Cambridge University Press & Assessment
978-1-107-08303-5 — Colours and Colour Vision
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Excerpt
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1 Colour vision in everyday life

In my childhood, the surrounding world was rather sparsely coloured. In the 1930s to 1950s, photographs and movies were typically in black and white and there were no TVs or computers and, hence, no associated colour monitors. Typewriters wrote in black (sometimes also in red), and important sections of a text were not highlighted but simply underlined with a pencil. The telephone was immobile and typically black. Books about the visual arts were largely illustrated in greyish halftones, perhaps supplemented with a small number of expensive colour plates. Since then, colours have exploded into almost all sections of modern life, at work as well as in leisure activities: colour TV, computers with colour monitors and colour printers, digital cameras with colour sensors, even telephones take colour snapshots, and magazines and newspapers are illustrated in full colour. This present-day ubiquity of colour probably does not signal a sudden change in human culture and preferences but rather it reflects the power of modern electronic and chemical technology, allowing the innate human fascination with colour to become more fully expressed.

In this introductory chapter, I write a little about the practical importance and use of colours, their names, history and cultural significance, things one might discuss without much knowledge about the colour mechanisms. For instance, how many different colours can one actually see? How can they be described and labelled?

1.1 Numbers and dimensions of colours: hue, colourfulness, brightness

Laptop manuals often mention the mind-boggling number of about 16 million colours that may be seen on the monitor screen.[3] However, this only means that, technically, the screen can produce about 16 million different light qualities. It does not tell you how many of these qualities the human eye can distinguish from each other, seeing them as different colours; many of the 16 million colour settings will actually look the same to a human observer. Still, the total number of distinguishable colours is very large. For the analysis of this complex landscape, it is practical to consider its three main dimensions (Plate 1.1):

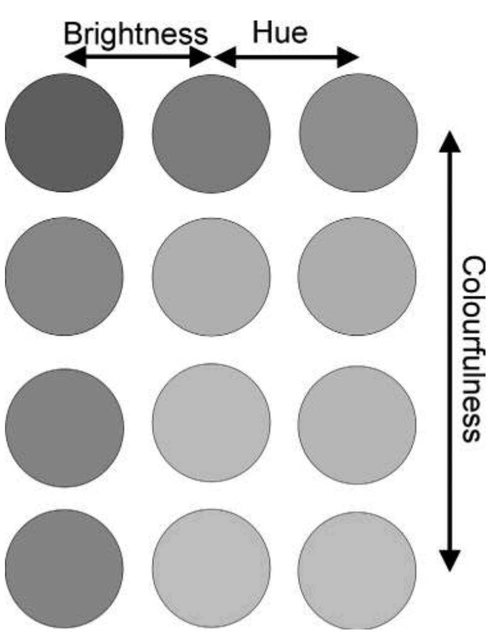

Plate 1.1 The three dimensions of colour: "*Brightness*" (approximate synonyms: *lightness* / *value*), here darker vs lighter blue. "*Hue*" (here blue vs. yellow). "*Colourfulness*" (approximate synonyms: *chroma* / *saturation*) here decreasing from above to below.
A black and white version of this figure will appear in some formats. For the colour version, please refer to the plate section.
In perception psychology, a distinction is often made between brightness versus lightness and between colourfulness versus chroma or saturation (cf. note 73; Hunt and Pointer (2011); in the present very general account, such technical distinctions will not be made between these various approximate synonyms. The RGB values used for the diagram: 0/0/153; 105/105/153; 135/135/153; 153/153/153 for the dark blue circles (upper to lower); 0/0/204; 140/140/204; 180/180/204; 204/204/204 for the lighter blue circles; 204/204/0; 204/204/140; 204/204/180; 204/204/204 for the yellow circles.

1. The *hue* of the colour, the property that we label with terms such as red, yellow, green, blue, etc.
2. The *colourfulness* of the colour (also often referred to as its saturation, purity or chroma), i.e. how strongly the hue is expressed. The colourfulness varies with admixtures of white/grey/black: the more white/grey/black one adds to a colour, the less saturated, pure and colourful it becomes (Plate 1.1, from upper to lower circles). Some colour names specifically concern unsaturated colours (e.g. rose, pink, brown).
3. The *brightness* of the colour (also often called lightness or value), i.e. the perceived intensity of the light reaching the eye. For colours of reflected light, the absolute level of brightness depends both on the intensity of illumination and on the reflectance of the material. The perceived relative brightness depends, of course, on the distribution of light in the surrounding scenery (for further comments on the complex issues of colour terminology, see note 73).

In direct comparisons between different coloured samples, a person with normal colour vision can distinguish between about 150 different hues, 100–150 levels of saturation and 100–200 levels of lightness. Taking all three colour dimensions into account, this implies that such a person can differentiate between at least $150 \times 100 \times 100 = 1.5$ million different colours; the maximal number might be about $150 \times 150 \times 200 = 4.5$ million. These numbers are very large, but they are still substantially lower than the 16 million colours mentioned in laptop ads. Besides, there are also a number of highly saturated colours, which our eyes are capable of seeing although computer screens cannot produce them (cf. Plate 2.6).

The number of isolated colours that can be named and reliably identified in stand-alone situations is much smaller than the huge multitude of colours that are distinguishable from each other in direct comparisons. This is, of course, largely due to the fact that colours are continuous variables; how many weights or lengths or temperatures would you be able to quantify directly without recourse to comparisons or measurements? A person with normal colour vision can directly identify an isolated colour as being red, green, yellow or orange, but has a very limited ability for pinpointing the colour with regard to its finer details of relative hue, saturation or lightness. Without direct comparisons, only about 15–30 different stand-alone colours can be safely identified and correctly named.[4] This agrees quite well with the limited number of colour names in everyday use (see Section 1.2). A much larger number of colour names does, of course, occur in relation to various vocations, professions and industries. However, in these contexts the colours are either externally named (e.g. labels on paint tubes) or they are identified using various sample collections and technical procedures (see Appendix B).

Our subjective experience of colour is strangely dualistic: besides the 'colourful' *chromatic* colours we also have a category of *achromatic* colours in the series white, grey, black, which may be defined as completely unsaturated colours, i.e. colours without a hue. Thus, the achromatic colours are, as it were, one dimensional: they vary only in lightness and not in hue or saturation (cf. bottom row in Plate 1.1). Consequently, they can easily be ordered on a linear scale from white via varying degrees of grey to black. In spite of their colourless nature, white, grey and black play an important role in all systems for the ordering and classification of colours (Appendix B). The paradoxical subdivision into chromatic and achromatic colours illustrates an important dualistic property of our visual system: in daylight our eyes and brain are capable of seeing colour but, simultaneously, they are also used for the detection and analysis of borderlines between lighter and darker regions in the surrounding world, i.e. for the processing of achromatic black-and-white contrast patterns (for further details and comments, see Chapter 4).

1.2 Commonly used colour names in different languages

Most of the colour terms used in everyday life concern the names of hues (red, orange, yellow, green, blue, violet, purple) and names of achromatic colours (white, grey, black). In addition, a few of the everyday colour names specifically refer to unsaturated colours (e.g. rose, pink, brown).

The British statesman William Gladstone (1809–98), besides his intense political activities, also conducted detailed studies of classical Greek literature,[5] and when reading Homer (written in the eighth century BC) was surprised to find that the major epic works, the *Iliad* and the *Odyssey*, contained few names of colour hues; Homer seemed mainly interested in achromatic colours. Gladstone's list of Homer's unambiguous colour terms includes white, black, yellow, red, violet and indigo (i.e. a kind of blue). In a later article, published in 1877,[6] Gladstone suggests that the scarcity of colour terms in Homer's work was perhaps caused by biological deficits in colour vision among the ancient Greeks. Gladstone suggested that perhaps the colour vision of later generations had become gradually 'trained' to discriminate between more hues and nuances, and that the results of this training had become heritable (which is not consistent with present-day scientific knowledge). Thus, in spite of the fact that much of Gladstone's very detailed analysis of Homer was a linguistic effort, he did not realize that the relative lack of Homeric colour terms might have more to do with language and culture than with the physiology of colour vision. Modern investigations have indeed shown that the extent and nature of the colour nomenclature may differ widely between different cultures (Plate 1.2).

Cultural differences in the classification of colours have mainly been investigated by anthropologists studying relatively isolated communities. A classical and very influential study of this kind was published in 1969 by Berlin and Kay. They performed a direct experimental study of 20 different languages (see below); in addition, they studied the colour terms in 78 other languages. They concentrated on the analysis of non-composite 'basal' colour terms, i.e. words which were in common everyday use within the target population.

In the experimental studies, the visiting anthropologists first performed introductory interviews with members of the population in order to make a list of all the colour terms in the local language. Then individual participants were shown a collection of 329 different colourcaps (from the Munsell system, see Appendix B), including black, white and seven grades of grey.[7] At first the participant was asked, for each local colour term, to select the cap which best represented the colour in question. Most participants found this choice of *focal* colours to be an easy task, and the same individual made very similar choices on different occasions. The next task concerned the range of validity for each colour term; this was generally considered to be much more difficult than the determination of focal colours. In this context, the participant was asked to select all caps that might belong to the same named colour category. Participants were then very hesitant and repeated measurements gave varying results for the same individual. This is, of course, in accordance with everyday experiences within our own culture: also Europeans with normal colour vision may often disagree with regard to how various 'intermediate' colours should be named, e.g. green or bluish-green, red or reddish-orange, etc.

With regard to the focus colours, the results of Berlin and Kay (1969) were very clear and surprisingly reproducible for comparisons between different languages (Table 1.1).[8] Whenever applicable (see below), the colour terms red, yellow, green and blue were represented by very similar test caps within different languages and cultures. Such a correspondence between languages is

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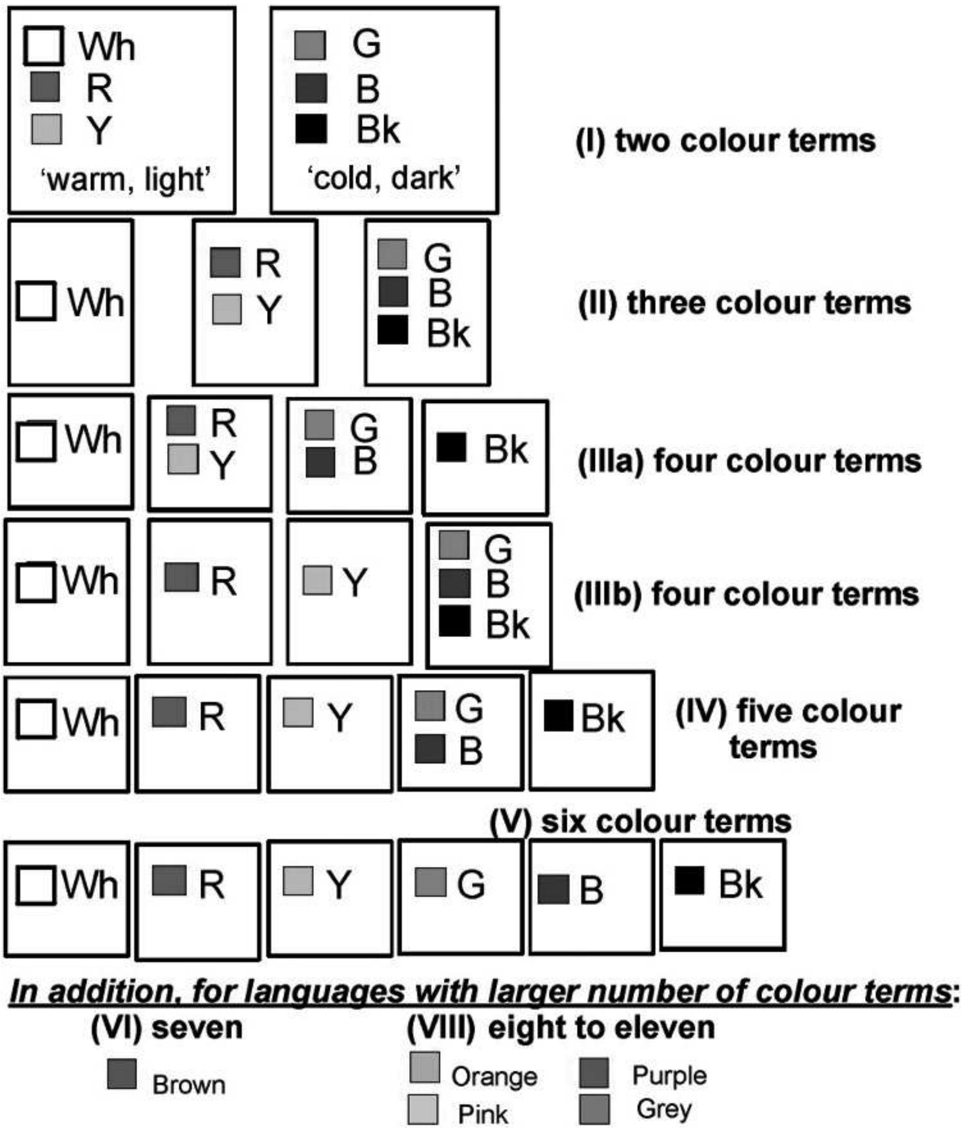

Plate 1.2 Diagram summarizing the "validity-ranges" of colour names in languages with few colour terms. Small coloured squares signify each one of 11 basal colour names / categories in common European languages. The diagram shows in which manner these basal colours have generally been bundled together in languages with fewer terms. Depending on the number of basal colour terms, the languages were classified into seven different stages, here signified with Roman numbers I - VII. Note that languages of stages I-IV have one or several composite basal colour terms comprising >1 of our own most elementary colours of red, green, blue and yellow. *Abbreviations*: B blue, Bk black G green, R red, Wh white, Y yellow. A black and white version of this figure will appear in some formats. For the colour version, please refer to the plate section.
This illustration is based on data from Figure 17.13 in Kay and McDaniel (1997), and it gives a summary of findings from several investigators, including the classical study of Berlin and Kay (1969) and their successors. For a corresponding, and earlier, survey of 'focus colours', see Table 1.1.

Table 1.1 Focus colours in languages with different numbers of basal colour terms.

Number of colour terms	Focus colours
2	white, black
3	white, black, red
4	white, black, red, green *OR* white, black, red, yellow
5	white, black, red, green, yellow
6	white, black, red, green, yellow, blue
7	white, black, red, green, yellow, blue, brown
8, 9, 10, 11	*all above plus one or more of:* orange, purple, pink, grey

From results published by Berlin and Kay (1969). For a later and somewhat different analysis, see Figure 1.2.

not self-evident. Colour hues show a continuous variation (e.g. in a rainbow or solar spectrum) and, therefore, the general similarity of the four indicated focus colours across different cultures seems in accordance with the view that these four colours have some sort of special status in the physiology of human colour vision.[9]

In the most 'colour-poor' languages that still have general colour words, only two basal colour terms are used (e.g. Dani language, New Guinea; Plate 1.2, stage I). In modern Western languages about 11 basal colour terms are in everyday use (Plate 1.2, stage VIII). Between these extremes, focal colour terms are added in a remarkably similar way between different languages (Berlin and Kay, 1969): languages with only two terms have the focus colours 'white' and 'black' ('light' and 'dark'), languages with three terms have 'white' and 'black' plus 'red', etc. (Table 1.1).

There are no indications that people with different numbers of basal colour terms would differ in the number and quality of colours that they can actually see. Colour vision has been tested for people from many different cultures and countries, and only a minority of 4–5% or less have been found to have a permanent and inborn deviation of colour vision (Tables 5.2 and 6.1). In languages with few basal colour names, each term must represent a whole range of colour perceptions which are bundled together under a joint name, probably depending on how the colours were used within this linguistic region. In cultures with only two basal colour terms, colours apparently had a very limited relevance for the design of clothes, the performance of rituals, etc.

For the understanding of the role of colours in different cultures, the range of the various local colour terms is, of course, highly interesting. This problem was not extensively dealt with in Berlin and Kay (1969), but it has been analysed in several later studies by various investigators. As an example, I here show a summary of findings published by Kay and McDaniel (1997) (Plate 1.2). Also for such matters, variations between languages follow a general reproducible pattern. Comparisons between Table 1.1 and Plate 1.2 show that it is important to know both the focus and range aspects of colour linguistics: they are not directly predictable one from the other. After white and black, red is usually the first chromatic focus colour with a name of its own (Table 1.1); in stage-II languages this term does, however, represent a greater spectral region than the one we would call 'red'. Such composite colour terms may even have several, almost equivalent focal colour terms, e.g. red and yellow for the 'warm' composite colour in stage II (Plate 1.2, II). A colour term that has both a focus and a range corresponding to the European concept of 'red' appears only in languages with at least four basal colour terms (Plate 1.2, IIIb).

The linguistic study of colour classification is rapidly developing and some of the recently published models are mathematically and geometrically highly complex.[10] Following the classic study of Berlin and Kay (1969), a huge number of observations have been collected, and part of this material is even freely available for everyone via the internet.[11]

In the cultural evolution of colour names, green and blue have long been associated, sometimes collectively referred to with the English term 'grue'. This is, for instance, true for most of the indigenous American languages. Also among modern high-technology languages, the subdivision into different basal colours may sometimes differ. Russian has, for instance, no general name for 'blue' but makes a distinction between dark blue and light blue. However, it is obvious that the four colours blue, green, yellow and red appear rather early in the 'evolution' of colour terms, earlier than unsaturated chromatic colours (brown, pink) and earlier than colours that may be described as hue mixtures (orange = red + yellow; purple = red + blue).

Almost no language seems to have more than about 11 basal colour names in everyday use (Plate 1.2, VIII), i.e. colour categories that practically everybody who speaks this language uses (including colour-blind individuals, in spite of their risk of confusion). Of course, this does not mean that there are no more than 11 words for colours in such a language. Some of the common colour names are more or less synonymous with one of the basal terms (e.g. purple versus violet), and others are 'extra' everyday terms used for colours of specific objects (e.g. 'blond' for hair). Furthermore, as has already been mentioned, there are large numbers of colour names specifically used by various categories of professionals and specialists, e.g. artists, house painters, home decorators, etc. This is not a new phenomenon; for instance, hundreds of years ago very specific colour names were already used by horse traders to describe their animals: about 13 terms in the Latin of the fifth to seventh centuries, about 14 in thirteenth-century Spain and about 30 among present-day Kyrgyz.[12]

As one might expect, colour names are often derived from natural objects illustrating the meaning of the term. 'Green' is related to 'grow' and associated with the green of plants. 'Brown' is thought to be related either to 'bear' or to the German word for 'burned' (gebrannt). 'Rose' is, of course, named after the flower.

Sometimes colour terms may be difficult to interpret because they might be associated not only with the colour of a material but also with (other aspects of) the material itself. Thus, from about AD 900 until the Renaissance, the word 'purpura' was often used for a particular quality of silk fabric which could possess almost any colour, e.g. white, black, red, yellow, green, blue.[13] Only from the seventeenth century onwards did this term become used to indicate only one specific colour. A similar ambivalence existed for the word 'scarlet', a term originally used for an expensive kind of imported cloth, later on acquiring the associated meaning that the cloth was intensely red. After the import of cochineal from America started in the 1580s (Plate 1.4a), 'scarlet' started to become used as a stand-alone colour name, referring to crimson colours like those derived from the cochineal beetles.

1.3 Development of colour vision and colour naming in children

The physiological ability to distinguish different colours comes about very early during the development of children. Using various non-verbal methods, it has been found that a high level of colour discrimination is already reached in babies at 2 months of age.[14] Children start saying various basal colour words at the age of 2 years, but the appropriate use of these terms develops very gradually during the course of several years. A 3- or 4-year old might have a completely normal colour vision and still give you a wrong answer to the question, 'What colour is this?' Colour is an abstract concept and for children it is much easier and quicker to learn the names of common objects than to associate the correct colour term with the correct colour. The complexity of this process is suggested by the varying manners in which different colours are linguistically bundled together in different languages (Plate 1.2). During development, children usually learn to couple colour names to the correct colour most easily/quickly for red and then, in an order of increasing difficulty, for green, black, white, orange, yellow, blue, pink, brown and purple.[15] In this list, the six 'primary' or 'elementary' colours of red, green, black, white, yellow and blue precede most of the 'secondary' colours, i.e. colours that conveniently may be described as mixtures or transitions between the elementary ones. The only exception to this rule is the colour orange (= red + yellow), which might have had the advantage that in some languages (including English) orange is also the name of a fruit with the same colour.

The childhood development of correct colour naming takes place in roughly the same order as the evolution of focal colour names when comparing languages: also, in this latter case, the terms for primary colours precede those for the secondary ones, and red tends to be the first focal colour with a name of its own (Table 1.1, Plate 1.2). Results from a recent Dutch investigation give a concrete example of how young children deal with colour categories.[16] Colour samples were shown to the children and they were asked: 'what colour is this?' For the four chromatic elementary colours (red, green, yellow, blue) the 3-year olds gave a correct answer in 67% of the cases, and the corresponding numbers were 75% for the 4-year and 96% for the 5-year olds. In case of the secondary colours pink, orange and brown the scores for correct answers were clearly lower, particularly for the younger children. Average percentages of correct answers were then only 28% for the 3-year, 54% for the 4-year and 95% for the 5-year olds.[17] Only at the age of 6–7 years did the answers for all kinds of colours become 98–99% correct. Among the seven tested colours, orange and brown gave the lowest scores for the 3- and 4-year olds; in modern Dutch the words for the orange colour ('oranje') and the fruit ('sinaasappel') are quite different. The fact that children learn correct naming most quickly for the four elementary colours (red, green, yellow, blue) might partly, of course, depend on the frequency with which such colour terms are used by surrounding grown-ups and older children.[18]

In English, as well as in several other languages (e.g. Swedish and Dutch), the colour term typically precedes the name of the coloured object (e.g. 'the blue bird'), and this apparently makes things more difficult for the young child. In the course of a spoken sentence the colour is then, as it were, detached from the real world until the coloured object is mentioned.