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COMMISSION INTERNATIONALE DE L'ECLAIRAGE
INTERNATIONAL COMMISSION ON ILLUMINATION
INTERNATIONALE BELEUCHTUNGSKOMMISSION

TECHNICAL REPORT

A FRAMEWORK FOR THE MEASUREMENT OF VISUAL APPEARANCE

CIE 175:2006

UDC: 612.84

Descriptor: Physiological optics, vision

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The International Commission on Illumination (CIE) is an organisation devoted to international co-operation and exchange of information among its member countries on all matters relating to the art and science of lighting. Its membership consists of the National Committees in about 40 countries.

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3. To provide guidance in the application of principles and procedures in the development of international and national standards in the fields of light and lighting.
4. To prepare and publish standards, reports and other publications concerned with all matters relating to the science, technology and art in the fields of light and lighting.
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5. De maintenir une liaison et une collaboration technique avec les autres organisations internationales concernées par des sujets relatifs à la science, la technologie, la normalisation et l'art dans les domaines de la lumière et de l'éclairage.

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3. Richtlinien für die Anwendung von Prinzipien und Vorgängen in der Entwicklung internationaler und nationaler Normen auf dem Gebiet der Lichttechnik zu erstellen.
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Die Arbeit der CIE wird in 7 Divisionen, jede mit etwa 20 Technischen Komitees, geleistet. Diese Arbeit betrifft Gebiete mit grundlegendem Inhalt bis zu allen Arten der Lichtanwendung. Die Normen und Technischen Berichte, die von diesen international zusammengesetzten Divisionen ausgearbeitet werden, sind von der ganzen Welt anerkannt.

Tagungen werden alle vier Jahre abgehalten, in der die Arbeiten der Divisionen überprüft und berichtet und neue Pläne für die Zukunft ausgearbeitet werden. Die CIE wird als höchste Autorität für alle Aspekte des Lichtes und der Beleuchtung angesehen. Auf diese Weise unterhält sie eine bedeutende Stellung unter den internationalen Organisationen.

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COMMISSION INTERNATIONALE DE L'ECLAIRAGE
CIE Central Bureau
Kegelgasse 27, A-1030 Vienna, AUSTRIA
Tel: +43(1)714 31 87 0, Fax: +43(1) 714 31 87 18
e-mail: ciecb@ping.at
WWW: <http://www.cie.co.at/>

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This Technical Report has been prepared by CIE Technical Committee 1-65 of Division 1 "Vision and Colour" and has been approved by the Board of Administration of the Commission Internationale de l'Eclairage for study and application. The document reports on current knowledge and experience within the specific field of light and lighting described, and is intended to be used by the CIE membership and other interested parties. It should be noted, however, that the status of this document is advisory and not mandatory. The latest CIE proceedings or CIE NEWS should be consulted regarding possible subsequent amendments.

Ce rapport technique a été élaboré par le Comité Technique CIE 1-65 de la Division 1 "Vision et couleur" et a été approuvé par le Bureau de la Commission Internationale de l'Eclairage, pour étude et emploi. Le document expose les connaissances et l'expérience actuelles dans le domaine particulier de la lumière et de l'éclairage décrit ici. Il est destiné à être utilisé par les membres de la CIE et par tous les intéressés. Il faut cependant noter que ce document est indicatif et non obligatoire. Il faut consulter les plus récents comptes rendus de la CIE, ou le CIE NEWS, en ce qui concerne des amendements nouveaux éventuels.

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The following members of the TC 1-65 "Visual Appearance Measurement" took part in the preparation of this report. The committee comes under CIE Division 1 "Vision and Colour".

Peter Bodrogi	Hungary
Elvo Burini Jr.	Brazil
Joachim Campos	Spain
Andrew Chalmers	New Zealand
Soon Cheung	Korea
Peter Clarke	Great Britain
Osvaldo da Pos	Italy
Gunilla Derefeldt	Sweden
Peter Hanselaer	Belgium
Richard Harold	USA
John Hutchings	Great Britain
Tore Kolas	Norway
Daniel Lozano	Argentina
Ronnier Luo	Great Britain
Lindsay MacDonald	Great Britain
Sharon McFadden	Canada
Todd Newman	USA
James Nobbs	Great Britain
Claudio Oleari	Italy
Michael Pointer	Great Britain (Chairman)
Giuseppe Rossi	Italy
Ken Sagawa	Japan
Janos Schanda	Hungary
David Simmons	Great Britain
Françoise Viénot	France

Corresponding members

Michael Brill	USA
Jennifer Veitch	Canada

TABLE OF CONTENTS

SUMMARY	VI
RESUME	VI
ZUSAMMENFASSUNG	VII
1. INTRODUCTION	1
1.1 Who benefits from the measurements	1
1.2 How industry will benefit from the measurements	1
1.3 Soft metrology - a definition	2
1.4 Measurement scales	3
1.5 Economic relevance of soft metrology	6
2. APPEARANCE	7
2.1 The measurement of light	7
2.2 Appearance - a definition	7
2.3 The measurement of appearance	8
2.4 Total appearance	9
2.5 Factors affecting total appearance	10
2.6 Discussion	13
3. OPTICAL PROPERTIES	15
3.1 Measuring optical properties	15
3.2 Cesia	16
3.3 Measuring colour	16
3.4 CIE colorimetry	17
3.5 Colour appearance	21
3.6 Colour appearance models	21
3.7 Geometry	25
3.8 Non-uniformity and surface texture	30
3.9 Discussion - colour	31
4. GLOSS APPEARANCE	31
4.1 Experiments	33
4.2 Measuring gloss - gloss meters	35
4.3 Measuring gloss - goniophotometers	37
4.4 Discussion - gloss	39
5. TRANSLUCENCY	40
5.1 Theory of scattering in materials	41
5.2 Haze of transparent plastics	44
5.3 A potential new technique	44
5.4 Discussion - translucency	45
6. SURFACE TEXTURE	46
6.1 Psychophysics	47
6.2 Illumination	48
6.3 Analysis techniques	48
6.4 Autocorrelation	49
6.5 Fourier power analysis	49
6.6 Co-occurrence matrices	51
6.7 Run length analysis	53
6.8 Other methods	53
6.9 Data sets	54
6.10 Spatial colour difference and texture uniformity	54
6.11 Texture and colour	55
6.12 Discussion - surface texture	55
7. DISCUSSION AND OPPORTUNITIES	56
7.1 Colour	57
7.2 Gloss	58

7.3	Translucency	59
7.4	Surface texture	59
8.	CONCLUSIONS	60
9.	GLOSSARY OF TERMS	61
10.	ACKNOWLEDGEMENTS	71
11.	REFERENCES	72

A FRAMEWORK FOR THE MEASUREMENT OF VISUAL APPEARANCE

SUMMARY

Visual appearance can be one of the most critical parameters affecting customer choice and it needs, therefore, to be quantifiable to ensure uniformity and reproducibility. A starting point in assessing the appearance of a consumer product might be the measurement of its colour. A description of its total appearance, however, cannot be achieved by the definition of colour alone; other attributes of the material from which it is fabricated contribute to the overall appearance.

Starting from a definition of soft metrology and a description of measurement scales, this report describes a framework on which a set of measurements could be made to provide correlates of visual appearance. It will be shown that the interactions between the various components of the framework are complex, that physical parameters relating to objects are influenced, at the perception stage, by the physiological response of the human visual system and, in addition by the psychological aspects of human learning, pattern, culture and tradition.

The result might be to conclude that an attempt to measure appearance may be too bold a step to take. Thus, a sub-framework is considered in terms of what can now be measured, and what might be measured after further investigation and research. By dealing with the optical properties of materials it is seen that there are, perhaps, four headings under which possible measures might be made: colour, gloss, translucency and texture. It is recognised that these measures are not necessarily independent; colour may influence gloss, colour will certainly influence translucency, and texture is probably a function of all three of the other measures.

Colour measurement, colorimetry, is based on the measurement of spectral reflectance, and is an established science that is possible using commercial instrumentation available at reasonable cost. Two shortcomings are identified. First, there are a number of modern materials where colour measurements made using a single pair of illumination/viewing angles is not sufficient to describe the perceived colorimetric effect. Thus, measurement at more illumination/viewing angle combinations is required. Second, the traditional, CIE recommended colorimetric parameters, while providing correlates of visual percepts, are not able to predict the absolute appearance of a coloured sample: colour appearance models are now able to do this.

The measurement of gloss is an established methodology but there is some doubt as to the scientific basis for making the measurements using the present method and attempts are being made to define alternative approaches. The extension of gloss measurement, which is essentially a measurement made at a specific angle depending on the apparent gloss of the sample, to investigate the shape of the gloss peak, should provide more information.

Translucency is a subjective term that relates to a scale of values going from total opacity to total transparency. This whole subject area needs investigation to find a rigorous measurement solution that will probably be industry specific.

Texture is a harder variable to measure. The advent of digital imaging systems makes the acquisition of images of materials relatively easy, assuming due consideration is given to the resolution of the image capturing device, be it a camera or a scanner. Characterising these images to give accurate CIE based colorimetry is now possible and the application of suitable analysis software should be able to provide measurement scales that relate to the perceived texture. The idea of establishing a series of 'standard' textures has been suggested.

UN CADRE POUR LA MESURE DE L'APPARENCE VISUELLE

RESUME

L'apparence visuelle peut être l'un des paramètres les plus critiques affectant le choix des clients, aussi doit-elle être quantifiable pour assurer l'uniformité et la reproductibilité. Un point

de départ pour évaluer l'apparence d'un produit de consommation pourrait être la mesure de sa couleur. Une description de son apparence totale, cependant, ne peut pas se limiter à la seule définition de sa couleur ; d'autres attributs de la matière dont il est fabriqué contribuent à l'apparence globale.

À partir d'une définition de la métrologie sensorielle et d'une description des échelles de mesure, ce rapport décrit un cadre dans lequel on pourrait faire un ensemble de mesures fournissant des corrélats de l'apparence visuelle. On montre que les interactions entre les divers éléments de ce cadre sont complexes, que des paramètres physiques relatifs à des objets sont influencés, au niveau perceptif, par la réponse physiologique du système visuel humain, et en outre, par les aspects psychologiques liés à l'apprentissage humain, à un modèle, à la culture et aux traditions.

On pourrait en conclure qu'une tentative de mesure de l'apparence constitue peut être un défi trop audacieux à relever. On envisage donc un cadre réduit prenant en compte ce qui peut actuellement être mesuré, et ce qui pourrait être mesuré après davantage d'études et de recherche. En traitant des propriétés optiques des matériaux, on réalise qu'il existe, peut-être, quatre rubriques où des mesures seraient possibles: la couleur, le brillant, la translucidité et la texture. On admet que ces mesures ne sont pas nécessairement indépendantes ; la couleur pouvant influencer le brillant, la couleur influençant certainement la translucidité, et la texture étant probablement une fonction des trois autres mesures.

La mesure de la couleur, la colorimétrie, est fondée sur la mesure de la réflexion spectrale. C'est une science bien établie rendue possible par l'instrumentation commerciale disponible à un coût raisonnable. On identifie deux insuffisances. D'abord, pour un certain nombre de matériaux modernes, les mesures de couleur obtenues en n'utilisant qu'une seule paire d'angles d'éclairage et d'observation ne suffisent pas à décrire l'effet colorimétrique perçu. Une mesure à un plus grand nombre de configurations angulaires d'éclairage et d'observation est donc nécessaire. En second lieu, les paramètres colorimétriques traditionnels, recommandés par la CIE, tout en fournissant des corrélats de percepts visuels, ne peuvent pas prédire l'apparence absolue d'un échantillon coloré : les modèles d'apparence colorée peuvent maintenant le faire.

La mesure du brillant est obtenue selon une méthodologie formellement établie mais il règne un certain doute quant à la base scientifique de la méthode de mesure actuelle et on tente de définir des approches alternatives. L'extension de la mesure de brillant, laquelle est essentiellement une mesure à un angle spécifique dépendant du brillant apparent de l'échantillon, afin d'étudier la forme du pic de brillant devrait fournir davantage d'informations.

La translucidité est un terme subjectif qui se rapporte à une échelle de valeurs allant de l'opacité totale à la transparence totale. Ce domaine entier nécessite des recherches pour trouver une solution de mesure rigoureuse qui sera probablement spécifique à chaque industrie.

La texture est une variable plus difficile à mesurer. L'arrivée des systèmes d'imagerie numérique rend l'acquisition des images des matériaux relativement facile, en supposant que l'on prenne en considération la résolution du dispositif de capture d'image, que ce soit un appareil-photo ou un appareil à balayage. Il est maintenant possible de caractériser ces images pour fournir une colorimétrie CIE exacte et l'usage de logiciels d'analyse appropriés devrait pouvoir fournir les échelles de mesure qui se rapportent à la texture perçue. L'idée d'établir une série de textures types a été avancée.

EIN ARBEITSRAHMEN FÜR DIE MESSUNG DER VISUELLEN ERSCHEINUNG

ZUSAMMENFASSUNG

Die visuelle Erscheinung kann einer der kritischsten Parameter sein, die die Auswahl eines Kunden beeinflussen, und muß daher quantifizierbar sein, um Vergleichbarkeit und Reproduzierbarkeit sicherzustellen. Ausgangspunkt für die Bewertung der Erscheinung eines Konsumgutes könnte die Messung seiner Farbe sein. Eine Beschreibung seiner Gesamterscheinung jedoch kann nicht durch die Farbe allein erfolgen; andere Merkmale des Materials, aus dem es gefertigt wurde, tragen zur Gesamterscheinung bei.

Beginnend mit der Definition einer weichen Meßtechnik und einer Beschreibung der Meßskalen beschreibt dieser Report einen Arbeitsrahmen, innerhalb dessen ein Satz von Messungen vorgenommen werden könnte, um eine Korrelation zur visuellen Erscheinung zu erhalten. Es wird gezeigt, dass die Wechselwirkungen zwischen den verschiedenen Komponenten dieses Arbeitsrahmens komplexer Natur sind, dass die Wahrnehmung der physikalischen Parameter von Gegenständen durch die physiologische Reaktion des menschlichen visuellen Systems und zusätzlich durch die psychologischen Aspekte des menschlichen Lernens, durch Prägung, Kultur und Tradition beeinflusst werden.

Das Ergebnis könnte die Schlußfolgerung sein, dass ein Versuch, die Erscheinung zu messen, ein zu gewagter Schritt sein könnte. Daher wurde ein Teilarbeitsrahmen ins Auge gefaßt, hinsichtlich dem, was schon heute gemessen werden kann und dem, was erst nach weiteren Untersuchungen und Forschungsarbeiten gemessen werden könnte. Beschäftigt man sich mit den optischen Eigenschaften von Materialien, so erkennt man, daß es vielleicht vier Bereiche gibt, zu denen möglicherweise Messungen durchgeführt werden können: Farbe, Glanz, Transluzenz und Textur. Zugegebenerweise sind diese Messungen nicht notwendigerweise unabhängig voneinander: Farbe kann Glanz beeinflussen, Farbe wird sicher Transluzenz beeinflussen und Textur ist wahrscheinlich eine Funktion aller drei anderen Maße.

Die Farbmessung basiert auf der Messung des spektralen Reflexionsgrades und ist eine bewährte Wissenschaft, die kommerzielle Meßgeräte einsetzen kann, die zu einem vernünftigen Preis erhältlich sind. Auf zwei Schwächen ist hinzuweisen. Erstens gibt es eine Reihe moderner Materialien, bei denen eine Farbmessung unter Verwendung von nur einem Paar von Beleuchtungs- und Beobachtungswinkeln nicht ausreicht, um den empfundenen Farbeffekt zu beschreiben. Daher sind Messungen unter mehreren Kombinationen von Beleuchtungs- und Beobachtungswinkeln erforderlich. Zweitens sind die traditionellen, von der CIE empfohlenen Parameter der Farbmessung, obwohl sie mit der visuellen Empfindung korrelieren, nicht in der Lage, die absolute Erscheinung einer farbigen Probe vorherzusagen. Farberscheinungsmodelle können das jetzt.

Die Messung des Glanzes ist eine eingeführte Methode, aber es gibt einige Zweifel an der wissenschaftlichen Basis der Messungen mit den jetzigen Methoden und es gibt Bemühungen, alternative Ansätze zu finden. Die Erweiterung der Glanzmessung, die im wesentlichen eine Messung unter einem spezifischen Winkel je nach Glanzgrad der Probe ist, hin zur Erkundung der Form der Glanzspitze, sollte zusätzliche Informationen liefern.

Transluzenz ist ein subjektiver Begriff, der sich auf Skalenwerte zwischen totaler Lichtundurchlässigkeit und totaler Lichtdurchlässigkeit bezieht. Das gesamte Gebiet verlangt noch nach Untersuchungen, um ein eindeutiges Meßverfahren zu finden, das wahrscheinlich produktspezifisch ausfallen wird.

Textur ist eine schwerer zu messende Variable. Das Aufkommen digitaler Bildverarbeitungssysteme macht die Erfassung des Bildes eines Materials relativ leicht, vorausgesetzt dass dem Auflösungsvermögen des Bildaufnahmegerätes genügend Aufmerksamkeit geschenkt wurde, sei es eine Kamera oder ein Scanner. Eine Auswertung derartiger Bilder mit CIE basierter Farbmessung ist jetzt möglich und unter Verwendung einer geeigneten Auswertesoftware sollte es auch möglich sein, Meßskalen zu erhalten, die einen Bezug zur gesehenen Textur aufweisen. Es wurde empfohlen, eine Serie von 'genormten' Texturen herzustellen.

1. INTRODUCTION

Regulation and standardisation in industry has brought greater requirements to "measure" the manufacturing process from raw material to finished product. Not only is measurement required but also the data must be archived to provide a historical record to satisfy the various members of the supply chain.

The visual appearance can be one of the most critical parameters affecting customer choice and it needs, therefore, to be quantifiable to ensure uniformity and reproducibility. A starting point in assessing the appearance of a consumer product might be the measurement of its colour. The description of its total appearance, however, cannot be achieved by the definition of colour alone; other attributes of the material from which it is fabricated contribute to the overall appearance. The texture of a surface, for example, will cause changes in colour depending on the lighting direction; the freshness of food is judged by its overall appearance, but in a way that is much more subtle than by just its colour; and novel effects such as pearlescence are added to products to enhance their attractiveness. For some products, such as cosmetics, it is not only their own appearance characteristics that are important, but also the visual effect after they have been applied to the skin, nails, hair, etc. It is clear, therefore, that the interest of industry in the measurement of appearance goes beyond simply measurement of surface colour.

1.1 Who benefits from the measurements

- Consumers:

Tools will be developed to understand better the correlation between what customers see and buy, often by judging the appearance, and the influence of the manufacturing process on the total appearance of those products.

- Industry:

Instruments will provide measurements that give greater confidence in the manufacturer's ability to make quality products. The scales used for measurement can be agreed, leading to universal compliance. It should be possible to influence the development of new products based on a consumer's judgement of quality related to measured values.

1.2 How industry will benefit from the measurements

- Improved measurement technology - leading to better quality control:

Research will be highlighted that focuses on techniques key to the understanding of the measurement of appearance. The goal is to understand some of the problems, to provide a framework describing the relationships between the various proposed measurement parameters, and to encourage others to contribute the findings of their research to the knowledge base that will support the framework.

- Access to and support of measurement traceability:

Success in defining new measurement scales can be enhanced by an understanding of the uncertainties in the measurements. Once a primary scale is established then traceability of industry-based measurement systems is possible.

The measurement of visual appearance can be considered a part of the overall science of soft metrology.¹

¹ Definitions of relevant terms can be found in Section 9 *Glossary of Terms* of this report. These terms, and their associated definitions, are offered as suggestions, except where they are denoted as coming from the CIE International Lighting Vocabulary or ASTM E284 Standard Terminology of Appearance. After separate discussion and consideration by CIE TC 1-64 *Terminology for Vision, Colour and Appearance*, additional terms will be included in a future edition of the Vocabulary, or a component of it.

1.3 Soft metrology - a definition

Soft metrology covers the development of measurement techniques and mathematical models that enable objective quantification of the properties of materials, products and activities, that are determined by human response (Fig. 1).

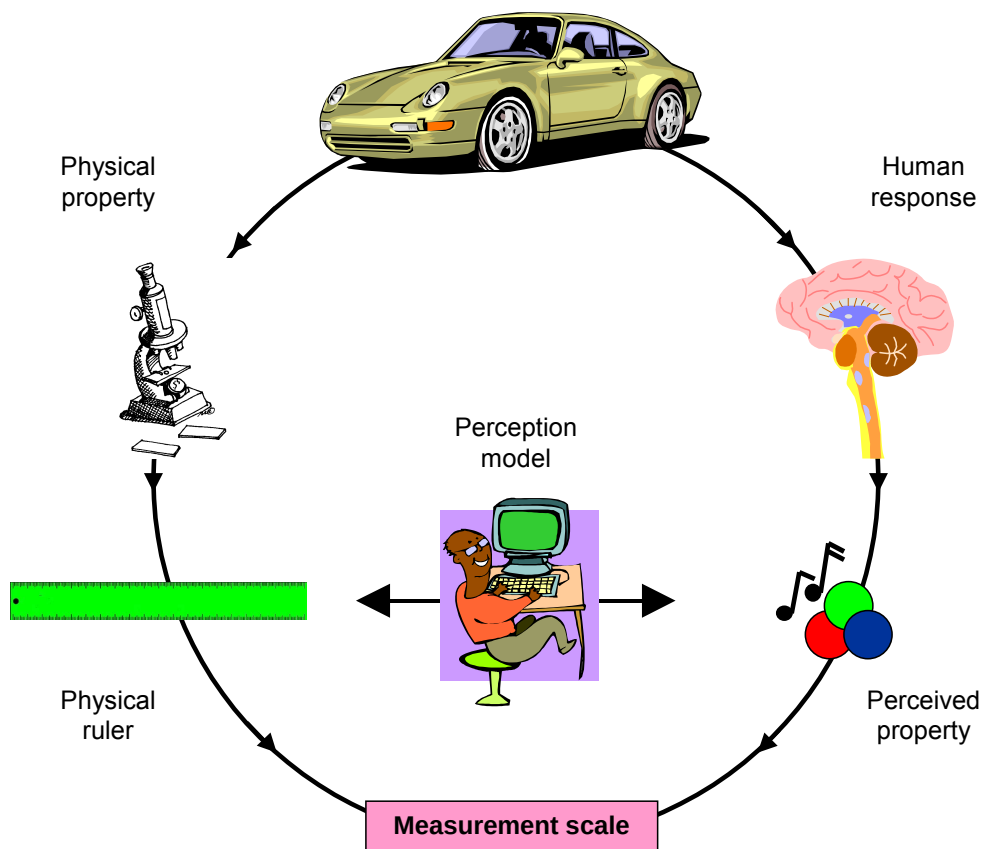


Fig. 1. A perception model that relates a physical property of an object as measured, to an aspect of that object defined by a human response.

Soft metrology, in its broadest sense, is not yet an established branch of metrology but it can be formally defined as:

The measurement of parameters that, either singly or in combination, correlate with attributes of human response.

NOTE: The human response may be in any of the five exteroceptual senses: sight, smell, sound, taste and touch.

Thus, soft metrology¹¹ entails the measurement of appropriate physical parameters and the development of models to correlate them to perceptual quantities. Traceable soft metrology can be achieved both through traceable measurement of the physical parameters and the development of accurate correlation models.¹

¹¹ The definition given is limited to the responses to the exteroceptual senses because these are the senses that advise us of the outside world. Additional senses, the proprioceptual senses, give us, for example, the sense of the position of parts of the body, relative to neighbouring parts of the body.

1.4 Measurement scales

Soft metrology can be considered as the investigation of correlation between human, subjective responses, and physical, objective measures. What is generated is a measurement scale, a number series, that allows the subjective response to be predicted from the objective measure (Fig. 2).

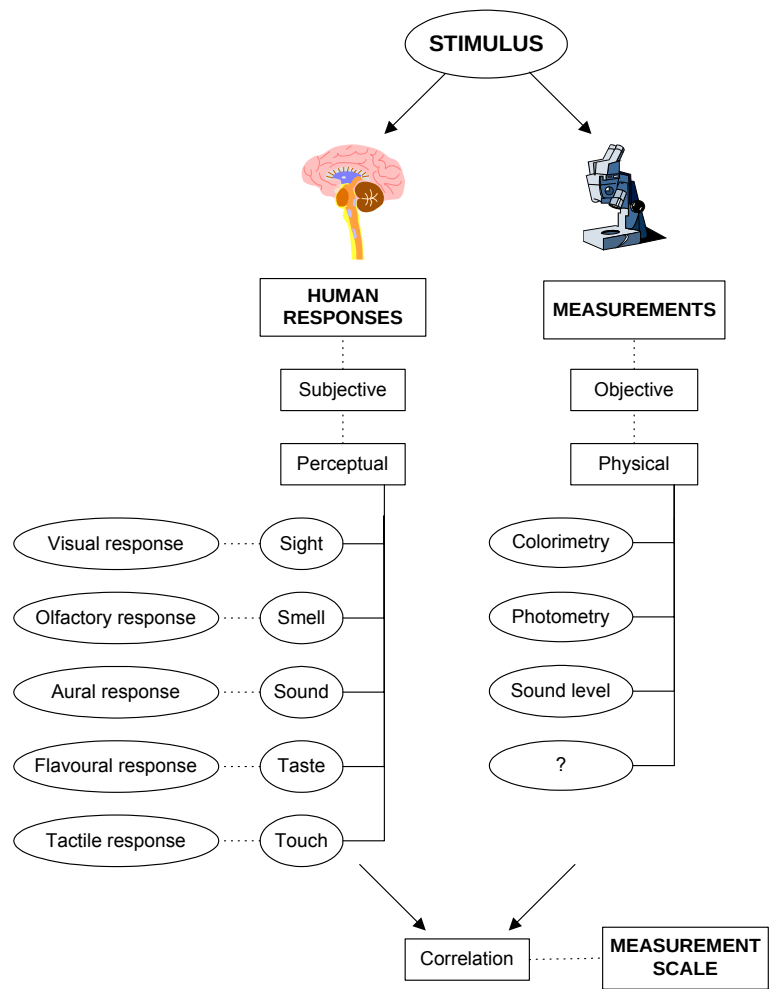


Fig. 2. The concept of a measurement scale correlating human responses to physical measurements.

One way of thinking about the subject of soft metrology is to consider, as an example, the perception and measurement of length. Consider a series of boxes perceived to increase in size (Fig. 3).



Fig. 3. A set of boxes that are perceived to increase in SIZE: if the boxes are square then the corresponding physical measurement is of LENGTH of the side (for example, in metres).

A human observer could be asked to denote a number that relates to their impression of the size. Equally, a device could be constructed, for example a ruler, which could be used to "measure" the size of each box. It is likely that the human responses, the "soft" measure, will correlate with the measurements made using the ruler, the physical measure. This example may be thought trivial because the concept of using a ruler as a readily available measuring device is well understood.^{III} If required, the ruler can be calibrated and form part of a traceable measurement system with associated measurement uncertainties.

A second example might prove a little more demanding. Consider the series of boxes shown in Fig. 4.



Fig. 4. A set of boxes that differ in a systematic manner.

To the human observer, something is changing as the boxes are scanned from left to right - what is it? How can it be described? Some may call it lightness, some brightness, some density; others may think in terms of the amount of ink or toner that has been laid down on the paper in reproducing each box. It has been shown by experiment that human observers, after a little training, can give a consistent response to the changes they see. Equally, a number of physical measures, for example the reflectance factor, the density or even the (relative) luminance, can be made of each box using a suitable meter, and a scale constructed that relates the two "measures".

Thus, in the example shown in Fig. 4, the perceived lightness of each box can be predicted from a measure of its relative luminance. It should be noted that the relationship between the subjective and the objective measures that define the scale does not have to be linear and may involve more than one objective measure. For example, if the boxes in Fig. 4 were coloured, their appearance may change according to the level and colour of the illumination used to view them as well as by the variation in the reflectance of the substrate surface.

There are many other examples that could be given of human responses and their associated measurements. To date most of these examples are associated with visual and aural response because it is in these areas that most advances have been made in seeking correlations between the subjective and objective measures. Fig. 5 and Fig. 6 provide illustrations of the soft metrology associated with two consumer products: a car and a tomato respectively.

^{III} This example can be further explored: one can choose the length to describe the boxes, but also the area as the objective measure. The relationship will be different, which illustrates that measured quantities sometimes have to be "processed" in order get suitable correlation.

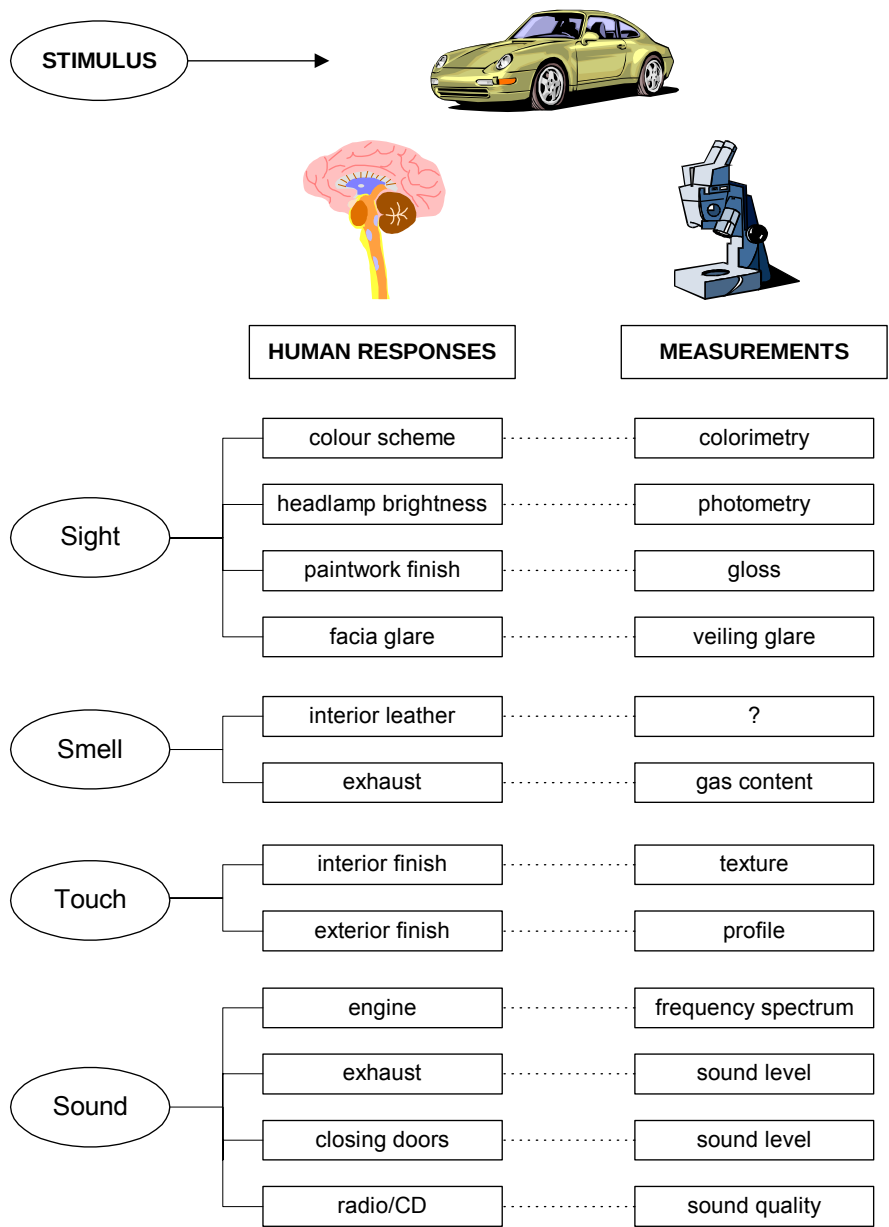


Fig. 5. An example of soft metrology showing some of the physical measurements associated with human responses to a stimulus - a car - in a defined, lit, environment.

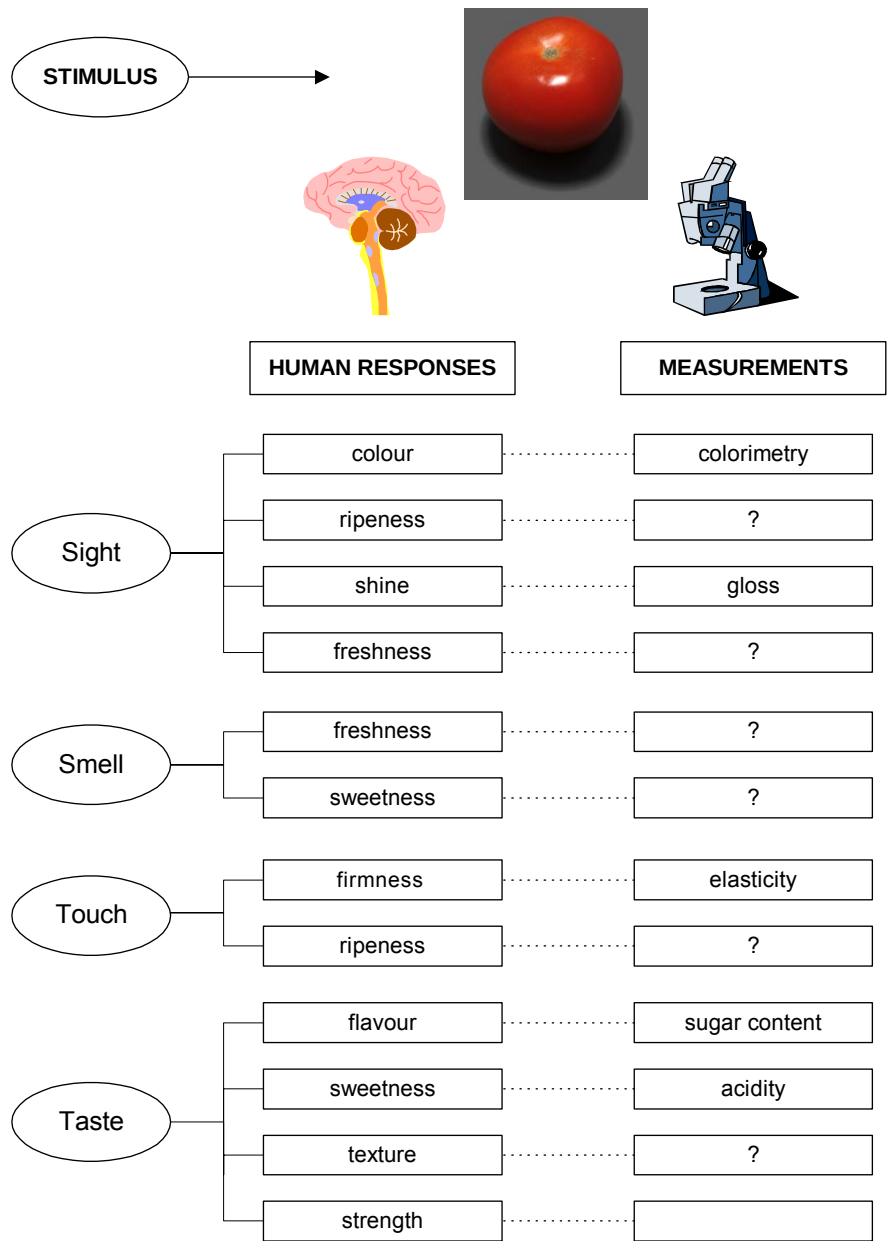


Fig. 6. An example of soft metrology showing some of the physical measurements associated with human responses to a stimulus - a tomato - in a defined, lit, environment.

The examples given above, where a relationship is sought between a subjective observation and a physical measure, come under the general heading of psychophysics which was first introduced by Fechner in 1860 and Weber in 1846. S.S. Stevens^{2,3} describes how methods including ranking, paired comparison, interval scaling and magnitude estimation can be used to determine the variability and dispersion of human behaviour when presented with a series of stimuli.^{4,5}

1.5 Economic relevance of soft metrology

Much of human behaviour is controlled by responses to the five senses. To the consumer, the appearance, the feel, the smell, the sound and the taste of specific products, whether natural or man-made, is used to assess quality, both consciously and subconsciously, and hence mediate product choice.

There is an industrial requirement to characterise consumer products to enhance their attractiveness to consumers and to ensure appropriate quality control of perceptual attributes during manufacture. It is therefore essential that instrumentation and methods are available to measure characteristics of products that are correlated to the human response. This is especially true of "quality" related parameters that have been judged traditionally by human response using an "expert" or product panel. The ISO 9000 / ISO 14001 quality framework, however, requires that these parameters be "measured" in a more formal way, together with associated tolerances, to establish a formal quality-control system. Measurements are more easily made using instruments because of their inherent controllability, stability and repeatability: they are more reliable than the human being but cannot replace him.

2. APPEARANCE

Light touches so many areas of modern life that it is important that measurements of light itself, the detection of light and the optical properties of materials, including their colour and gloss, are made on a recognised and traceable basis. Such is the importance of light; it is the only human response that has an associated SI Unit, the candela.

2.1 The measurement of light

Quantification of a psychophysical parameter, such as the level of illumination in an operating theatre, appears straightforward. The purchase of a simple meter, a quick measurement, and an entry in a notebook should provide a complete process. The validity of the measurement is however, open to question unless comparison is made with the measurement of an appropriate reference standard. Even then, there is no guarantee of validity unless that reference standard is in turn directly traceable to a well-maintained national scale that is validated by international comparison.

2.2 Appearance - a definition

Appearance may be defined as follows:⁶

the aspect of visual experience by which things are recognized

in psychophysical studies, perception in which the spectral and geometric aspects of a visual stimulus are integrated with its illuminating and viewing environment.

Members of TC 1-65 felt that the first definition was not correct because the concept of recognition is not automatically part of "appearance": it is perfectly possible to give a good description of the "appearance" attributes of an object without recognising the object. Thus, visual appearance impacts on recognition but does not necessarily result in recognition.

After much discussion the members of TC 1-65 move towards accepting the following definition of appearance:

visual sensation through which an object is perceived to have attributes such as size, shape, colour, texture, gloss, transparency, opacity, etc.

There is however, an implied pre-condition in this definition in that there should be a desire in the observer to want to perceive various attributes of the object. In fact, this is an inbuilt response that comes as part of the processing ability of our brain. We perceive an "image" of the outside world in our visual cortex and automatically apply pre-learned rules to what we "see" in that image. This leads to perception and subsequent interpretation of the objects in the image. Thus, we might perceive a vase of flowers on a table. In passing, that is all we see but if our attention is drawn to the flowers, perhaps by additional responses, the fragrance or someone remarking on them, then we apply further rules to interpret the image and may distinguish the type of flower, and perhaps how they got there or who gave them to us. This might further evoke memories of other instances when flowers were significant. Thus the concept of appearance, leading to the perception of objects, is very important to the way we lead our lives.

There are however, many different views of "appearance" and it is important to distinguish between the appearance of an object, the appearance of a scene, and appearance as feelings or expectations derived from the look of the object or scene. This leads to the concept of "total appearance" that can be defined as:

the visual aspects of objects and scenes

It is important, when considering any appearance related definition, that we are clear as to whether we are trying to define the scene, an object or an expectation. Commercially and industrially all three are of significance. Digital methodology will permit the specification of the scene, and each object within it. Thus, it should become possible to relate measurements using this methodology to specific expectations of a specific material or scene. With respect to the whole scene, expectations derived from the total appearance of that scene (which include our feelings as individuals) can be classified into the following:

- visually assessed safety (that is, safety of our existence within the scene);
- visual identification of the scene;
- visually assessed utility or usefulness of the scene;
- visually assessed pleasantness of the scene;
- and visually assessed satisfaction that we predict we shall get from the scene.

Each object occurs as part of a scene. Each scene possesses a visual structure. Each element of this visual structure possesses distributions of colour, gloss, translucency, surface texture, and temporal properties (aspects of these properties that change with time). Hence, it is important to specify whether we are talking about the "material" or the "scene". The following definitions of appearance have been used successfully within the food industry for some years:⁷

The appearance of a material can be defined in terms of its visual structure; each element of which possesses distributions of surface texture, colour, translucency, gloss, and temporal properties.

The appearance of a scene can be defined in terms of the properties and interrelationships of its constituent materials and of the expectations these generate.

2.3 The measurement of appearance

The quantification of the appearance of an object or a scene is an altogether more complicated issue.⁸ We use the response from our visual sense to process the complex patterns of light around us into objects, space, location and movement, and from that information, we make judgements leading to a particular course of action. For example, how we perceive the visual appearance of a product may cause us to buy it, reject it or even write to complain about it. We may choose to buy a particular food because its appearance suggests freshness. Our choice of car may have been influenced because its glossy appearance made us think of quality and prestige. Alternatively, we may reject a particular surface finish because its appearance suggested poor quality and the presence of defects. All of these examples represent judgements made on appearance.

Is this food safe/desirable to eat? Will this car improve our image? Is this surface finish adequate for the job? If it were possible to measure appearance, and make the link between those measurements and consumer perception and product characteristics, then the possibility would exist to ensure an affirmative answer to all the above questions before the products left the factory. It is not surprising to learn, therefore, that there is considerable interest within industry to be able to make quantitative measurements of appearance, in order to improve efficiency in such areas as product development and production/quality control.

The sophistication of our visual sense works against us when considering the measurement of appearance, since we perceive appearance so easily that it is often difficult for us to analyse what actual physical attributes contribute to our observations. The overall appearance of an object is a combination of different attributes, which are produced via the interaction of the object with the light falling upon it. Spectral absorption and diffuse reflection of the light by the pigments within the object gives it the attribute of colour. Some objects

reflect the light from their surface, which we then perceive as gloss or haze. The amount of scattering of the light as it is transmitted through parts of an object, prompts a judgement on translucency. Although, at the moment, it is not possible to make a single measurement called appearance - and this will probably never be achievable, it is possible to design instruments to "measure" the various components of appearance and to make some kind of correlation to visual perception. Thus, a goal of making measurements that ensures appropriate quality control in the manufacturing process is achievable, but the measurement process will be multi-dimensional, product specific, and probably application specific.

2.4 Total appearance

In order to develop a strategy for appearance measurement it is useful to derive a framework that describes the requirements in a structured manner.^{9,10} This framework should, ideally, include the measurements that it is possible to make now, and predict the measurements that are required to describe fully the total appearance of an object or scene. The concept of total appearance, introduced by Hutchings, extends the concept of the appearance of an object beyond a description of its colour^{11,12} and has already been defined in Section 2.3 above.

Thus, we might be asked to describe the appearance of a piece of fabric and respond in terms of its colour, thinking we have fully satisfied the questioner. The total appearance, however, would require a description of the shape, size, texture, gloss and any other apparent quality that the fabric exhibits.

The structure of an object (Fig. 7), may be described in terms of its constituent molecules arranged in particular geometries in space. This is a self-contained concept in that it looks within the object such that the object itself defines the region of interest. It is usual, however, to view the object in an environment and this provides the stimulus. Thus, the object is perceived as illuminated with light that has a measurable spectral distribution of energy that will dictate its colour and absolute level; the object is surrounded by other components of the scene that themselves have a total appearance; our visual senses, in terms of our retinal response and associated neural synthesis, lead to an appearance response or perhaps more correctly a total appearance response; and finally, the appearance response is modified by temperamental factors into images that evoke reactions or expectations - quality judgements, acceptance or not, etc.¹³

In terms of objective and subjective measurement, it is usually the stimulus that is exposed to a physical measurement and the appearance response, the subjective response, often comes from an expert panel within the relevant industry. It is the man-in-the-street, the consumer, who has an expectation for a particular object or product and exhibits a preference for that object over another.

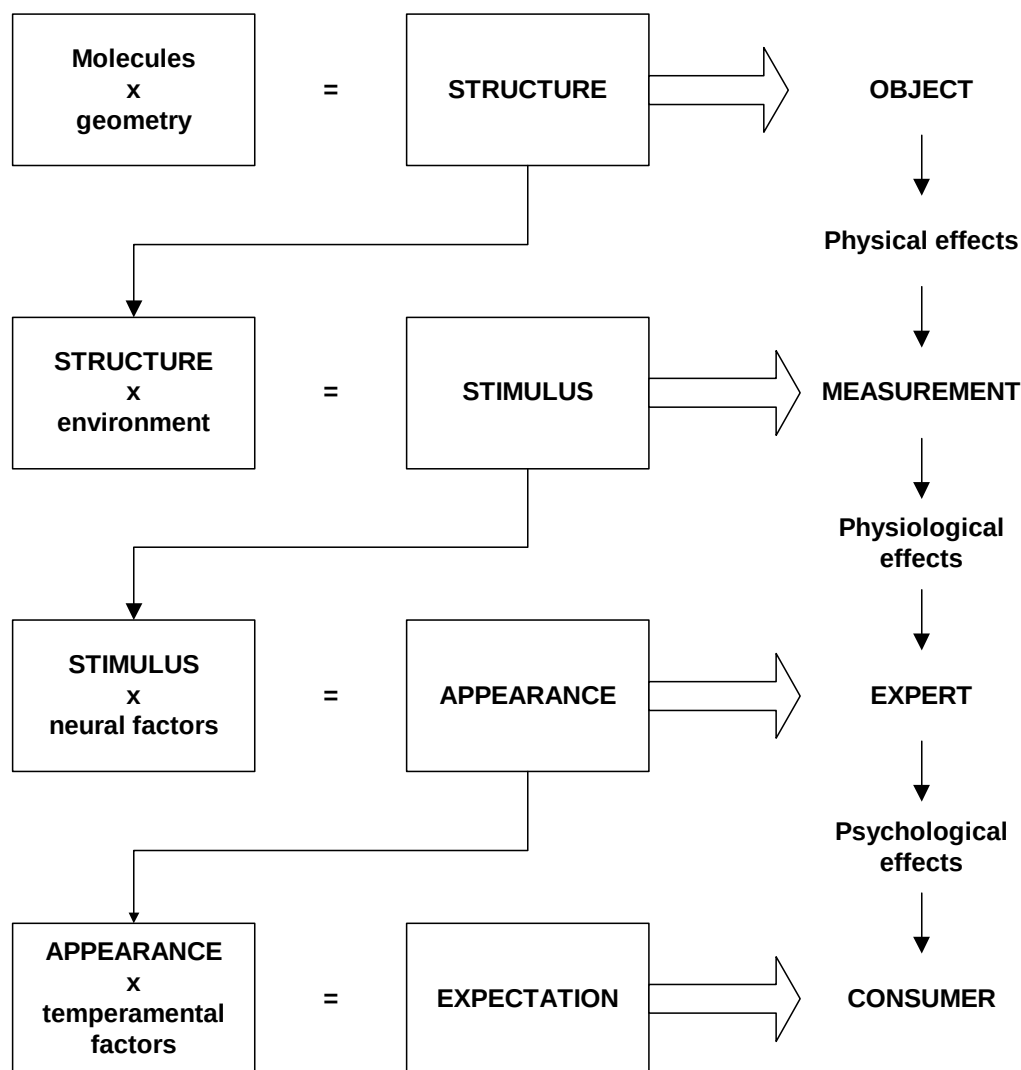


Fig. 7. A framework linking the neural and temperamental factors associated with appearance.

Another way of thinking of an object¹⁴ is to consider three aspects of appearance: physical, physiological and psychological (Fig. 7). For instance, the gloss and colour of objects depend on the geometrical spatial distribution of light reflected by those objects (the physical aspect); this light distribution then stimulates the binocular human visual system, i.e. it provides a sensation (physiological aspects); and finally, thanks to long training, these sensations are interpreted by the cortex and perceived as objects (psychological aspects).

Some synergy between these two ways of thinking is apparent in that the physical aspects are similar and measurable. The structure shown in Fig. 7, however, ignores (or hides) the physiological aspects of appearance by assuming that their influence is on the appearance as interpreted by the visual response - the expert response. It is only after taking the temperamental factors into consideration that this response is modified and the psychological response obtained.

2.5 Factors affecting total appearance

At each of the three lower levels described in Fig. 7, there are important factors that contribute to the response.¹⁵ As already described, the light source that illuminates the scene has a spectral power distribution that defines the colour and absolute level of that illumination (Fig. 8). The object itself has physical properties (structure), optical properties, and temporal properties. The appearance response is influenced by the colour vision of the observer, by

the spatial vision of the observer, and by the age of the observer, and the influence of responses from the other senses: hearing, smell, taste and touch. While these other responses are not considered as part of the framework for appearance measurement, their existence cannot be ignored because they influence any subjective data derived by observers.

The final stage, that defines the expectation of the observer, is influenced by many factors including the pre-conceptions of what the object should look like based on memory, cultural difference, what is in fashion, as well as our preference.

The inference from the above is that "total appearance" is a concept that is derived from a physical object or stimulus under the influence of the factors described by the various levels described by Fig. 7 and Fig. 8. In the real world, however, this is not the case because the appearance images come first - we see what we see - and we base our responses and decisions on our interpretation of that image. Thus, Fig. 8 could, with strong reason, be drawn the other way up!

Hutchings¹¹ suggests there are two classes of appearance images: the impact (or Gestalt) image, and the sensory image. The impact image is the initial perception of the object or scene (the Gestalt), plus an initial opinion or judgement. For the sensory appearance image, three hedonic descriptors are suggested for use, perceptual, emotional and intellectual, that are used to prompt questions that should be asked of the image. For example, when eating jam, the sensory image contains an assessment of the visually perceived sensory properties - this jam will taste of strawberry. The emotional aspect might indicate that "we are eating this cake because we are celebrating my birthday". The intellectual aspect might provoke the question "who baked this cake?"

Thus, the concept of total appearance is indeed complicated, not least because of the multiple interactions between the various components of the process from object to expectation via visual response.¹⁶

An example serves to illustrate this complexity. Tomatoes are perhaps initially perceived as being round red objects. Experience (memory - training) tells us that these are tomatoes, or at least they look like tomatoes (they might be real; they might be models). Depending on our expectation of the tomatoes, other responses are evoked. If we are in the supermarket and want to buy them, then we might take particular notice of the colour and firmness as an indication of ripeness, the shine as an indication of freshness and the smell as an indication of sweetness. These responses are inter-related and their outcome leads to a decision based on the overall (perceived) quality; we either buy or not. Assuming a purchase is made then the decision is vindicated at home when the product is eaten because now the taste response, the flavour, the sweetness and the texture, all bear on our feeling of enjoyment (quality).

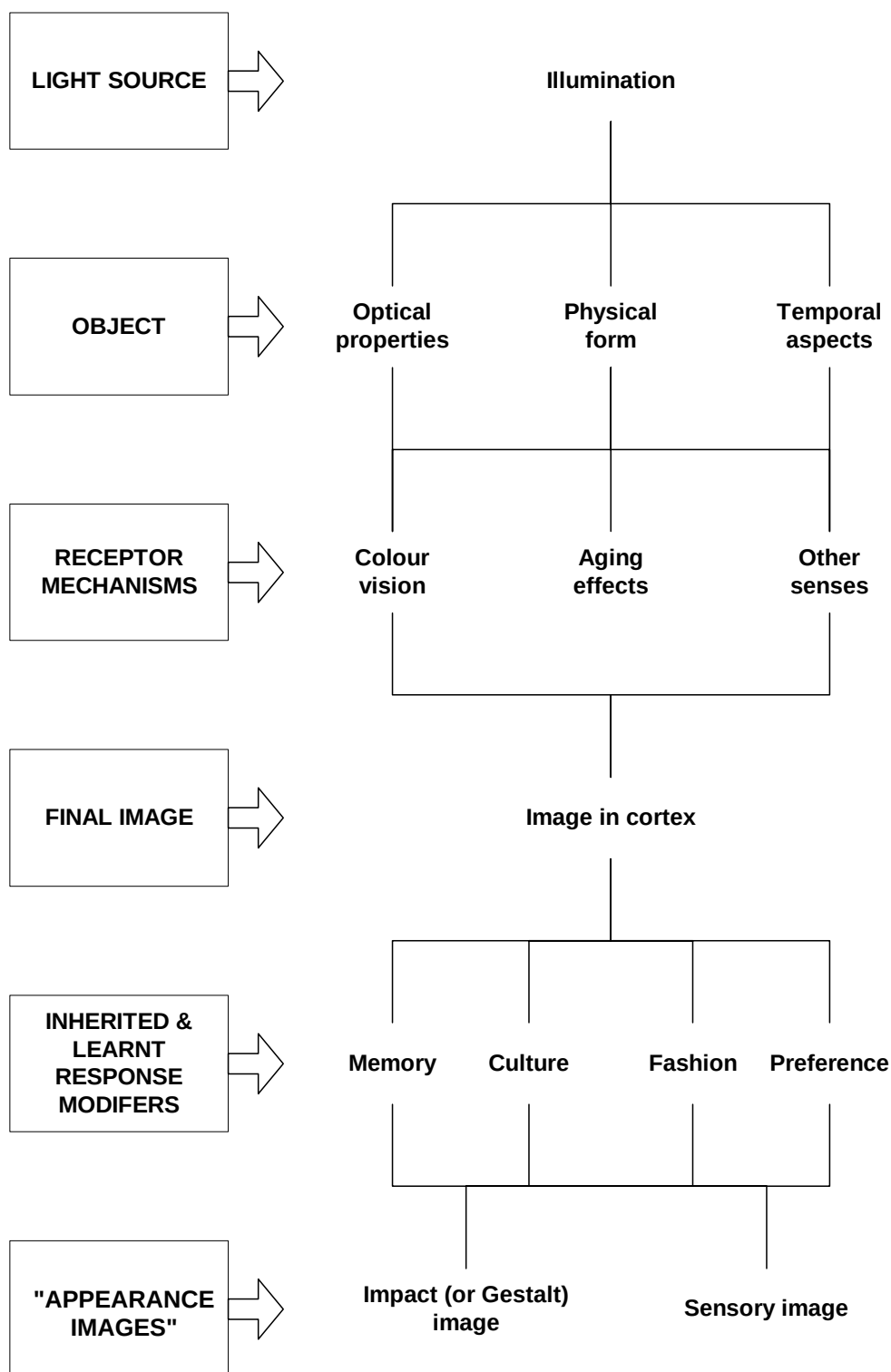


Fig. 8. Factors affecting total appearance.

As indicated above, it is unlikely that any physical scale called "appearance" will be possible and it is, therefore, necessary to look into the framework and find physical parameters that can be measured and the most obvious area for exploitation is that described in terms of the optical properties.

2.6 Discussion

The above section attempts to provide a logical framework that describes the way in which the human observer responds to an external stimulus and, with the added benefits of both experience and memory, is able to make judgements about that stimulus in terms of its appearance. Observers can make a distinction between two kinds of human response:

- a) a perceptual response (perception) can be considered a response to the stimulation by producing (as a consequence of being stimulated) the appearance of perceived objects in our phenomenal world;
- b) a motor response, and behaviour in general, can be considered a response to the perceived objects (not to the stimulus): in this case human response is determined in large part by evolutionary factors.

In order to "measure" this concept called appearance, part of the framework includes the consideration of physical parameters that might correlate with the human response, Fig. 7. The next section of this report considers a further sub-division of the measurements into several different classes based on the optical properties of the object whose appearance is being assessed.

In all of the discussion, several important considerations have been assumed. Most of these considerations might in themselves influence the final appearance of the object and so, in a complete assessment of appearance, need to be considered as variables in the system. It is reasonable for the sake of simplicity, however, and within the scope of this report, to consider these parameters as fixed, defined or constant.

Our reaction to the appearance of an object is governed by the stimulus received by our senses and our response to that stimulus; the latter being the result of both physiological and psychological factors that have elements of commonality and difference across ethnic, cultural and geographical boundaries. The way a person responds to a stimulus is governed largely by his experience. It is likely that human experience does not have enough commonality to allow the development of universal measurement scales. Thus, each scale may relate only to a specific object as perceived by the members of a given population.

In all situations requiring an assessment based on appearance it is a precursor that the object be lit, and the design of the lighting itself can either enhance or detract from the quality of the perceived object. A successful lighting design, whether it is daylighting or artificial lighting or, as is more usual, a combination of the two, needs to satisfy a number of often conflicting requirements, one of which can be termed the visual function.^{17,18,19} This function includes many parameters:

- the size of the light source, large and diffuse, or a point source, relative to the distance from the object - this will effect the highlights and shadows;²⁰
- the angular position of the light source, or sources, relative to the object and to the direction of view - this will effect the light modelling, as well as the highlights and shadows;²¹
- the spectral distribution of the output of the source;
- the level of illumination - as characterised by the brightness at the task area;²²
- the uniformity of that illumination over the task area;
- the contrast between the task area and the surrounding area;
- the amount of glare coming from extraneous light sources;
- the colour performance of the light source;²³
- the presence of flicker from the light source;²⁴
- the reflectance of the object(s) to be lit.²⁵

In addition, there are other areas which must be considered in any good lighting design.²⁶ These include - in no particular order:

- energy efficiency;
- installation maintenance;
- capital and operational cost;
- architectural integration;
- visual amenity;
- durable development.

The scene is defined in part by the illumination. Thus the lighting appearance of a scene, in which there is a space where a task has to be performed, can be an important additional consideration in any discussion of total appearance. Lighting can be regulated, but only to the extent that a number of Codes of Practice are available that provide recommendations for lighting specific scenes, both interior and exterior.²⁷ The concept of personal preference also plays an important part in many lighting installations especially for social use: for example, a low level of illumination may not be realistic for reading the menu in a restaurant, but it may be preferred from an aesthetic point-of-view! Preference is subjective and requires careful assessment; suggestions have been made, however, for its definition when applied to practical applications.^{28,29}

Another parameter that has arguably been assumed in the above description is that of shape, or form perception. This aspect of appearance also includes depth and motion perception. There are many different theories about how we recognise shapes.^{30,31,32,33,34,35,36}

- Template theory - we have idealised templates stored in memory and we perform a match between these templates and the visual stimulus.³⁷
- The Gestalt psychologist's approach that emphasizes the whole context of an object and is not so interested in the individual elements of a scene but how they are all arranged together.
- The information processing approach which focuses on a sequence of events and has the goal to try to understand each part of the sequence in terms of hierarchical or parallel organisation.

This latter theory attracts most support perhaps because it encompasses elements of the other two.

Template theory requires only the knowledge of the shape of elemental parts of objects, the so-called primitive features. These can be both two-dimensional and three-dimensional, and it is assumed that the cortex "parses" the information from the scene, a process known as perceptual parsing, and "interprets" its appearance in terms of the different primitives and their relationship one with another.³⁸

Gestalt theory has dominance over template theory because it requires not so much the recognition of templates but the understanding of the organisation of the whole scene: not the parts of the scene but the sum of those parts. Thus, the form or shape of an object is not perceived as a collection of its individual components but as a whole (Gestalt: a German word that can be taken to refer to "an organised whole"). As an example of a Gestalt interpretation, we recognise a television newsreader as a human being and assume that he/she has legs, even though they are not usually seen on the television screen. A mere analysis of the component parts of the image would not lead to this conclusion because the information perceived would be taken at face value.

The size of an object, in its viewed environment, gives a clue as to the location of that object in a depth perspective and the temporal change of the object gives clues as to its movement (or not). Traditionally it has been assumed that depth perception is facilitated by the fact that the two two-dimensional images formed on the separate retinas of the two eyes are different and that the cortex uses the different information to construct the three-dimensional image of the scene. There are however, a number of monocular depth clues and an example is objects seen alongside receding railway lines. The parallel lines will converge

in the distance, thus indicating where the distant point is and providing a suitable scaling point.³⁹

3. OPTICAL PROPERTIES

The appearance of an object depends upon its visual structure, and this is described in Section 2 in terms of the ability of an observer to perceive the object. Perception is possible because of the interaction between light and the materials of the structural elements of the object. This perception process is rapid and usually very accurate, and comes about because of the reflection, transmission, refraction, absorption and scattering of light by the object.

The relationship between the physical structure of a material and its optical radiation properties (scattering, reflection, etc.) is complex. For example, selective absorption, which is largely responsible for the colour of a material, takes place during the passage of light through that material. Scattering occurs where light encounters interfaces between pigments and resin, fibre, air, etc. Normally, when particle sizes are made smaller, less light is absorbed during the passage through each particle resulting in less colour being apparent. At the same time, the total particle surface becomes greater, leading to an increase in light scattering, or diffusion, since reflection occurs at the particle surfaces.

3.1 Measuring optical properties

It is possible to divide the characterisation of the optical properties of materials into at least four groups (Fig. 9): colour, gloss, translucency and surface texture⁹. These groups are perhaps not definitive but they are intuitive and represent useful categories for measurement, especially in view of the fact that measurement techniques already exist for some of them. In addition, note that they are not independent in that there must be links between colour and gloss, and colour and translucency, etc.

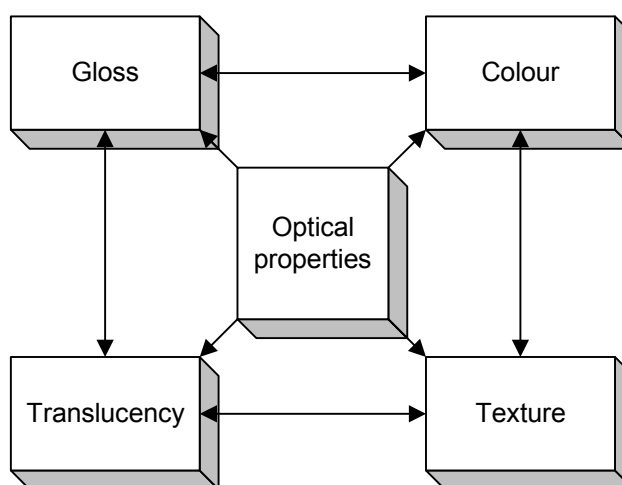


Fig. 9. The suggested sub-division of the optical properties of materials into measurement groups - with interactions between those groups.

Colour is involved in the perception of all optical properties and the optical radiation can be measured using a radiometer, a photometer or a colorimeter. While a radiometer measures the optical energy present however, photometers and colorimeters include functions that take into account the spectral response of the human visual system and so measure visual properties. Thus, in radiometry the amount of radiant power is measured using detectors that have a known response for each wavelength. In photometry, the amount of light in a stimulus is compared with that of a standard stimulus to provide a photometric measure. These amounts of light may be compared by visual assessment, but it is common to use a filtered photo-detector whose spectral response approximates to that of the human

eye. In colorimetry, the amount of light reflected from, or transmitted by, a stimulus can be detected using three photo-detectors whose individual spectral response approximates to the colour responses of the human eye.⁴⁰

These measurements can also be made spectrally by measuring the amounts of radiation using narrow bands of wavelengths situated at regular intervals throughout the spectrum. The photometric and colorimetric parameters are then calculated using tables of data corresponding to the appropriate spectral responses.

Thus, the human perceptual attribute, the "colour", of a sample can be "measured" in terms of the response of the CIE standard observer using a CIE illuminant and its position relative to any other colour located on a colour map. This type of measurement is important, for example, in assessing whether the colour of a signal light is appropriate. To be correct, the measured colour must fall within a defined area on the colour map, and this area is usually specified by an appropriate standard. There should be no overlap between the areas designated for different coloured signals to avoid confusion to the observer. An application is in railway signalling where red signals from different manufacturers may appear to have a slightly different colour but their measured colours must all fall within the designated area of the colour map. Thus, to the train driver they should all appear "red".⁴¹

In industry, often the relative "colour-difference" between a reference sample and a test sample is more important than absolute colour. In the clothing industry, for example, a cloth sample swatch might be provided for a dye-house to formulate a recipe and dye a sample to match. While an instrument can measure the colour of both pieces of fabric in an absolute sense, it can also calculate the colour-difference between them, on a scale that correlates with the colour difference perceived by a human observer.

3.2 Cesia

In 1991, Caivano has published several papers describing his concept of cesia, which he describes as the psychophysical evaluation of different modes of appearance.^{42,43,44,45,46,47,48} Cesia recognises four elements of an object that are similar to those described above and to be elaborated on in this report: colour, gloss, translucency and surface texture. The proposal is interesting in that it attempts to embrace the concept of "total appearance", but confusing in that it recommends the use of scales that mix various aspects of perception. For example, the "matt white - matt black" scale mixes two basic perceptions, i.e. matt (a gloss term) and black/white (a colour term). In addition, the "specular - transparent" scale mixes a gloss term (specular) and a translucency term (transparent). This mixing of perceptual terms for the scales defined by the concept means that their measurement would be difficult. Thus, while the concept of cesia is recognised as contributing to the very complex subject of total appearance, it is not obvious how it contributes to the measurement of appearance.

In the following sections of this report, each of the four separate groups: colour, gloss, translucency and surface texture will be discussed in more detail. The present knowledge of how they can be measured will be described, together with an indication as to how improved measurement can contribute to understanding the way in which visual appearance might be "measured".

3.3 Measuring colour

Colour can be "measured" using the human eye and an example of a visual colorimeter is the Lovibond Tintometer that uses glass filters that conform to the three Lovibond Scales.⁴⁹ Originally constructed to measure the colour of beer, it relies on three sets of glasses that are uniformly graded to provide a continuous scale in red, yellow and blue. The observer makes a match between combinations of these glasses and the object whose colour is being monitored. The result is then expressed in terms of the amounts of the three glasses. As such, this can be considered to be a measurement of the appearance of the object, for example a particular sample may be matched as 25 Yellow 10 Red. While this instrument has found wide acceptance in the brewing, edible oil, petroleum spirit, honey, tallow and fats, rosins and resins industries, it relies on the individual observer to make the match and thus represents a simple means of measuring colour. An interesting extension of this visual colorimeter is the establishment of a large number of one-dimensional scales for specific

products. Examples are the European Pharmacopoeia scales^{50,51} for the pharmaceutical industry, (Fig. 10), the Gardner scale for resins,⁵² the ASTM D1500 scale for petroleum oils,⁵³ the ICUMSA scale for sugars,⁵⁴ the EBC Scale for beer,⁵⁵ the Platinum-Cobalt/Hazen/APHA Colour Scale for water,⁵⁶ and the US Naval Stores Scale for rosins.⁵⁷ These scales are truly appearance scales in that a series of glasses is designed to visually match the range of a specific product.

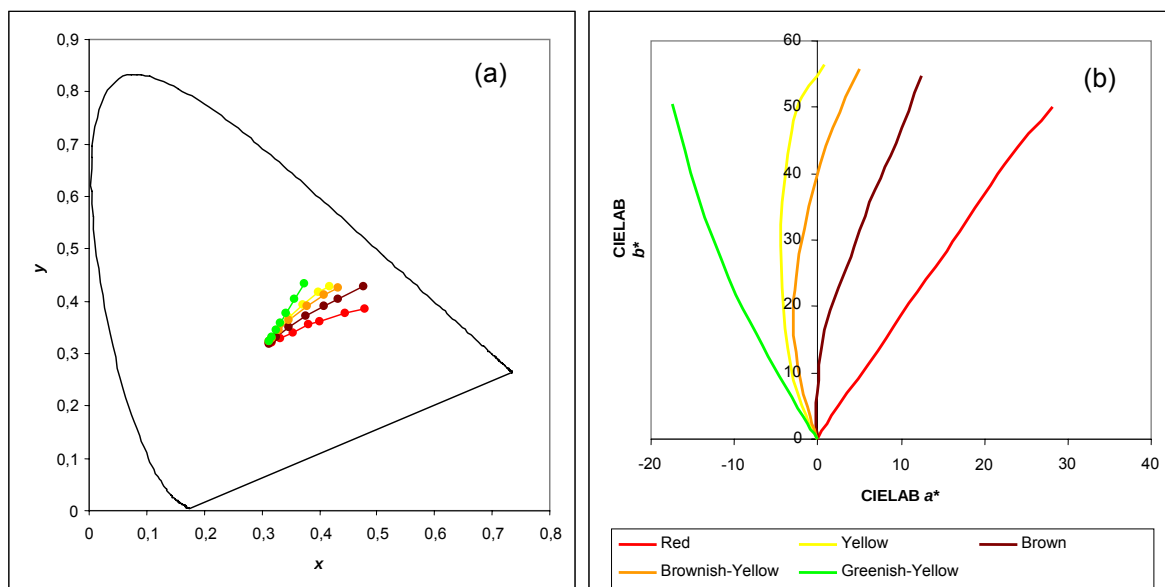


Fig. 10. The 5 colour scales of the European Pharmacopoeia standards plotted in (a) the x, y chromaticity diagram and (b), the a^*, b^* diagram.

3.4 CIE colorimetry

In order to measure the colour of a surface more rigorously, three things must be characterised: the light source used to illuminate the surface, the spectral absorption properties of the surface and the spectral response of the human eye (Fig. 11). The CIE (Commission Internationale de l'Eclairage) has specified a helpful measure of the light source and the observer, and the measurement of the spectral reflectance (or transmittance) can be made using a suitable spectrophotometer.⁵⁸

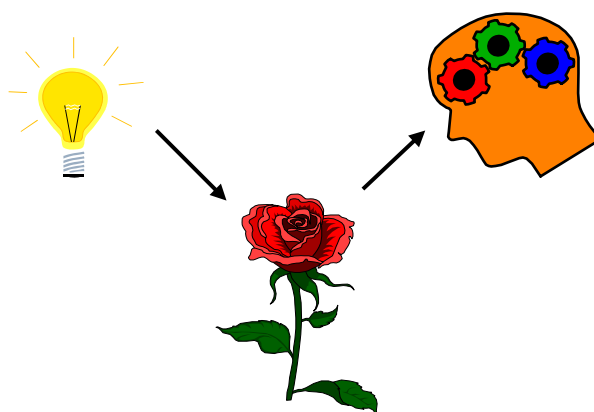


Fig. 11. The fundamental components that lead to the perception of colour: a light source, a selectively reflecting surface (of an object) and a three-channel detector,

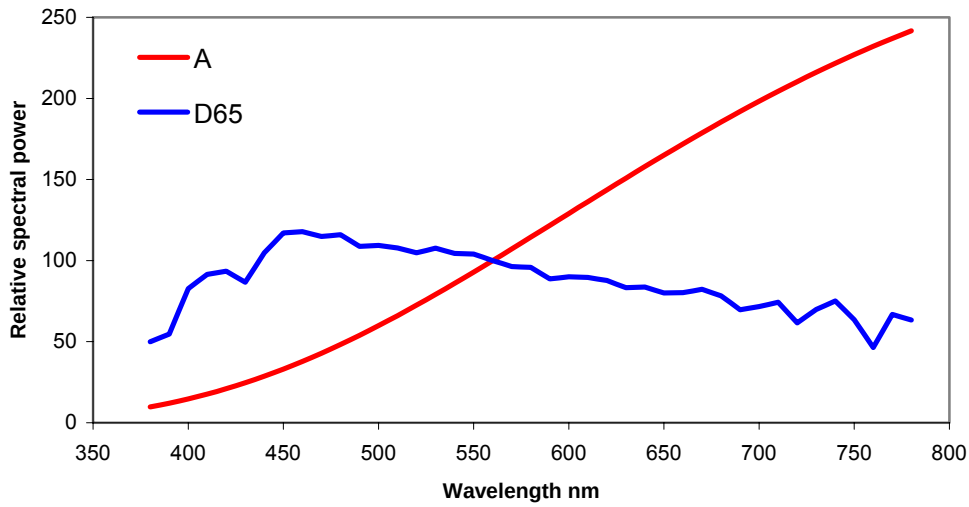


Fig. 12. Relative spectral power distributions of CIE standard illuminants D65 and A.

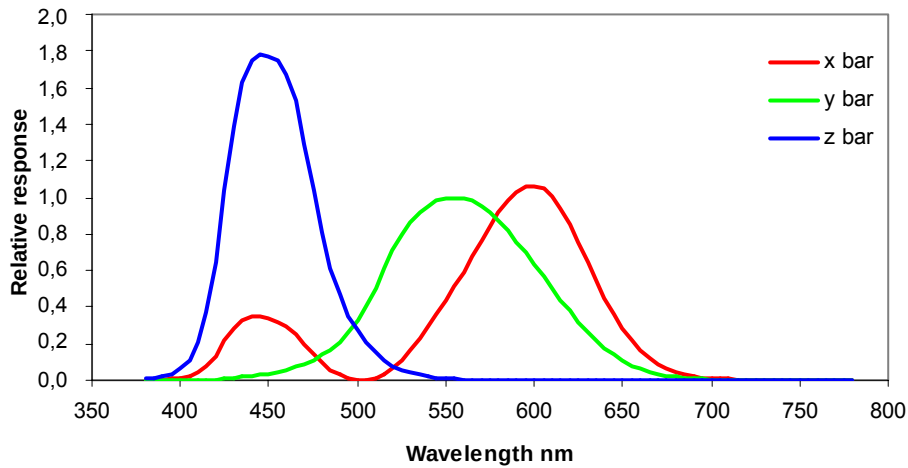


Fig. 13. The CIE colour-matching functions for the 1931 Standard Colorimetric Observer.

The CIE recommends the use of two standard illuminants: one representing a phase of daylight with a correlated colour temperature of 6500K (D65) and a second representing incandescent illumination (A). While these might not be real sources of illumination, they are presented as tables of data, their use implies consistency wherever in the world the measurements are made. Similarly, the CIE has been able to specify the colour matching functions of a "standard observer", based on early experimental work involving 17 observers at Imperial College and at the National Physical Laboratory, both in the UK (Fig. 13). By integrating the spectral reflectance data, $R(\lambda)$, with that of the illuminant, $S(\lambda)$, and the observer, $\bar{x}(\lambda)$, $\bar{y}(\lambda)$, $\bar{z}(\lambda)$, three numbers, the tristimulus values, X , Y , Z , are obtained that uniquely define a perceived colour as viewed in the given environment:

$$\begin{aligned} X &= k \int R(\lambda) S(\lambda) \bar{x}(\lambda) d\lambda \\ Y &= k \int R(\lambda) S(\lambda) \bar{y}(\lambda) d\lambda \\ Z &= k \int R(\lambda) S(\lambda) \bar{z}(\lambda) d\lambda \end{aligned} \quad (1)$$

$$\text{where } k = 100 / \int S(\lambda) \bar{y}(\lambda) d(\lambda) \quad (2)$$

The CIE system is configured such that the Y tristimulus value approximately correlates with brightness or, more usually with lightness (relative brightness). The X and Z tristimulus values, however, have no perceptual correlates.

Important colour, or chromaticity attributes can however, be related to the relative magnitudes of the tristimulus values and it is therefore helpful to calculate the chromaticity coordinates:

$$\begin{aligned}x &= X / (X + Y + Z) \\y &= Y / (X + Y + Z)\end{aligned}\quad (3)$$

The original CIE 1931 x, y chromaticity diagram provides a convenient way of mapping coloured samples relative to the "white" light that is used to illuminate them (Fig. 14). The boundary of this diagram, the spectrum locus, is the locus of points that represent monochromatic stimuli throughout the spectrum. It has been found, however, that the sensitivity of the eye to colour differences varies in different parts of the chromaticity diagram, and in particular, in the green region quite large changes in position are not very obvious visually. To correct this, the diagram can be altered in shape so that equal distances more nearly represent equal perceptual steps. This has led to the recommendation of the CIE 1976 u', v' diagram as a more uniform chromaticity diagram.

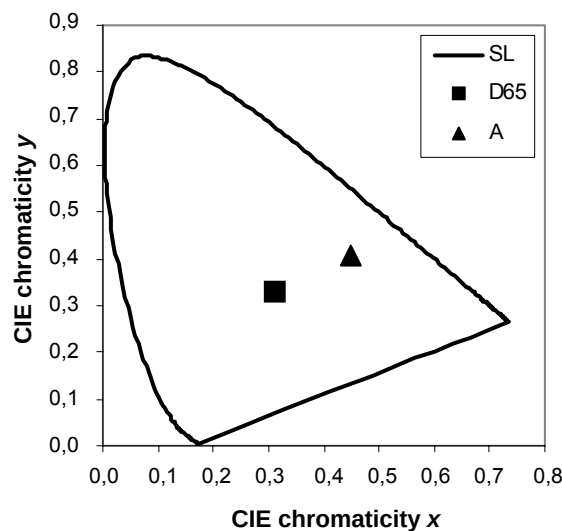


Fig. 14. The CIE x, y chromaticity diagram.

Chromaticity diagrams have many uses, but, as they show only proportions of tristimulus values, and not their actual magnitudes, they are only strictly applicable to colours having the same luminance. In general, colours vary in both chromaticity and lightness, and some method of combining these variables is therefore required. To meet this need, the CIE has recommended the use of one of two alternative colour spaces, designated CIELAB colour space and CIELUV colour space, and it is the former that has found favour in the world of surface colours. The coordinates of CIELAB colour space are L^* , a^* , and b^* , and these are, or can be combined to form correlates of the perceptual quantities, lightness, chroma and hue. There is also a colour-difference formula, associated with both spaces, that assumes a correspondence between equal psychological differences and equal spatial distance.^{40,59}

$$\begin{aligned}L^* &= 116(Y/Y_n)^{1/3} - 16 & Y/Y_n &> (24/116)^3 \\a^* &= 500 [f(X/X_n) - f(Y/Y_n)] \\b^* &= 200 [f(Y/X_n) - f(Z/Z_n)]\end{aligned}\quad (4)$$