	3.31	3.42	3.08
G0-GW8	5.38	6.04	6.34	6.00	5.47	5.68	5.55	5.90	4.85
G0-GB0125	3.02	3.09	2.85	1.93	2.41	2.11	2.12	1.97	2.52
G0-GB025	5.34	5.72	5.65	3.63	4.74	4.93	5.03	4.63	5.25
G0-GB05	10.10	10.50	9.78	6.99	9.39	9.71	9.59	9.49	9.94
G0-GB1	16.49	17.16	16.31	11.47	15.47	16.18	16.14	16.07	16.28
G0-GB2	25.40	26.39	26.02	17.82	24.38	25.35	25.40	25.03	24.76
G0-GB4	37.00	38.91	38.50	25.80	35.67	37.34	37.83	37.12	35.58
G0-GB8	47.75	50.84	50.97	33.27	46.60	49.54	48.87	48.97	45.94

* these instruments have 45/0 illuminating/viewing geometry.

TABLE 3

Colour differences (ΔE_{ab}^*) between standard blue (B0), blue + white (BWxx), blue + black (BBxx) cuttings, measured with various instruments.

	Instruments								
Pairs of samples	A	B*	C*	D	E	F	G	H	I
B0-BW0125	0.62	0.57	0.30	0.45	0.40	0.34	0.46	0.52	0.21
B0-BW025	0.84	0.83	0.71	0.85	0.75	0.71	0.85	1.10	0.58
B0-BW05	1.71	1.78	1.62	1.70	1.72	1.73	1.79	1.75	1.55
B0-BW1	3.03	3.11	2.90	2.82	2.78	2.82	2.93	3.02	2.33
B0-BW2	5.07	5.20	4.99	4.80	4.79	4.92	5.00	5.34	4.48
B0-BW4	8.78	8.80	8.60	8.17	8.45	8.62	8.68	9.07	7.65
B0-BW8	13.57	13.73	13.51	12.31	13.03	13.39	13.49	13.94	11.92
B0-BB0125	3.78	3.68	3.74	5.04	3.69	3.84	3.58	2.93	3.92
B0-BB025	6.92	6.85	6.94	8.89	6.54	7.09	7.13	6.12	6.97
B0-BB05	12.92	13.05	12.92	16.31	12.97	13.20	13.44	12.22	13.15
B0-BB1	18.32	18.40	18.09	22.23	18.20	18.53	18.93	17.50	18.11
B0-BB2	25.86	26.00	25.62	29.82	25.76	26.09	26.50	25.11	25.00
B0-BB4	32.80	33.11	32.51	35.80	32.65	32.86	33.38	32.22	31.31
B0-BB8	38.00	38.73	37.89	39.64	37.77	37.92	38.49	37.42	35.73

* these instruments have 45/0 illuminating/viewing geometry.

Table 4: Correlation coefficients (r) calculated for values in Table 2.

	B*	C*	D	E	F	G	H	I
A	0.9999	0.9993	0.9981	0.9998	0.9995	0.9996	0.9993	0.9999
B*		0.9997	0.9984	0.9999	0.9997	0.9997	0.9996	0.9997
C*			0.9985	0.9998	0.9999	0.9998	0.9998	0.9989
D				0.9986	0.9984	0.9984	0.9986	0.9977
E					0.9999	0.9999	0.9998	0.9996
F						0.9999	0.9999	0.9992
G							0.9999	0.9994
H								0.9990

* these instruments have 45/0 illuminating/viewing geometry.

TABLE 5

Correlation coefficients (r) calculated for values in Table 3.

	B*	C*	D	E	F	G	H	I
A	1.0000	1.0000	0.9941	0.9999	0.9999	0.9999	0.9994	0.9989
B*		0.9999	0.9934	0.9999	0.9998	0.9998	0.9995	0.9987
C*			0.9940	0.9999	0.9999	0.9998	0.9993	0.9990
D				0.9949	0.9953	0.9954	0.9901	0.9979
E					0.9999	0.9999	0.9991	0.9993
F						1.0000	0.9989	0.9994
G							0.9989	0.9994
H								0.9969

* these instruments have 45/0 illuminating/viewing geometry.

TABLE 6

Mean and standard deviation for differences measured with various instruments.

		Standard deviation	
Pairs of samples	Mean	absolute	% on mean
G0-GW0125	0.37	0.13	34.83
G0-GW025	0.46	0.16	35.17
G0-GW05	0.67	0.17	24.90
G0-GW1	1.10	0.17	15.34
G0-GW2	1.88	0.18	9.61
G0-GW4	3.31	0.18	5.30
G0-GW8	5.69	0.42	7.31
G0-GB0125	2.45	0.43	17.37
G0-GB025	4.99	0.60	11.96
G0-GB05	9.50	0.94	9.92
G0-GB1	15.73	1.56	9.93
G0-GB2	24.51	2.43	9.92
G0-GB4	35.97	3.75	10.42
G0-GB8	46.97	5.11	10.87
B0-BW0125	0.43	0.12	28.94
B0-BW025	0.80	0.14	16.86
B0-BW05	1.71	0.07	4.24
B0-BW1	2.86	0.21	7.50
B0-BW2	4.95	0.24	4.77
B0-BW4	8.54	0.39	4.58
B0-BW8	13.21	0.64	4.81
B0-BB0125	3.80	0.52	13.56
B0-BB025	7.05	0.71	10.13
B0-BB05	13.35	1.09	8.17
B0-BB1	18.70	1.30	6.95
B0-BB2	26.20	1.35	5.17
B0-BB4	32.96	1.15	3.48
B0-BB8	37.95	1.00	2.64

A MODULAR DESIGN SMART COLORIMETER

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1. INTRODUCTION

There are many colorimetric applications where the colour has to be determined under real, non-standard conditions of illumination. The CIE has published a method for predicting corresponding colours with a change in chromatic adaptation [1] that could be used to transform colorimetric data obtained under one illuminant to those determined for a standard illuminant. To our best knowledge there is no colorimeter available that would supply this transformation as a built-in feature.

It is also difficult to find a portable field instrument where other colorimetric calculations (e.g. brightness to luminance corrections [2] are incorporated in the evaluation program, or where computation routines can be changed easily for adaptation to a particular application (see e.g. [3]).

We have set us the task to construct a modularly built colorimeter that will permit both "illuminance" and "luminance" type viewing conditions, will permit easy adjustment of evaluation routines lo the special requirements of the user and will be flexible enough to perform measurements in the field where no main supply is available, without the loss of the computational convenience of a freely programmable PC.

With current progress in manufacturing tristimulus colour correcting filters we have decided to use tristimulus techniques as opposed to spectrometric ones and to construct the light sensing measuring head by adding enough intelligence to this part of the instrument to deal with the instrumental corrections of the raw measuring data (zero-correction, averaging, correcting for range changing errors, etc.) and feeding the data via an RS-232 line into a lap-top PC for data manipulation and storage.

2. CONSTRUCTION OF THE COLORIMETER

2.1 Block diagram crf the colorimeter

The central part of the colorimeter is the smart sensor consisting of a Si-photoelement, an operational amplifier, an A/D converter and a microprocessor unit. All these parts are located in the measuring head, the block diagram of which is seen in Figure 1. The Si-detector receives the light input from the input optics unit. The output of the detector is coupled to an operational amplifier, the feedback resistors of which are switched by the microprocessor. The amplified signal is fed to an A/D-converter, the output of which is read by the microprocessor. The microprocessor senses not only the optical signal, but receives information from the input optics on the type of the optics (illuminance or luminance measuring geometry), the filter in use and the temperature of the sensor. The microprocessor communicates via an RS-232 line with the lap-top personal computer.

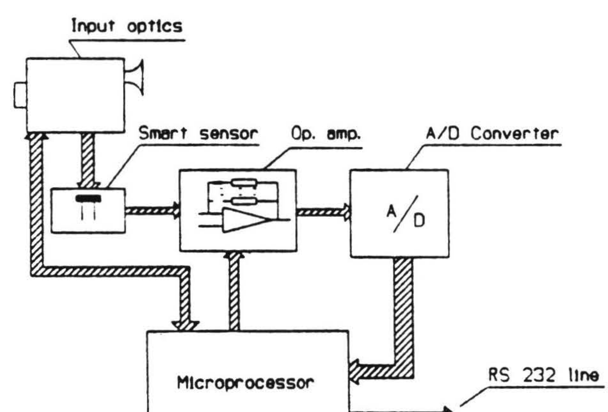

Fig. 1. Block diagram of the 'smart' colorimeter.

2.2 Input optics

Two input optics have been developed. The "illuminance" type input optics consists of a filter wheel for the $\bar{x}_1(\lambda)$, $\bar{x}_2(\lambda)$, $\bar{y}(\lambda)$ and $\bar{z}(\lambda)$ filters and a stationary cosine corrector. Typical spectral responsivity curves are seen in Figure 2.

The second optical unit is of the "luminance" type (see Figure 3). Changeable lenses permit to set the field of measurement from a tenth of a degree to over one degree. The field of measurement is seen in the eye-piece as a small dark dot in the field of view. In this unit the colour measuring filter turret is sitting in the exit optical path.

Both input optic units can be coupled to the smart sensor via a "Pentax-D" mount connector. Built-in sensors identify which input optics is coupled to the smart sensor and which filter is in the light path. (Other input units convert the smart sensor into a radiometer with flat-filter characteristics, a UV-meter, etc.).

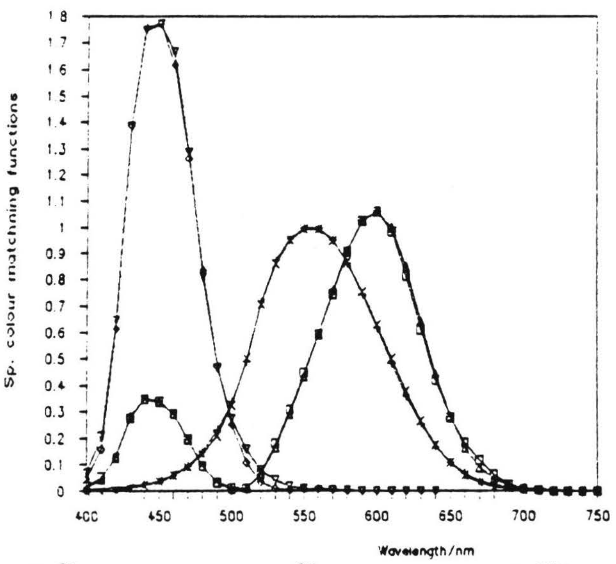

Fig. 2. Instrumental and CIE 2° colour matching functions.

2.3 Smart sensor unit

As already mentioned, the smart sensor incorporates all the building blocks of a photometer or colorimeter electronics. Its dimensions are: length: 2,5" (60 mm), diameter: 3" (76 mm), and it contains all the necessary photoelectric and electronic parts, amplifier, analog to digital converter and microprocessor control for an RS-232 standard output with a maximum baud rate of 9600.

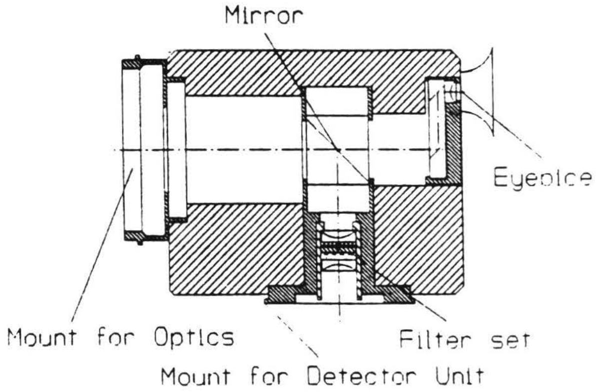

Fig. 3.: 'Luminance' type input optics.

Six sensitivity ranges are built in for photocurrent measurements between 1 pA and 400 μA. For every range a software-sensitivity correction is provided.

Table 1 contains some of the commands and their interpretation the smart sensor understands. As seen from the table, the ranges can be set from software or automatically by the microprocessor itself. To decrease the load on the PC, the sensor itself can average up to 256 individual readings. The "REL ON/OFF" command enables the automatic subtraction of dark-current or stray light readings.

3. PERFORMANCE TESTING OF THE COLORIMETER

For testing the colorimeter performance the characteristics of a series of aviation reference filters (Hoffman Eng. Corp. M.E.L. Chromaticity Reference Filters Mod. CF-35) was determined and compared with the nominal value.

Figure 4 shows the spectral transmittance characteristics of the filters, Table 2 summarises the CIE LAB colour differences both for Standard Illuminant A and D65. As seen, the absolute colorimetric accuracy is reasonable for Standard Illuminant A, it is somewhat high for illuminant D65, but if the inaccuracies of D65 simulators are considered, even this absolute accuracy seems to be acceptable.

TABLE 1

RESET or !	Sets the system in reset position
START	Starts the measurement cycle
RANGE ?/1/2/3/4/5/6/UP/DOWN/AUTO	
?	Reads in the number of the selected range
1..6	Sets the Range
UP	One range up
DOWN	One range down
AUTO	Automatic range change
REL ON/OFF/?	Relative measurement: The result of th elast measurement is stored and subtracted from all subsequent measurements (dark current correction)
ON	Switches on the function
OFF	Switches off the function
?	Seeks the actual state

READ VALUE/AD/SN/ID/T	
VALUE	Reads in the measured value
AD	Reads in the output of the A/D converter
EN	Seeks for the code of the last error
SN	Read in the status code
ID	Checks for the ID Number of the unit (a factory set ID for software setting of correction/range change values)
T	Measures the temperature of the head
AVERAGE N/?	Allows averaging measurement; the output is the average of n single measurements
n	The number of single measurements averaged
?	Seeks for the last introduced number

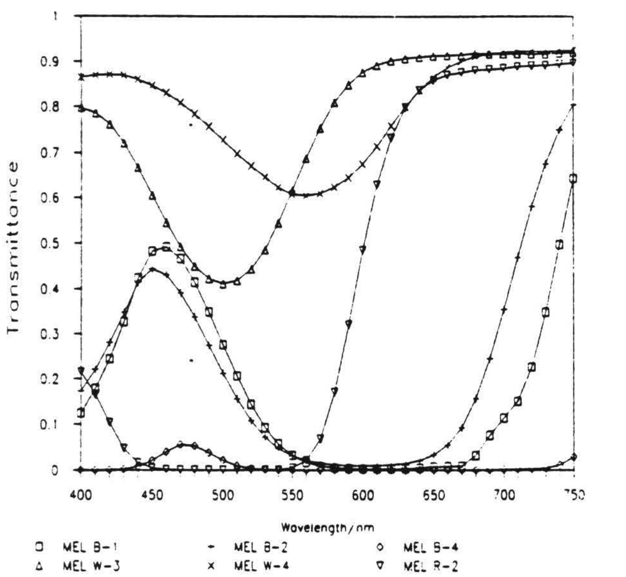

Fig. 4. Spectral transmittance of selected aviation reference

TABLE 2

CIELAB colour differences obtained with smart colorimeter on Hoffman aviation reference filters

No. of filter	DE_{ab}* (IIll. A)	DE_{ab}* (Ill. D65)
MEL B-l	4.30	7.41
MEL B-2	4.03	7.32
MEL B-4	1.05	1.68
MEL W-3	2.70	3.04
MEL W-4	4.1 0	4.78
MEL R-2	1.53	1.05

A colour difference measuring accuracy can be much higher.

At present we investigate the implementation of a matrix transformation [4, 5] for further increasing the accuracy of the instrument.

4. SUMMARY

By using modern electronic technology we succeeded in incorporating into a small measuring head all the features of a photoelectric measuring system. The modular construction permits to build colorimetrics for different purposes, radiometers and photometers using the same basic unit.

The smart sensor unit is coupled to a lap-top personal computer - or for laboratory work to a PC via an RS-232 line, providing maximum flexibility for the evaluation of measurement results.

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PARAMETERISING COLOUR-DIFFERENCE EVALUATION

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1. INTRODUCTION

The problem of quantifying colour discrimination is still unresolved. CIE, therefore, promoted a scientific program, which should deal with studies at five colour centers with defined parameters [1]. One aim was parameterising colour discrimination and eventually of implementing parametric effects in a colour-difference formula. This now is the duty of a new TC of CIE: TC 1-28.

2. HUMAN FACTORS

First of all we must consider human statistical effects in psychophysical experiments, which may be split into two components: in-observer and between-observer variability. Between observer variability may well extend over that of in-observer. In an experiment of constant stimuli 22 observers produced rather heterogeneous responses, but groups of homogeneous judgments could be formed, the extremes of which differed by a size-factor of two [2].

On the other hand probabilities of observing colour-differences in pairs of constant stimuli are rather well related to colour difference by a sigmoid function of Gaussian character [3]. The scattering of data is due to variance of colorimetric measures and random fluctuations of the observers' binomial responses, which give rise to broad shells of uncertainties about threshold ellipsoids, demonstrated by using a Monte Carlo technique [3]. A parameter to be significant must provoke new ellipsoids that fall outside those shells.

3. PHYSICAL PARAMETERS

Let us assume a CIELAB-type colour-difference formula to be representative of colour-difference space and parameters to be acting as factors, either constants or functions, at the components of the formula:

$$\Delta E' = \Delta E / K_E$$

$$= \left((\Delta L^* / K_L)^2 + (\Delta a^{*2} + \Delta b^{*2}) / K_{ab}^2 \right)^{0.5}$$

or

$$= \left((\Delta L^* / K_L)^2 + (\Delta C^* / K_C)^2 + (\Delta H^* / K_H)^2 \right)^{0.5}$$

The reference situation is defined by setting all factors at unity. Therefore, $\Delta E'$ measures colour-difference due to changed step width in relation to that of the reference, which could be given as threshold units or some other psychophysical scales.

The adoption of $\Delta E'$ provides for a single value of colour difference in tolerance settings for various parametric effects.

Some known physical parameters are: - sample size, - sample separation, - texture, - colour of surround, - lightness of sample.

Their action has been studied for several experimental conditions (or not). Examples of some approximate numbers of factors are given in Table 1. In the case of texture a relation between structured and homogeneous specimens of the same colour is unknown, though the contrast effect of texture is thought to increase thresholds. A change of threshold chromaticity ellipses with lightness of colour may not be clearly separated from the surround-effect.

TABLE 1

Numerical values of some parametric factors

Parameter	K_E	K_{ab}	K_L	K_C	K_H	comment
Sample size		0.5	1			related colour
(2°/12°)		0.7	1			unrelated colour [4]
Sample separation						
(≥1.6°/hairline)		1.5	1.6			related colours [5]
(0.5°/hairline)	2.6		2.9	2.1	2.0	Blue samples
	1.6		1.4	1.7	1.5	Yellow samples [6]
Colour of surround						
(grey, L*10 =	1.4		1.8	0.9	1.8	Blue samples
87/41)	1.1		1.0	0.9	1.3	Red samples [6]

4. FUTURE WORK

The methods of presenting colours with visual colorimeters, colour monitors or physical samples may be used to study e.g. the following parametric effects:

- the size effect, how factors may change between small (2°) and large areas of industrial interest,
- the gap effect, whether there is a critical gap that separates changing factors from constant ones,
- the texture effect, which might relate homogeneous surfaces to those of increasingly coarse structure,
- the surround effect, as dependent on a variety of center/surround contrasts and of field size,
- the size of colour-difference, if and for which difference there might be a break of linear extension of threshold steps,
- further possible effects like illumination level, gloss or others.

These effects have there counterparts in the physiological organisation of perception of colour and structure. It may be possible to find a link between psychophysical phenomena and the organisation of retina and neural networks. Therefore an interdisciplinary work between psychophysicists and physiologists may be the most successful.

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COLOUR UNIFORMITY AS A FOOD QUALITY FACTOR

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Colour is an important factor in evaluating the quality of foods as it may serve as an indirect index of other quality attributes, and it can psychologically influence consumer choice and behaviour. This laner aspect can be examined either by considering colour absolute value (i.e. a numerical specification of a single visual stimulus defined by hue, saturation and lightness) or, preferably, by measuring colour differences on a food product surface or between products in the same packaging or batch. Indeed, for several food products, such as biscuits and other bakery products, processed meats, preserved fruit and vegetables (as well as for other industrial products), colour uniformity can be considered a relevant quality parameter.

The research project that we have started aims to investigate experimentally to what extent the colour of these food products results non-uniform, and to what extent such colour differences are visually perceptible, with the aim of fixing industrial tolerance limits.

In the first stage, and this is the subject of the present paper, we were concerned with the identification of the most adequate methods and instruments among those commonly available.

The following instruments have been examined and compared, with the aim of correlating their measurements:

- Filter tristimulus colorimeter Zeiss Elrepho; standard illuminant C and d/0 measuring geometric; measuring area diameter: 30 mm;

- Distance colorimeter Topcon BM-7; external illuminating system realised by using a "daylight" tungsten light source; 45/0 illuminating/viewing system; measuring area can vary with the selected measuring field angle and the distance to the measured object (actually employed measurement area diameter: 30 mm);

- Portable spectrophotometer Delta-E Crom made by Ma~ Meyer- Duco; pulsed xenon lamp as lighting source and d/0 illuminating/viewing geometry; measurement area diameter: 9 mm; wavelength range: 400 to 700 nm;

- Spectrophotometer Perkin-Elmer Lamhda 1~ endowed with integrating sphere (measuring geometry: 0/d). Measurement area: 1 x 10 mm: Wavelength range: 380-780 nm.

The choice of the instruments was based on the technical characteristics of each, particularly the size of the measuring area. Indeed, we were interested in examining the behaviour of different instruments such as the very small area spectrophotometer (P.E. Lambda 15) or the large area colorimeter (Zeiss Elrepho) in measuring the surface colour of products which, like foods, are mostly non-uniformly coloured.

In order to avoid the influence of surface colour distribution. the instruments were tested on uniformly coloured surfaces (coated and uncoated Panlone standard paper selectors).

Tristimulus values for standard paper selectors measured by different instruments are shown in Table l; the selectors were chosen in various points of the colour space.

As expected, we obtained different results when measuring colour as an absolute value, even though a similar trend was evident for the two spectrophotometers.

However, when we measured colour differences for pairs of similarly coloured uncoated paper selectors, we noticed a good correlation between the considered instruments (see Tables 2 and 3). This allows us to state that, in the case of uniform colours, differences measured by the tested instruments are comparable.

The two lowest correlation coefficients obtained concern the TOPCON BM-7 colorimeter. We would like, however, to point out that, in the measurements made with this instrument, we used a light source which does not exactly correspond to any CIE standard illuminant.

The same instruments have been used to measure the colour uniformity of some industrial processed food products: crackers, biscuits and other bakery foods, ham, mortadella, fruit in syrup, tinned vegetables (beans, peas, tomatoes), frozen vegetables and other processed products.

Colour differences measured on samples of such products are reported in Table 4-7.

The sample codes, when used, are made up of a number, referring to a packaging of a certain brand of products, and, eventually, a letter identifying the single part from which the samples where taken. The tables contain the highest colour differences between products in the same packaging (or part).

In order to evaluate the colour uniformity of crackers within each single unit, a measurement was taken in several points of the sample surface. The highest differences measured for each unit were heterogeneous (from a minimum of 1,61 to a maximum of 9,01).

As to colour uniformity between different cracker samples, it Is evident from Table 4 that colour differences obtained with P.E. Lambda 15 spectrophotometer are greater than those obtained with the other instruments. This is probably due to the larger measuring areas of the two colorimeters than that of the spectrophotometer.

It is well-known that readings made with wide measurement areas give mean results in case of nonhomogeneous surface colour. The same happened for other not uniformly coloured food products, for instance boiled ham (see Table 7).

On the contrary, as far as mortadella is concerned, the lowest colour differences were obtained with the spectrophotometer; indeed the use of a small area instrument allowed us to measure the bare meat paste colour, while the other instruments' wider areas included in their measurements also the chopped bacon fat.

As to biscuits (Table 6), which are uniformly coloured products, all the employed instruments gave similar results, as the different area widenesses did not affect the results.

We can conclude that the identification of the most adequate instrument depends on the characteristics of the food product surface (spatial distribution of not uniformly coloured areas and their extent) and the objective of the measurement (identifying the extreme difference between small differently coloured areas, quantifying the mean colour uniformity of the product).

It is our intention to continue this work, using other available instruments for measurements on a wide range of foodstuffs, in order to test operative indications for the qualification and standardization of foods.

TABLE 1

Comparison among colorimetric measurements made with various instruments on Pantone standard paper selectors (Tristimuls values under illuminant C: 2° and 10° standard observer).

	Tristimulus values									ΔE^*_{ab}		
	I			II			III			I-II	I-III	II-III
Samples(a)	Spectroph. Lambda 15			Spectroph. Delta-E Crom			Colorimeter Elrepho					
	X	Y	Z	X	Y	Z	X	Y	Z			
101 (ly)												
std.obs 2°.	79.97	88.20	33.21				73.07	81.15	30.29		3.39	
std.obs. 10°	79.06	84.68	31.27	70.38	75.70	27.15				4.17		5.62
101c												
std.obs 2°.	64.88	72.49	29.49				64.61	71.90	27.64		2.30	
std.obs 10°.	64.14	70.00	27.66	63.12	68.71	25.77				1.95		3.70
116 (y)												
std.obs 2°.	69.46	62.90	14.45				64.01	59.55	12.40		4.95	
std.obs 10°.	67.48	59.54	13.54	59.11	52.27	11.00				4.37		8.45
116c												
std.obs 2°.	59.98	59.62	9.99				60.70	60.80	8.50		5.84	
std.obs 10°.	58.69	56.24	9.07	58.12	55.15	8.45				1.55		9.61
176 (pk)												
std.obs 2°.	72.55	59.96	56.23				69.03	58.45	53.97		4.01	
std.obs 10°.	70.50	58.87	55.68	63.25	53.32	52.22				4.47		4.45
176c												
std.obs 2°.	63.97	54.39	57.13				64.94	55.65	55.27		3.20	
std.obs 10°.	62.39	53.71	56.56	61.37	52.57	54.81				0.98		3.24
354 (g)												
std.obs 2°.	18.42	31.03	23.93				15.61	26.50	21.26		5.08	
std.obs 10°.	19.02	31.13	22.34	16.35	27.53	18.80				3.38		6.28
354c												
std.obs 2°.	14.68	30.06	17.51				13.73	28.00	17.30		3.81	
std.obs 10°.	15.47	30.08	15.78	15.84	30.22	15.63				1.71		8.35
293 (b)												
std.obs 2°.	17.84	15.99	50.43				15.44	13.20	46.83		6.05	
std.obs 10°.	17.76	17.68	49.73	15.09	15.00	45.33				3.74		14.69
293c												
std.obs 2°.	12.58	9.89	47.46				11.86	8.90	47.42		4.78	
std.obs 10°.	12.54	11.72	46.91	12.29	11.52	46.02				0.58		20.10
246 (p)												
std.obs 2°.	37.63	23.67	43.75				35.37	21.80	38.85		3.10	
std.obs 10°.	35.73	24.14	44.02	30.51	19.89	39.36				5.27		9.37
246c												
std.obs 2°.	32.72	18.39	43.10				33.83	19.50	41.81		4.27	
std.obs 10°.	31.00	19.06	43.40	29.74	18.15	42.02				1.13		8.62
185 (r)												
std.obs 2°.	42.00	27.31	16.26				40.02	26.70	13.17		7.04	
std.obs 10°.	39.66	26.33	16.23	34.03	22.10	12.96				4.23		8.65
185c												
std.obs 2°.	36.03	21.31	11.39				38.66	24.00	10.69		8.13	
std.obs 10°.	33.69	20.53	11.39	32.42	19.70	10.76				1.04		9.39
497 (br)												
std.obs 2°.	13.61	13.11	12.73				11.47	11.10	10.33		3.37	
std.obs 10°.	13.45	12.90	12.53	10.52	10.05	9.73				4.70		2.43
497c												
std.obs 2°.	8.28	7.66	7.52				8.52	7.70	7.44		1.79	
std.obs 10°.	8.12	7.56	7.39	7.98	7.47	7.52				0.93		2.93

TABLE 2

Comparison among colour differences obtained with various instruments on Pantone standard paper selectors

ΔE^*_{ab} (CIE 1976)

Pairs of samples[a]	Colorimeter Elrepho	Colorimeter BM-7	Spectrophotometer Delta-E C.	Spectrophotometer Lambda 15
138-1385	6.19	5.91	6.07	6.24
140-1405	0.96	2.26	1.60	1.26
159-1595	4.16	5.87	4.74	4.02
164-165	3.85	3.77	3.53	4.50
211-212	5.56	6.14	4.83	4.29
220-221	4.01	4.03	3.24	4.29
224-225	5.22	5.37	5.14	4.09
2573-2577	5.70	5.17	4.47	4.59
3955-3965	2.10	2.51	1.93	2.63
2593-2603	5.24	4.30	4.74	4.50
404-405	3.51	3.89	3.39	3.28
497-4975	2.46	2.99	1.39	2.01

(a) = Pantone standard colour codes.

TABLE 3

Correlation coefficients (r) calculated for values in Table 2.

Elrepho Delta-E C.	Delta-E C. BM-7	Elrepho Lambda 15	Lambda 15 Delta-E C.	Elrepho BM-7	BM-7 Lambda 15
0.93	0.92	0.91	0.89	0.89	0.79

TABLE 4

Comparison among colour differences obtained with various instruments on cracker samples

ΔE^*_{ab} (CIE 1976)

Samples	Colorimeter Elrepho[a]	Colorimeter BM-7	Spectrophotometer Lambda 15
1A	6.13 (3.19)	9.23	9.37
1B	7.26 (7.37)	7.92	-
2A	1.84 (2.91)	3.62	9.38
2B	4.95 (4.74)	6.33	-
3	2.04 (1.58)	0.64	4.74

(a) = colour differences in brackets were calculated from the mean of several measurements on each sample surface.

TABLE 5

Comparison among colour differences obtained with different instrumentation on biscuit(a) samples.

	ΔE^*_{ab} (CIE 1976)		
Samples	Colorimeter Elrepho	Colorimeter BM-7	Spectrophotometer Lambda 15
1	8.33	8.39	2.96
2	6.75	7.28	3.29

(a) bread dough baked.

TABLE 6

Comparison among colour differences obtained with different instruments on biscuit samples.

	ΔE^*_{ab} (CIE 1976)		
Samples	Colorimeter Elrepho	Colorimeter BM-7	Spectrophotometer Lambda 15
1A	4.98	5.28	4.16
1B	4.58	4.14	5.34
2	7.42	7.28	7.75
3A	1.55	0.37	2.75
3B	1.38	1.25	-

TABLE 7

Comparison among colour differences obtained with different instruments on foodstuff sample.

	ΔE^*_{ab} (CIE 1976)		
Samples	Colorimeter Elrepho	Colorimeter BM-7	Spectrophotometer Lambda 15
Peaches in syrup	24.07	17.46	-
Tinned tomatoes	8.89	7.70	-
Tinned peas	5.02	9.01	-
Tinned beans	2.18	6.92	-
Frozen peas	9.85	14.91	-
Boiled ham	10.80	15.13	2.71
Mortadella	4.22	6.01	1.28
Tinned meat	9.15	8.77	9.03
Ham	15.07	-	12.70

TABLE 8

Colour differences (ΔE_{ab}^{*}) in preserved fruit and vegetables measured with Zeiss Elrepho colorimeter.

	Tinned			Frozen	
Tomatoes	Peas	Beans	Peaches	Beans	Peaches
6.20	7.63	6.83	3.52	3.89	6.82
4.32	5.37	4.14	2.90	10.12	10.48
6.28	4.30	3.49	0.72	8.20	12.04
6.82	3.13	7.98	3.71	8.02	6.86
12.84	6.42	3.47	4.71	7.40	7.96
5.58	7.10	9.17	3.92	7.23	13.38
13.73	8.70	4.52	7.62	7.88	-
6.37	0.45	5.22	8.31	6.16	-
4.82	3.55	-	7.25	6.05	-
13.66	4.57	-	9.66	9.00	-
12.16	9.80	-	9.38	6.52	-
7.00	8.44	-	-	10.08	-
14.26	-	-	-	5.95	-

TABLE 9

Colour differences (ΔE_{ab}^{*}) in preserved meat measured with Zeiss Elrepho colorimeter.

Tinned meat	Boiled ham	Ham
10.71	13.86	11.77
5.46	10.37	15.07
6.13	12.65	9.10
3.59	17.64	8.34
2.71	9.32	12.70
7.45	9.13	9.08
4.87	7.20	-
4.63	9.82	-
9.15	6.31	-
2.33	8.16	-
12.16	9.80	-
7.00	8.44	-
14.26	-	-

Miscellaneous

THE COLOURS OF THE STARS

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Introduction

The limits that darkness imposes on human perception makes the night sky unique in our experience of the wider world. At night, half our field of view might be filled with points of light, yet we can learn nothing of their size and shape or distance by simply looking. And if vision is less than perfect, it is all we have, for our other senses are of no use whatsoever in understanding that which lies beyond the earth's atmosphere.

We cannot hear the stars, nor smell or taste them, nor can we reach out and touch them to find out if they are hot or cold, friendly or alien. Indeed we can barely see them at all. In the struggle to collect enough of their light to render the stars visible, the eye loses its sense of color and we notice only pallid hues amongst the brightest members of the constellations.

But colour is there. It is hidden from us by the inability of the eye to recognise it when the source of light is both small and faint, as it is with the stars. Even more difficult is the recognition of colour in extended objects such as nebulae and galaxies, where the surface brightness remains low, irrespective of the power of the telescope.

The discovery that many of the objects of the night sky were coloured had to await the application of photography to astronomy a little over 100 years ago. Even then, the images obtained were not coloured, but the comparison of the relative brightness of the photographic (i.e. blue light) images of stars with their visual (green light) appearance showed that some stars were distinctly bluer than they appeared to the eye.

In the version of this talk presented to the AIC Conference in Sydney, many coloured slides were shown to emphasise the importance of colour in understanding the objects of the night sky, including the stars. These images have been widely published (e.g. Malin 1990a). Here I will briefly describe the source of these colours in a range of astronomical objects and explain why special photographic techniques are necessary to make them visible and how colour imagery aids astronomical understanding.

The sources of light

Colour of the luminous objects of the night sky arises in three main ways, but each of these depends ultimately on nuclear fusion reactions occurring in the cores of the stars themselves.

The stars, and the extended objects that are made of vast numbers of stars, such as the Milky Way and other galaxies far beyond, are visible by virtue of their temperature. This is thus essentially black body radiation and its spectrum shows a broad, almost featureless continuum like that of sunlight. Because they have a range of temperatures from less than 3000K to over 50,000K, individual stars exhibit colours from a deep orange--yellow to sky blue. These are truly colour temperatures and the hues are subtle, but full of meaning for astronomers.

The hottest of these stars are blue, and radiate much of their energy in the far ultraviolet part of the spectrum. If there are clouds of gas nearby, this short wavelength radiation can be absorbed by the gas atoms, exciting them into glowing by a fluorescence mechanism This energy interchange is similar to that occurring in terrestrial neon' lights. Light from such luminous clouds is characterised by its spectrum of a few narrow emission lines. Such monochromatic emission is naturally strongly coloured and the deep red of hydrogen or vivid blue--green of oxygen dominate in the visible region. While the colours are certainly intense, the excited gas is so tenuous that light levels that are produced are very low, which is why the eye sees emission nebulae only as the pearly grey of scotopic rod vision.

Finally, the gas between the stars is often mixed with dust, itself the result of the creation of heavy elements within the stars. Such dust consists of particles of a size more akin to those found in smoke than to the dust familiar in the household and such particles tend to reflect the shorter wavelengths of blue light rather than the red end of the spectrum. This, of course, is Rayleigh scattering and is the same mechanism that produces the blue of the daytime sky. Because dust also transmits longer wavelengths more effectively than short, luminous objects seen through it appear to be both fainter and yellower, while the scattered light is appears as a blue reflection nebula. Once again, the light levels are so low that no colour is visible to the eye.

Given this interesting and unfamiliar range of colour--producing mechanisms it is not surprising that the colours themselves are unusual. But the colours are not merely surprising; they reveal the composition, morphology, distribution and temperature of the stars and star--forming materials in astonishing detail. That such colours exist has also come as something of a shock to many astronomers, for whom colour is rather an abstract concept to be expressed numerically rather than enjoyed visually since they are not accessible to the eye, even with the largest telescope, nor are they well recorded by colour film.

Astronomical Photography with Color Film

Commercial color films are intended for photographing sunlight, scattered by the earth's atmosphere and reflected from the flesh and foliage of everyday life. Exposures are usually measured in fractions of a second and the range of contrasts encountered is small. The color reproduction is chosen to correspond to human color memory rather than to precisely reproduce the original scene. None of these properties is particularly useful in astronomy!

Only in the solar system are we concerned with the broadband colors of reflected sunlight. Beyond the planets we record the light from stars which may be much redder or bluer than the sun and can be mixed with light from emission nebulae. In these glowing gas clouds, most of the visible light is concentrated in very narrow bands or lines in the spectrum. Color pictures of them are of interest because color reveals the complex interplay between gas, dust and the light from bright stars in a way that cannot be appreciated in black and white, even by examining individual color separations.

These objects are particularly difficult to record on color film since one common nebular emission line occurs in a blind spot at around 500nm between the blue and green responses of most color films, and another on the peak of the red sensitivity. Thus objects with mixtures of green and red line photograph only as red on colour film. In just the same way, terrestrial emission-line objects such as fluorescent tubes or mercury street lights are also a problem for color films. They reveal that color film and the eye see some things very differently.

Serious though these problems are, a further difficulty is encountered when color films are used for long exposures of faint objects. The three sensitive layers in the film have their characteristics matched for 'snapshot' exposures which are usually shorter than a second or so. When exposures are much longer than this, both the speed and contrast of the layers may become badly mis-matched, resulting in large shifts in color balance which cannot be readily corrected.

Finally, commercially-available colour films lack the contrast that is essential for the faint, low contrast objects that are the usual targets of astrophotography. If the exposure is increased to compensate for the faintness, the contrast in the image decreases as the film records more and more of the glow of the night sky. The overall effect is to fog the film and de-saturate the colours.

The only satisfactory way to overcome all of these problems is to abandon colour film for serious deep sky astronomical photography and resort to colour separation techniques. However, there are problems to be faced before good results are reliably obtained and the amount of darkroom work involved at first is considerable. And before dismissing colour films completely, it should be emphasised that for some purposes, especially where bright objects are concerned or for revealing star colours (Malin, 1986), commercial materials are quite satisfactory.

Colour Separation - An Outline

Once a satisfactory set of colour separation negatives has been obtained with matched exposures in red, green and blue light, there are many ways to combine them into colour photographs. Several of the possibilities have been described in the book *Colours of the Stars* (Malin and Murdin, 1984). In a technical appendix we also discuss the essential preliminary steps towards establishing a reliable and predictable working system.

The process we have developed at the Anglo-Australian Observatory (Malin, 1979) is based directly on Maxwell's 1861 colour demonstration. The subject is photographed three times, each exposure with a different filter and emulsion, to produce three separate monochrome negatives containing the blue, green or red information from the scene. These negatives are contact copies to make film positives, sometimes with an unsharp mask to modify the contrast range or with photographic amplification for faint objects. The positives are projected in an enlarger, one after the other, through a red, green or blue filter on to a 'receiving material', thus recombining the colour information in the original scene.

The individual exposures of the three positives are adjusted so that a sun-like star appears a neutral colour in the final reproduction. This is difficult to achieve with real stellar images because sun-like stars are not always conveniently placed, even if they could be identified. In practice, the telescope camera includes a small projection sensitometer which projects a grey scale on to each plate during the exposure. The light source in the sensitometer is filtered to a colour temperature of 5500K, mean noon sunlight. This is reproduced as a neutral shade and all the other colours are balanced to this 'neutral point'. The receiving material can be a positive-working colour paper such as Ektachrome for a single print or for tests, or a colour negative film such as Vericolour for multiple copies. In both cases, registration is achieved with a simple superimposition device developed for multiple image addition described in Malin 1990.

The Value of Colour Images in Astronomy

But is colour photography necessary for astronomical understanding? The answer is undeniably yes. Astronomy depends on observation alone for the facts about the distant Universe. In the visible part of the spectrum, a change in the proportions of light at different wavelengths is seen as a change in colour, and colour brings with it extra information that monochrome cannot. But our sense of colour is not much use in astronomy without the aid of photography because the eye is colour blind at low light levels. That is not to say the eye ceases to function, far from it, but evolution has sacrificed night-time colour vision for sensitivity. Much better to know that the tiger is there than to notice its hue.

At night we see extended objects, such as a landscape beneath the full moon, only in shades of grey. If we turn binoculars or a modest telescope on to the moon-lit scene it does nothing to improve our perception of the colour we know to be there. The same is true of other extended objects seen in the dark, such as the Milky Way and gaseous nebulae. A few of the brightest, such as the Orion nebula and some planetary nebulae, are seen by some to have a greenish hue, but this is on the threshold of colour vision and other colours are not seen.

Although a telescope collects more light than the eye, it does nothing much to increase the apparent brightness of non-stellar objects, merely their apparent size. Although many individual stars *are* bright enough to stimulate the colour-sensitive part of the retina, another weakness in the eye interferes. This is small-field tritanopia, a natural inability to reliably distinguish colours when the size of the source is small. And stars are very small sources. Big telescopes do little to help here either, though out of focus images of stars do show some colour.

Although some stars had long been known to be coloured, and coloured pairs of stars are a favourite target for many casual observers, it was not until visual and photographic magnitudes could be compared that astronomers realised how broad the range of hues was and, in particular, how many of the brightest stars were extremely blue. The earliest measurements of star colours were derived from the difference between the blue (photographic) and green (visual) magnitudes of a star. This gives a 'colour index' of a star and, on the assumption that it is a blackbody radiator, a star's colour index is a good indicator of its surface temperature. From this information, a star can be classified and its distance can be derived. Colour is clearly vital astronomical information.

If the famous 18th Century astronomer William Herschel in his pioneering attempts to understand 'the construction of the heavens' had been equipped with superhuman colour vision, both science and society may well have been different. Herschel was a shrewd and persistent observer who was never reticent about interpreting what he saw.

If Herschel had noted that the stars bordering the dark spaces he found in the Milky Way were dimmer and yellower than others nearby, he would have discovered interstellar absorption and with it the reason why we see only a fraction of the galaxy in which we live. He would have had the key to understanding the fabric of the Milky Way in 1800. Though suspected decades before, the existence of the absorbing material between the stars was not confirmed until the late 1920's. That confirmation came from measuring star colours from black and white photographs.

If Herschel had noted that the bright stars were predominantly blue and the masses of faint stars that make up the brightest part of the Milky Way were yellower, he would have uncovered the crucial concept of stellar populations. This was not to be clearly identified until the 1940's, again by measurement of the colour of the stars photographically.

Both these discoveries have strongly influenced our views of the galaxy in which we live and the location of the sun within it. They have helped us to understand those far beyond and to realise that our Milky Way of a hundred thousand million stars is not unique or even exceptional, continuing the process of discovery and human understanding set in train by Galileo. This knowledge has shaped our philosophical views of the universe as a whole and our place within it, but it is recent. How different would our society have been if these discoveries had been made in 1800?

Though a gifted observer, Herschel and his successors had normal colour vision like the rest of us and we had to await the appearance of photography before the meaning of colour in astrophysics began to be appreciated. This process continues today, but, as in black and white photography of the night sky, advances do not come easily and special techniques are needed to make scientifically useful colour pictures of astronomical objects.

It is a remarkable fact that images of the hidden natural world, whether they be of a coral reef, the appearance of a crystal beneath a microscope or a picture of distant nebula hold a distinct fascination to even the most casual viewer. Without colour these scenes are much less rewarding, but only in astronomy is colour denied us by the eye's limitations and only here has the lack of perceived colour hindered scientific progress.

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1. Star trails at the Anglo-Australian Observatory

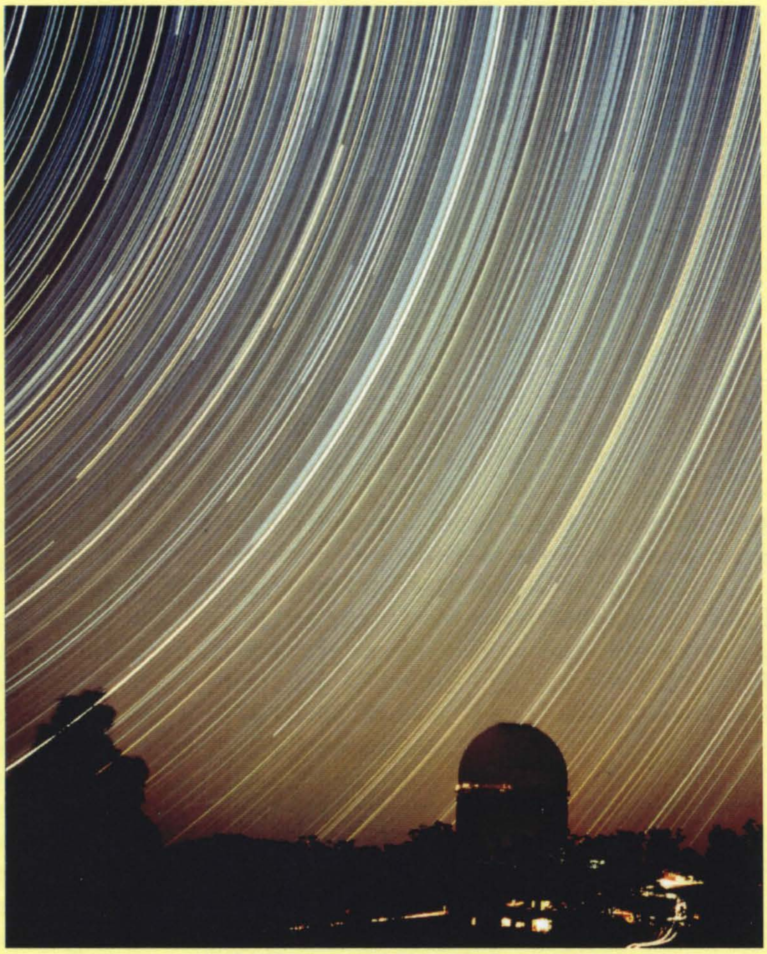
2. Horsehead Nebula

Photos by David Malin
Anglo-Australian Observatory

Images on this page and the Colour and Light 91 page were scanned and printed on a Canon Colour Laser Copier. Scans were done at half-resolution of 200dpi from photographic originals. Page layout was done in PageMaker 5.0 on a 486 PC. The layout was printed from PageMaker via a DICENet Graphics Server to the Canon Colour Laser Copier, with text printed at 400dpi and graphics at 200 dpi . Note the absence of dither pattern in the images, due to the continuous tone printing system used by the Canon Copier. With continuous tone printing, excellent results are obtained even at low resolutions, thus saving considerably on disk space and printing time.

For further information on this technology, call David Hill on 02-805-2600.

1



2

GOETHE'S THEORY OF COLOUR

B. Merz

Just as Newton's laws of motion suffice within the solar system, excepting when a complex motion called chaos is generated, so Newton's propositions with respect to colour are sufficient excepting for certain phenomena occurring in the perception of colour. Computations based on Newton's laws of motion enabled the Voyager to make its journey and observe the celestial motions of the planets and their moons. It observed not five moons on Saturn but ten, and one Hyperion tumbled in a complex and irregular way. Its motion is random in a system governed by law. Turbulent flow is another example where randomness has a deterministic underpinning.

Chaos came out of the minds of mathematicians. It is going into every natural phenomenon that exhibits irregularity, but in circumstances which suggest there ought to be underlying patterns. The phenomena known as simultaneous contrast, induction, and colour constancy, in the perception of colour could come under this heading.

Johann Wolfgang Goethe, best known for his immortal "Faust", but a prolific writer on science, rejected everything to do with Newton's theory of colour, and concentrated to a large extent on the many irregularities which occur in observing colours, particularly after images, coloured shadows and effects of simultaneous contrast. Newton's "Opticks" was published in 1704. His discovery about colour was the subject of his first scientific paper published in the Royal Society Transactions in 1672. It gave rise to acute controversy, so much so that he seriously contemplated abandoning research altogether. Many of his brilliant contemporaries could not accept that light existed in an infinite number of different independent colours incapable of being changed into each other and characterized by a definite refrangibility. This he proved in a series of experiments published in Newton's "Opticks".

In 1810 Goethe maintained in a most vitriolic manner, that far from being a fundamental phenomenon by which to explain colour, it is an unimportant incidental result of a truly basic fact. This fact was that circumscribed objects must be displaced by refraction in order to exhibit an appearance of colour. In his view it was the displacement and not the refraction which is the pertinent circumstance.

In a forward to Newton's "Opticks" reprinted in 1952 by Dover after having been out of print for 150 years, Einstein pays tribute to Newton's methods and discoveries including the first foundations of colour theory which he said have passed into the stock of accepted knowledge.

Goethe on the other hand in his book "Theory of Colour" undertook to lift the veil from Newton's theory which, he claimed, by virtue of its power and authority had long obstructed an unprejudiced view of colour. "We will take issue", he says, "with a hypothesis to which our age still pays traditional homage even though it is now useless". Goethe states that if the theory of colour is not to lag behind so many other more developed fields of science, its true nature must be made apparent and the old fallacies swept away. The violence of his objection to the Newtonian doctrine, caused a neglect by the scientific world of some valuable communications in Goethe's book.

Newton was not responsible for his followers taking the view that colour is a property of light and light alone. Diagrams still exist in books showing the light coloured as it emerges from the prism. Newton stated that rays properly expressed are not coloured. There is nothing else in them but a certain power or disposition which so conditions them that they produce in us the sensation of this or that colour.

GOETHE'S OBSERVATIONS AND VIEWS

It is likely that Newton would not have disagreed with some of these views of Goethe: Colours are the deeds of light, what it does and what it endures. Nature also speaks to other senses which lie even deeper, to known, misunderstood and unknown senses. Nature reveals itself to the sense of sight, the eye, through colour.

The eye does not see shape as such since brightness and darkness and colour operate together as the sole means for the eye to distinguish among objects. Light gives to the eye what is visible and the eye gives it to the whole man. The inner light emerges to meet the outer light. Thus Goethe stated that the eye had within it a latent form of light which becomes active with the slightest stimulus from within or without. For the eye, states Goethe, colour is an elemental natural phenomenon. Like all similar phenomena it manifests itself in division and opposition, combination and separation, poise and counterpoise, advancing and retiring, intensification and neutralization. It can best be observed and understood through these general principles of nature. Nature oscillates within her prescribed limits yet thus arise all the varieties and conditions of the phenomena which are presented to us in space and time. Light and non light are necessary for the production of colour. Going from dark to light affects the eye. The first makes it more sensitive to colour. In some manner bright or dark objects affect the retina.

Look as Goethe did at window bars against a bright sky, and then at a dark wall. The cross appears dark against a light ground. Look at the bars and then at a light wall. The cross appears light against a dark ground.

Look at a black disc on a light grey surface. Change the direction of the eyes in slight degrees. Bright halos float around the dark circle.

Grey is intermediate between brightness and darkness.

If a black object is held before a grey surface, then moved away, the space appears lighter. A white object held in the same manner, the space appears darker.

Most people are familiar with a grey object on black appearing lighter than the same grey object on white.

From such experiences, the universal formula was derived. When darkness is presented to the eye it demands brightness. When lightness is presented it demands darkness. The eye's fitness to receive the impression of an object is shown by its spontaneous tendency to an opposite state.

AFTER IMAGES

After images were studied by Goethe. The after images of a dazzling light are found to be different according to whether one looks at a white or black or grey surface. Coloured after images were represented by Goethe's chromatic circle. Although he called red and green complementary, the circle shows magenta opposite green. He noted that the complemental image is lighter on a white surface and darker on a black, and regarded this as more harmonic as it is more opposite.

INDUCTION

Goethe carried out induction experiments. His description (paragraph 76) of the shadows cast on a white surface by an opaque body lit by candlelight and moonlight, where the shadows are reddish yellow and blue, inspires one to try it.

Goethe's view that shadow is the proper element of colour, he noted to be illustrated in the flowing richness of colour in shadows in the works of Titian and Georgione. Blue shadows on the snow were observed by Goethe to be changing with changing conditions. The shadows cast by the setting sun he saw to be sea green, with every object in vivid harmonizing colour.

His exhaustive experiments over some twenty years, with minute observations and finely drawn descriptions are often covering ground which physicists have examined in laboratories, but may never have done so in situ among ordinary objects, where all the exceptions to the rule may appear.

Try this, as an example. When the sky is grey look at a horizontal window bar. Bend the head a little forward and one sees a bright yellow border under the bar and a bright light blue one above it. The greyer the sky, the better. Move the head backwards a little, and the phenomenon will appear reversed. The upper edge will appear yellow and the under edge blue.

That angle matters, we have found in examining simultaneous contrast. Not much attention has been paid to the effect of the angle at which colours are viewed.

Many of the experiments and observations carried out by Goethe drew him to the conclusion "The slightest change has only to take place in the component parts of bodies, whether by mixture with other particles or other such effects and colour either makes its appearance or becomes changed" (paragraph 692) and again "When the eye sees a colour it is immediately excited and it is its nature, spontaneously and of necessity, at once to produce another, which with the original colour comprehends the whole chromatic scale. A single colour excites, by a specific sensation, the tendency to universality" (paragraph 805).

SIMULTANEOUS CONTRAST

Ann Burge, an architect preparing a Master's theses on simultaneous contrast, has expanded these precepts considerably, with systematic and extensive observations. In examining the laws of simultaneous contrast, as propounded by Chevreul, she has discovered that the level of light can turn a law on its head. According to Chevreul a colour affects a neighbouring colour by adding the complement of the background colour to the colour.

By measuring the altered colour and the actual colour using the Munsell system it was found that for some colours low levels of light produce a change due to the complement of the background being added and at high levels the background colour is added. In between these levels, an interval was found where no change at all takes place.

For example, a primary blue on green, at levels of light between 10 and 55 lux had the complement added, but at levels from 300 to 580 lux the background colour was added. From 55 to 300 lux levels, no change took place.

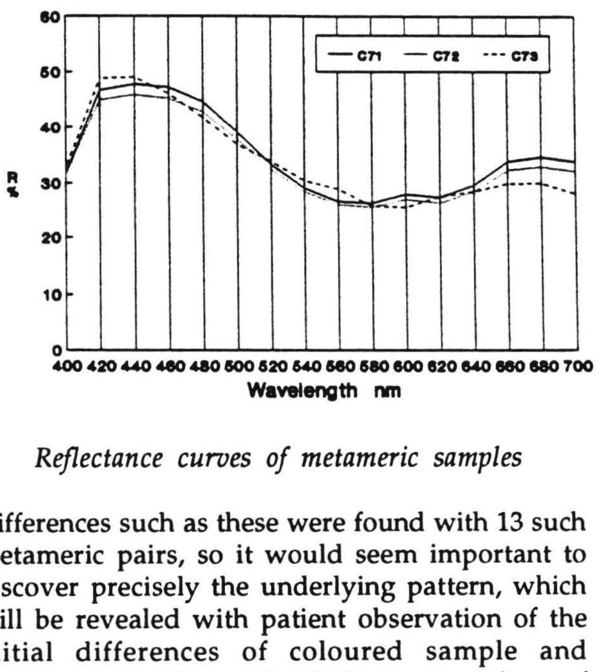
With blue on yellow, the complement was added right up to 480 lux. No change was perceived from 480 to 680 lux for fluorescent, incandescent or daylight. At 680 lux the background colour, yellow, was added to the blue.

For a light green on bright green, the complement was added right up to 60,000 lux, with a small range around 50 lux when no change was detected. For the light green on yellow the complement was added for levels from 10 to 80 lux, when there was no change, but with increase in levels the complement was again added up to 60,000 lux..

With this fascinating discovery, a more detailed examination is being made. For many pairs of colours the colour and its background are being measured using the Munsell system. The differences between the pairs in hue, value and saturation are designated as ΔH, ΔV and ΔS. The perceived differences in the colour due to the background are designated as Δh, Δv and Δs. Functions are being sought by plotting ~h against ΔH, Δv and ΔV and Δs against ΔS, the lighting levels being recorded in each case.

METAMERIC PAIRS

Metameric pairs have been found to be strangely affected by background. The metameric samples C 7.1, C 7.2, C 7.3 with reflectance curves as shown were viewed in a light box with different backgrounds. Their hue is a violet colour. C 7.1, C 7.2 appeared the same under a daylight fluorescent lamp with a reddish grey, a reddish orange and a black background, C 7.3 looking different in each case. C 7.1, C 7.3 appeared the same with a reddish cream and a yellowish orange background with a daylight lamp, and with a white fluorescent lamp they appeared the same with a steely grey background, C 7.2 looking different each time. C 7.2, C 7.3 looked the same when placed on a black background with a daylight lamp and a fleshy pink background with a white fluorescent lamp, C 7.1 looking different in both cases.



Reflectance curves of metameric samples

Differences such as these were found with 13 such metameric pairs, so it would seem important to discover precisely the underlying pattern, which will be revealed with patient observation of the initial differences of coloured sample and background and perceived change in colour of sample.

Let Goethe have the last word "True observers of nature however they may differ in opinion in other respects will agree that all which presents itself as appearance, all that we meet with as phenomenon, must either indicate an original division which is capable of union, or an original unity which admits of division, and that the phenomenon will present itself accordingly. To divide the united, to unite the divided is the life of nature, this is the eternal systole and diastole, the eternal contraction and expansion, the inspiration and expiration of the world in which we live and move" (paragraph 739).

ABSTRACT ONLY

THE GEM OF A THOUSAND LIGHTS

Mr Michael Costello - Managing Director, The Opal Skymine

Mr James Costello - Director of the Opal Skymine

Mr Rudi Weber - Director of Gem Studies Laboratory*

and CSIRO - Victoria

What better way to welcome the Association Internationale de la Couleur to Australia, than to reflect on Australia's most precious and unique natural colour - "Opal .... The fire stone.. " Opal is unique in Australia and unique among gemstones as no two stones are alike.

What is it about this gemstone that has intrigued people for centuries? Why is it that the ancient Greeks believed that this gem carried the gift of clairvoyance and prophecy? What is it's configuration and how is it valued?

Why is it that Opal fire erupts when white light is split into it's spectral colours and furthermore when the stone is turned the colours appear to change and flashes of brilliant colour are seen. How and why does this occur?

We would be delighted to present to the Conference this opportunity to learn from Michael Costello, (Managing Director of the Opal Skymine, 1988 World Expo keynote speaker and one of only two government appointed Opal valuers) present a thought provoking paper on the power, beauty and pleasure of Australia's natural colour!

IDEAL PRIMARY COLOURS: THEORY AND RELATIONS WITH OTHER FUNCTIONS

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The principal problem in additive or subtractive colour mixture is that mixtures tend to be whiter or darker respectively, than either of the component primaries. Hence, additive and subtractive primaries may be ideally defined as peaks of relative saturation (per watt) and relative brightness/lightness respectively. The former and latter have recently been defined as complementary pairs Blue-Yellow (447, 568 nm), Green-Magenta (531 nm, 531 c), Red-Cyan (607, 491 nn). These primaries work in colour reproduction because, it is shown, they reflect primaries in human vision, for example, the above six wavelengths characterize, as complementary peaks and troughs, several important functions including sensory functions. Implications to colour mixture's site in the visual pathway are discussed.

1. INTRODUCTION

Aim. This paper summarises my recently-published research on ideal primary colours [1], demonstrates similarities with sensory and other functions, and discusses implications for vision theory.

There is no complete theory of the ideal primaries, by number, wavelength, saturation or brightness. Existing theory is mainly empirical. Wyszecki and Stiles *Color Science* [2] gives this definition: "Primary color stimuli are color stimuli by whose additive mixture nearly all other color stimuli may be matched in color. Note. These . . are often chosen to be . . red, green and blue."

A basic requirement is that no two primaries can produce the third.2 Additive primaries are aperture colours (as in TV), generally near the spectrum middle and ends so as to achieve the greatest gamut of colours. Subtractive primaries are colorants such as paints, printing, inks, and dyes. They are roughly complementary to additive primaries, lying at cyan, magenta, yellow.

The subtractive primaries work by transmitting and/or reflecting light from materials or from the white surface beneath materials, ie, filters and paint layers which absorb (subtract out) certain energies. The residual energy is the colour perceived on entering the eye. So, subtractive primaries mix darker colours (in extremis, black) than either primary; whereas additive primaries mix lighter colours (in extremis, white) than either primary.

Terminology

Saturation shall denote colourfulness or chromaticness, defined identically by the CIE, and which increase with luminance.

Equal radiance shall apply, as it is close to natural light whereas equal luminance exists only in laboratories.

Optimum Colour Stimuli. I shall take colours not at maximum purity (invisible at the spectrum ends) but at optimum purity: ie, the spectrum locus limited to 442-613 nm, and a line drawn between those limits in colour space, describing the compound colours. These are optimum colour stimuli, and have maximum luminance for a given wavelength.[3] They are aperture colours.

Optical Colour Stimuli. These denote object colours at the MacAdam limits for a given luminance factor Y. [1,2]

TABLE 1.

Examples of functions with three complementary pairs of peaks and troughs, for the equal-radiance hue cycle.

Antinodes, nm or c

Relative Radiance, watts[1]	447	532	607	568	532c	491
Brightness per watt[1]	447	520	607	568	520c	491
Saturation per watt[1,4]	447	532	607	568	532c	491
Wavelength Discrimination[6]	450	530	605	575		490
ditto[7]	445	530	600+	570		480-90
Spectral Sensitivity[8]	440	530	605	570-80		480-90
ditto[9]	440	530	605	560-70		490-500
Complementary Efficiency E[1]	441	532	607	568	532c	491
Complementary Intervals Ratio[1]	445	530	605	568	530c	491
CIE Colour-matching Functions[10]						
(fundamentals only) 1931 XYZ	445	531	606	negative	(= unreal)	
(fundamentals only) 1931 RGB	445	531	606	negative	(= unreal)	
Matrix-R Diagonals[10]	446	532	601	568		487
Colour Constancy[11]	450	530	610	575 apprx		490 apprx
Colour Rendering[12]	450	535	610	580 apprx		495 apprx
Ideal Primaries B,G,R & Y, M, C[1]	447	532	607	568	532c	491

2. REQUIRED CHARACTERISTICS OF PRIMARIES

The purpose of a set of primaries is to mix the greatest gamut of colours. Any set of three well-separated primaries can realise the complete hue cycle. So the limiting factors to optimum colour mixture are loss of saturation and loss of brightness.

Additive Primaries

Admixture of two or three additive primaries produces decreasing saturation by increasing whiteness of colours. Central colour space is white. Saturation, not brightness, is the critical problem, since a mixture represents the added brightnesses of the primaries. Ie, the mixture is brighter than either primary. The purpose is not merely to mix the greatest gamut of colours, since some of colour space is irrelevant due to low luminosity (ie, the area outside optimum purity, near the invisible alychne).

Purpose. I propose the primary purpose of additive primaries is to mix the greatest gamut of saturated colours. This omits the alychne which is maximum purity but not maximum saturation/W. [4,5]

Theoretical Requirements. To achieve the above purpose, the additive primaries should be: (a) maxima of relative saturation for optimum colours; (b) constant-wavelength in all CIE illuminants; (c) within spectrum limits to optimum colours (442-613 nm).

Subtractive Primaries

Colorant primaries mix darker colours than at least one of the primaries. So subtractive primaries produce decreasing saturation by increasingly dark colours, to grey or black in the centre of colour space. The critical problem is brightness because the colorants do not emit light, as do additive primaries, but only absorb and reflect it. Hence colorants, to act as primaries, must resemble light itself as much as possible. Saturated colours like red or blue mix, as colorants, dark and greyish colours. So relatively unsaturated colours like yellow are better primaries.

Purpose. I propose the purpose of subtractive primaries is primarily to achieve the greatest gamut of bright/light colours.

Theoretical Requirements. To effect the above, the subtractive primaries should be: (a) maxima of brightness/lightness for optimum/optimal colours; (b) minima of saturation for optimum/optimal colours, since inverted saturation is similar to lightness.

3. DEFINITION OF PRIMARIES

Figure 1 shows saturation, from my recently published model.[4] Its lambda-max (447, 531, 607 nm) agree in number and hue with traditional RGB primaries, and vary little by illuminant.[1] They are also peaks of object color constancy (Table 1). Comparison with common primaries or peaks of colour-matching functions shows they agree well. [1] Eg, CIE 1931 RGB peaks are 447, 543, 604 nm.

The saturation peaks appear therefore to ideally define the additive primaries.

Table I shows relative brightness B, derived from relative luminance L times brightness/luminance ratios.[5] L quantifies lumens required for each λ to neutralise its complementary. Its radiometric equivalent is relative radiance (Table I). B has a dominant peak in yellow and minor peaks in cyan and magenta, in agreement with data on relative lightness and Munsell Value.[5] Notably, B maxima are saturation/W minima, thus meeting the above theoretical requirements. They also agree with the traditional Y,M,C primaries. Thus, saturation minima/brightness maxima ideally define subtractive primaries.

4. RELATIONS WITH OTHER FUNCTIONS

Table 1 lists visual functions with the same complementary antinodes as the ideal primary colours. From their opposed-coded (complementary) peaks and troughs, these functions indicate neural processing, ie. a postreceptor site in the visual pathway. Indeed, several are sensory functions. which represent the final stage. The correlation of peaks and troughs by number, wavelength and opposed-coding, indicates that colour-mixture primaries are collocated in the sensory (final) stage, contrary to the Young Helmholtz assumption of colour-mixture as a preneural preliminary to the neural process of colour vision.

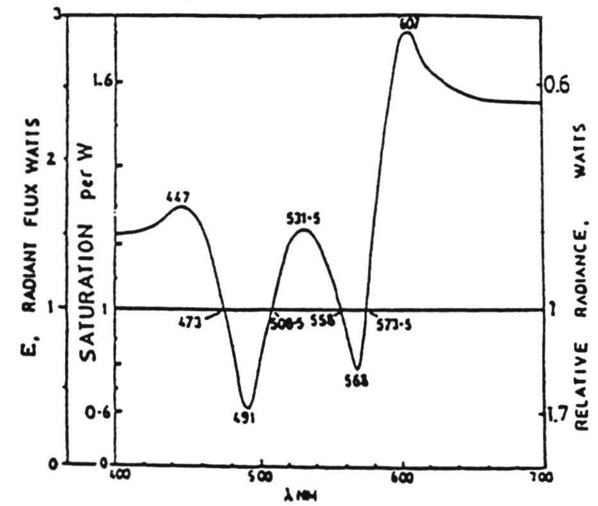

Fig. 1. Complementary Efficiency E and Saturation/W. Illuminant D65. Right: Relative Radiance for hue cycle, such that λ neutralises λ_c, at watts shown.

There are previous indications, of course, that colour-mixture is a neural process: eg, from research on additivity failure and temporal integration, and from the fact of vision models forming hue, saturation, and brightness dimensions post-receptorally.[2] A close relation between colour-mixture and sensation seems logical, given that the result of colour stimuli mixture is colour sensation. A possible explanation is that colour-mixture is a multi-stage process, initiated at receptor stage and finalyzed in the final stage of colour vision. After all, the colour vision process seems analagous to colour-mixture: the sole purpose or product of both is the complete, adapted, gamut of colour sensations.

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ERGONOMIC ASPECTS ON COLOUR MONITORS

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NEGATIVE OR POSITIVE?

Monitors for computers may produce *negative* or *positive* displays.

The simplest version of a negative display is the "monochrome" screen, which may be either completely achromatic with white characters on black, or "monochrome" in the sense of 'one chromatic colour', e.g. blue, green or amber against a dark background. Such screens may be extremely tiresome for the operator. After an hour in front of a display of green and black, the operator will frequently be disturbed by pink afterimages all around. This is a typical example of how manufacturers of computer equipment often neglect elementary facts of colour vision.

Today, most ergonomists recommend positive displays as the basic selection for ordinary office work. If the traditional black print on white paper is simulated by corresponding luminance relations on the screen, less stress is caused when the eye is switched between screen and paper.

However, this does not mean that the negative mode of display has to be discouraged altogether. In a basically positive display, the inverse mode can draw attention to important information in labels or boxes. Black and white monochrome displays may be satisfactory for ordinary office work, even if colour is valuable lo highlight important items and is a must in many CAD applications. Then the negative mode may offer a greater choice of chromatic colours that give good readability, and the dark background need not be dead black. Very often, the operator feels more comfortable when black as background is replaced by a dark gray or dark chromatic colour.

WHITE BACKGROUND

The "white" background of a monitor, either a "monochrome" or "colour" one varies according to preferences among users (or producers?). The most common measure of this white is its correlated colour temperature (CCT) on the Kelvin scale (K).

The first black-and-white monitors had a very high CCT of about 9000K. When colour television was introduced, skin colours could not be reproduced to satisfaction, and the guns were adjusted to give a "white" similar to CIE standard daylight 6500K (D65). However, this practice is not always followed, and many computer monitors arc still kept at 9000K to 10000K or higher.

One reason for this could be that cold-white fluorescent tubes still prevail in office lighting in some countries. But in other parts of the world, e.g. northern Europe, there is now a strong preference for a much warmer indoor lighting. A few years ago I had difficulties to find D65 tubes for my experiments, tubes around 4000K dominated the market. When a colleague of mine recently investigated current practice in Swedish offices, he found a strong preference for warm-white tubes and other luminaires in the region of 3000K

A common requirement is that energy saving fluorescent tubes must not only fit in standard Edison sockets but also mix comfortably with incandescent light to give a cosy atmosphere.

In this ambient illumination, a screen with a CCT of 9000K or more is felt rather uncomfortable, except when blue sky daylight is shining through the windows. Admittedly, we do have a problem here, in that natural daylight easily varies between 5000K and 9000K. In my country, where daylight is scarce half of the year, we do not want to keep it out by blinds to the same extent as in the many other countries. It then seems as if a contrast between room and outdoor lighting is more readily accepted than the same kind of contrast between objects within the indoor environment. The CIE recommends D65 as standard illuminant for daylight, and recently Brill and Derefeldt after a deeper analysis than the one given here have suggested 6500K as the maximum acceptable CCT. But still many manufacturers slick to 9300K as the standard white of their monitors.

THE COLOUR PALETTE

In an increasing number of applications it is not sufficient that the screen background looks acceptably white. The colour monitor is there, not only to give its user a higher status, but to produce colours with well defined appearances, and the user is required to make decisions from these colours. In colour reproduction technology, both by photography and in printing, computerised image processing has become an important tool.

Today, many application programs give the user an option to select the colours of the screen background—and other display elements—from a palette of some sixty to hundred colours. This enables him/her to adjust the screen colours to varying ambient conditions. But how many users take care to learn how to use this option? One reason may be that dialogue menus seldom are designed in a "customer-friendly" way.

Are today's computer systems with their default colour palettes suitable for this purpose? Well, maybe if the only need for colour is to obtain any kind of contrast against black and white. But we are now getting more and more users of CAD systems with higher demands than that. When designers and architects in Scandinavia and several other countries, who for a long time have been using the NCS as a tool in their design work, now turn to computers and CAD programs, they are frustrated by the low quality and lacking perceptual consistency of the colour palettes offered.

But how can a perceptive colour system (NCS, Munsell, DIN, OSA etc) - developed and defined for surface colours only - be reproduced on a monitor emitting luminous stimuli? Once the colour sense has identified a suitable white reference in the visual field, all other elements are judged in relation to this white. As soon as their luminances are lower than that of white, they are perceived not as luminous but as surface colours.

A major part of the default palettes arc made up of simple combinations of RGB values, i.e. the signals sent from the computer to the electron guns in the CRT. But these RGB values correspond badly to appearance, and also several transforms of them, such as HLS and HSV show serious errors. Colours generated by equal signal levels of one, two or three phosphors are e.g. supposed to be of the same lightness.

To implement the NCS colour atlas on a computer monitor, we followed two different routes. First, we made a visual match of screen colours against atlas samples. Then a computer program was written - based on a colorimetric calibration - to produce RGB signal levels from CIE tristimulus values. We succeeded quite well in reproducing atlas pages on the screen. Now there are already computer-monitor systems on the market, where this calibration is done automatically with an incorporated colorimeter.

COLOUR CONSTANCY?

The computerised colour atlas looked very well, until we compared it directly with atlas samples in an ambient illumination different from the screen background. This sharply revealed some severe limitations of colour constancy, when there are two areas in the visual field competing for the role of the reference white for the colour sense.

You may think of the NCS as a colour atlas of the same kind as the Munsell, DIN or OSA atlases. This is not quite correct. The Munsell, DIN and OSA systems are defined by CIE coordinates for selected points in colour space. If the conditions for which these were calculated are no longer fulfilled, there is no way to specify a colour.

The NCS is a *method* to describe the appearance of a colour percept under arbitrary conditions, in principle independent of colorimetry. A colour sample will take on different NCS notations under different conditions of illumination and viewing, as for instance the two central fields in this slide, which physically are produced in the same way.

The NCS atlas is just one particular illustration of the NCS method. But to produce atlas samples, we always need colorimetric specifications, and they must be evaluated for a particular choice of standard illuminant and standard observer, the latter supposed to be in a neutral state of adaptation. When the colour samples are seen in other illuminations, the colour constancy in our visual system enables us to see them in most phases of daylight without disturbing shifts in colour appearance. The relative positions in colour space remain approximately the same, even if the spectral compositions of all stimuli have changed considerably. But we cannot expect the atlas samples to look the same as the colours on a monitor with a fixed background different from the room illumination. To correct this, it is not only background has to be changed, all colours must be produced by new RGB signals.

In the NCS, six elementary colours serve as natural references for the description cf colour appearance under arbitrary conditions. There is a widely unanimous opinion about the appearance of these six colours - no physical samples are needed as references, but depending on viewing conditions different physical stimuli may be needed to produce them.

The user should be able to include in the colour palette - at the beginning of each session - the elementary colours for the prevailing conditions there and then. A software in the computer can then calculate a complete and logically arranged NCS atlas for the designer to chose from.

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ABSTRACT ONLY

CONE SENSITIVITY AND SPATIAL SUMMATION

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The cones' system is analysed using a laser of He-Ne with a radiation of 632.8 nm and employing the threshold detection technique.

The foveal and extrafoveal zones are searched to 30°. The stimuli varied between 0,5 and 4°, and were observed on backgrounds of variable luminance between 1 and 40 cd/m^2.

Variation in the speckle's size and two new radiations: green 514.5 nm and blue 480 nm proceeding from an Argon laser, are also considered for comparative purposes.

It is demonstrated that the thresholds of detection have a direct correlation with the number and quality of the receptors involved in the stimulation. It is also shown that the larger threshold level corresponds to a stimulus of 2.5° whose border coincides with the retinal zone where the proportion of cones and rods is approximately the same.

Conclusions obtained with incoherent stimulation such as the accomplishment of Block's, Ricco's and Fechner's laws are reaffirmed.

Finally, and starting from the obtained data, the 10 cd/m^2 are proposed as photopic threshold for stimuli of 1° and free field of gaze.

ABSTRACT ONLY

CMC(L:C) AND BFD(L:C) FORMULAS APPLIED TO CLASSICAL COLOR-DIFFERENCE THRESHOLDS

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Evaluation of chromatic and color-threshold differences has been carried out by means of CMC(1:1) and BFD(l:1) color-difference formulas from experimental threshold results obtained with visual colorimeters. The good results previously reported on the use of these two new formulas with surface colors are also found for the chromatic differences calculated, specially with the BFD(1:1) formula. In the case of color differences BFD(1:1) is weakly improved by CMC(1:1). The claim of CMC(l:c) and BFD(l:c) as a superior alternative to the currently recommended CIE formulas CIELUV and CIELAB can be also supported by the present results.

ABSTRACT ONLY

NEW APPROACH TO COLOUR INSTRUMENT CALIBRATION

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Calibration of instruments used in color measurement is achieved in many ways that tend to be arbitrary and do not lend themselves to general agreement of data for the same samples measured on different instruments. Several sets of physical standards will be shown that will provide specific information that allows either adjustment of instruments or computation of data to a reliable common basis. This is accomplished by the user with measurements of certain sets of plastic standards in which a specific attribute has been varied in a systematic way. When possible the measured properties are traceable to a national governmental standardizing laboratory.

The properties which can be controlled through these standards include:

Reflectance or transmittance photometric scales
Reflectance or transmittance wavelength scales
Fluorescent (white) excitation scales
Translucency scales

The standards are moulded acrylic plastic materials treated with a scratch-resistant coating. With the exception of the fluorescent standards, they are stable to light and exhibit small or no change with temperature.

ABSTRACT ONLY

THE TWO FACETS OF PSEUDOCOLOR TECHNIQUE

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A didactical program has been developed, in view of the widespread use of pseudocolor technique. Its philosophy is illustrated below. In computerized image digitization, the transition from an achromatic space to the trichromatic one implies an enlargement in the number of possible items. On the other hand, when the visual evaluation of pseudocolored images is considered, a strong reduction imposes, mainly when color identification (rather than discrimination) is at work. By recalling the dependencies on the "time to see" and visuo-motor reaction time on spatial frequency and contrast, some experimental situations are described. The first indicates how the use of a limited number of colors, in a complex pattern, decreases the "carrier" spatial frequency, thus favouring the speed of reading. The second, based on the use of a matrix consisting of pairs of equiluminous heterochromatic samples, shows how the speed of reading increases with increasing color difference. However, in some cases the relation above is biased by the deterioration of color discrimination in the extrafoveal retina, mainly at dim adapting luminances.

Dean B. Judd - AIC Award

Citation

DEANE B JUDD - AIC AWARD

1991 Recipience

Hans Vos and Pieter Walraven

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The Deane B Judd - AIC Award was established in 1975 to recognise work of international importance in the fields of colour perception, colour measurement or colour technology. Funds were provided by Mrs Deane B Judd to establish and administer the Award in memory of her late husband. The Award recognises important work in colour science. The selection committee is given wide latitude and the choice may be made for a single outstanding piece of work, for an on going programme that covers a wide range of co-ordinated studies, for leadership in colour science education or for some other meritorious service in the field of colour science.

Previous recipients of the Award have been:

- 1975 Dorothy Nickerson
- 1977 David Wright
- 1979 Gunter Wyszeckl
- 1981 Manfred Richter
- 1983 David L MacAdam
- 1985 Leo M Hurvich and Dorothea Jamieson
- 1987 Robert Hunt
- 1989 Tarow Indow

To these we now add

- 1991 Hans Vos and Pieter Walraven

The Award is given for, and I quote the committee,

".....many contributions to the understanding of the mechanisms of colour vision".

The linking of the names of Vos and Walraven for the Award is, of course, most logical and appropriate but they are two people from different backgrounds with other, rather different research interests. It may come as a surprise to many to know that joint papers represent a minority of their publications. It is therefore, the quality of these joint publications which makes them especially memorable.

Dr Vos completed a Master of Science degree in physics at the State University, Utrecht, in 1954. His published work from that time shows a mixture of visual and ocular work, which included night vision, glare, the Stiles-Crawford effect and radiation effects on the eye. He completed his PhD at the same university in 1963.

He joined the TNO Institute for Perception in 1953 rising to the Head of the Vision

Branch in 1966.

Dr Walraven graduated as an engineer from the Technical University, Delft, in 1963 with colour vision as his major field. Colour vision features largely in his publications right from the beginning. He completed his PhD in mechanisms of colour vision at the State University at Utrecht in 1962 and joined TNO in 1964 as Deputy Director of the Institute for Perception rising to Director of the Division for National Defence Research.

Their first joint paper was published in 1962 and related to the Stiles-Craw ford effect. Their first joint paper relating to colour appeared in 1963. Bouman, Vox and Walraven. "Fluctuation theory of luminance and chromaticity discrimination" in *The Journal of the Optical Society of America.*

Hans Vos maintained research interests in radiation changes to the eye, applied aspects of vision and visual ergonomics amongst many others.

Peter Walraven proceeded within a wider scope of colour vision issues including the applied and ergonomic aspects of colour vision and colour vision deficiencies.

They continued to come together to develop the work which has its basis in Walraven's PhD thesis "On the mechanism of colour vision".

It is a two stage colour vision model which is now commonly used as the basis of attempts to explain colour vision phenomena. Walraven's work was published after an opponent colour theory paper of Hurvich and Jameson and he brought together the classical Helmholtz trichromatic theory and the Hering opponent colours theory into one framework when they were seemingly incompatible and contradictory. His work precedes the first introduction of the electrophysiological colour vision works of De Valois, Hubel and Wiesel amongst others. The work also led to the best quantitative analysis of the Bezold-Bucke phenomenon and cone pigment density determinations. The combined approach of Vos and Walraven gave the model its mathematical basis and from the work they derived the foveal receptor primaries, ratios of L-M-&SWS cones and the line element colour discrimination analysis.

At the same time they also continued collaborating with other co-workers and also shared co-authors - a most productive group - not just the two of them.

The most conspicuous part of their work must have been the Helmholtz Memorial symposium on Colour Metrics in September 1971. Dr Walraven was the chairman of the organising committee and Vos, Fiele and Walraven edited the proceedings. It was a meeting which fell on the 150th anniversary of the birth of Hermann von Helmholtz, although this was a happy coincidence. This was the first in the series now know as AIC inter-sessionary meetings, of which this Sydney meeting is the most recent. It was intended to be a small specialised limited attendance symposium. Sixty-four participants met to hear twenty-five papers. They assembled a magnificent array of participants, provided a vital dialogue and created a proceedings publication which is still used as a reference book. As an illustration of the standing of the attendees and the effects the symposium must have caused, of the nine recipients of the Deane B Judd - AIC Award which I listed, including today's, only Hurvich and Jamieson were not present at that symposium. Including Vos and Walraven themselves, eight of the attendees are here at Colour and Light '91 including four paper presenters. It was clearly a landmark in colour science.

Their own paper at the meeting must now be a citation classic, The diagram of the neural processing model and the receptor primaries must have been made into slides for lectures around the world countless times.

In retrospect, knowing what we know now and having the techniques now available, electro-physiological, morphological, immunochemical as well as psychophysical, it is all too easy to underestimate the contribution of their work.

Like many, if not most, eminently successful researchers, they have also made substantial and significant contributions to other areas of colour science, visual science and other fields.

It never ceases to amaze me that so often I find the significant contributors to the field with which I associate them have also achieved prominence in another field. these two are no exception. One of the fascinating things about colour science is the diverse backgrounds the discipline brings together. Here we have the highly productive synergy of an engineer and a physicist, but then we should never confine people by looking at their first degrees.

It is appropriate, therefore, that this award is for their "....**many** contributions to the understanding of the mechanisms of colour vision".

I believe it was Newton that said "If I have seen further, it is because I have stood on the shoulders of giants".

I have no doubt Hans Vos and Pieter Walraven would say the same.

To them we, in turn, say - there are lots of people now standing on your shoulders.

ABSTRACT ONLY

Special lecture on the occasion of the acceptance of the Dean B. Judd AIC Award

BACK TO HELMHOLTZ

Vos JJ and Walraven PL

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Summary - The coincidence of the attribution of the Deane B. Judd AIC Award with the centennial of Helmholtz' line element for color metrics was an incentive to rewalk our own pathway through color science and show it come back, after some detours, to Helmholtz.

We will concentrate on three questions:

- What was the quintessence of Helmholtz ideas on higher color metrics ?
- How much of it still stands and what had to be added ?
- What were the consequences for color vision theory in general?

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