Colour Harmony

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The search for the rules of colour harmony has occupied the thoughts of some of the greatest artists and scientists. In this article, the main theories of colour harmony are considered and, in so doing, the question of whether there are any fundamental laws of colour harmony is addressed. Several colour issues are considered to be important to an understanding of the development of ideas in colour harmony, such as the circular nature of hue, the nature of colour primaries, and the concept of complementary colours. The prevalent view in the literature is revealed to be that it is impossible to separate the issue of colour harmony from the context of art and design. Thus, what is considered harmonious is to a large extent subject to fashion, personal preference and other cultural influences.

Introduction

The word 'harmony' derives from the Greek *harmonia*, a fitting together [1]. Pythagoras (c.580–500 BC) is credited with originating the idea of the harmony of the spheres, 'a mathematical theory in which the planets are separated from each other by intervals corresponding to the harmonic lengths of strings'. This idea was later extended to include forms and colours corresponding to the musical scale. Harmonia was one of the reputed daughters of Aphrodite, goddess of beauty, and this indicates that harmony is the province of aesthetics. In music, consonance refers to agreement or harmony within a musical composition, for example, a combination of notes that sounds pleasing when played simultaneously. But how do we know when something is musically or visually in agreement or harmoniously composed?

Arnheim described compositions as simply being either 'visually right or wrong' [2]. Art and design education provides an understanding of the formal elements of composition. This awareness, of the elements of composition and design is what Arnheim describes as 'visual rightness'. Evans explains visual rightness in terms of the simultaneous interaction of the component parts of composition within a given visual space, 'as objects in a defined space, expressed, as size, shape, colour and texture establishing dynamic relationships as these elements interact' [3]. Bowers provides the following explanation for visual art in a book about two-dimensional design: '...the arrangement of elements and characteristics within defined area... a grouping of related components that make sense together... balanced by an overall appearance of continuity' [4]. In the following text we shall see that concepts such as visual rightness and balance apply equally well to the notion of colour harmony, and that art theorists and practitioners have developed the informed view of which colour combinations are harmonious.

Judd described colour harmony in terms of two or more colours seen in neighbouring areas that produce a pleasing effect [5]. However, which combinations give rise to the pleasing effect is a question that has been of great interest for hundreds of years and shows no sign of abating. It is well known, for example, that Egyptian monuments and statues were vividly coloured, as were those of the Greeks, Babylonian/Assyrians, Mayans and other Mesoamerican cultures

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(though in many cases the remains of these structures have faded to white in the present day). Each of these cultures appears to have followed a distinct code of coloration that was presumably considered pleasing or harmonious at the time [1]. Of course, when we say that a particular combination is pleasing then we are not specifying whether it is pleasing because the combination is pleasing *per se* or because it is pleasing in that it achieves its purpose (certain colour designs may be effective, and hence pleasing, because those colours have symbolic meaning in the specific design context). This raises the question of whether colour harmony is related to the pleasing use of colours in a design or artistic context or whether it refers to special relationships betweens colours *per se* [6].

Granville seems to discount the notion that colour harmony is about special relationships *per se* when he writes that 'Color harmony is color usage that pleases people' and then that 'Fashion and fad are primary arbitrators of color harmony'. Kuehni takes a similar view that there is no doubt that perceptions of beauty and harmony are strongly influenced by nurture and culture so that it is quite evident that there are no universal laws of harmony [7]. Indeed, it has been argued that the articulation of such laws could even be stifling for creativity. Despite this, the search for the rules of colour harmony has occupied the thoughts of some of the greatest artists and scientists. In this paper, the main theories of colour harmony will be examined and, in so doing, the question of whether there are any fundamental laws of colour harmony will be considered. Several colour issues are regarded as being important to an understanding of the development of ideas in colour harmony and these include the circularity of hue, the nature of colour primaries and the concept of complementary colours.

Newtonian Ideas

Light is radiation in the form of electromagnetic waves that make vision possible to humans and other creatures with visual systems. Electromagnetic radiation can be classified by its wavelength or frequency, and the range of wavelengths to which we are sensitive is a narrow band between approximately 360 and 780 nm (1 nm = 0.000001 mm). Isaac Newton (1643–1727) showed experimentally that white light, such as sunlight, is composed of light of various hues. He identified seven distinct spectral colours: red, orange, yellow, green, blue, indigo and violet (these colours becoming separated when the white light is passed through a glass prism). It has since often been noted that it is difficult to differentiate between indigo and violet. Moreover, in the example spectrum (shown in Figure 1) it can be readily be observed that other hues are also visible such as reddish-orange [8]. It is widely believed that Newton's choice of seven colours in the spectrum was based on an analogy with the musical octave and the seven notes of the diatonic musical scale [9]. Nevertheless, the spectrum does not present a smoothly continuous variation in hue, and the perception of bands of colour is no doubt related to categorical perception. This is the sensory phenomenon that a change in some variable along a continuum is often perceived, not as gradual, but as instances of discrete categories. Examples are known not just in vision but in other modes of perception such as hearing.

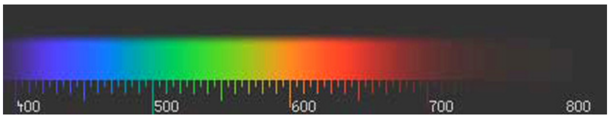

Figure 1 Representation of the spectral colours

Although the first colour circle appears to have been developed by Aron Sigfrid Forsius (1550–1637) (who represented the circle within a sphere) in 1611, Newton is commonly credited with originating the colour circle, since Forsius's circle was not discovered until the 20th century [10]. Newton created a hue circle by arranging his seven spectral colours into an incomplete circle thus inventing the geometric colour models that went on to form the basis of many subsequent theories of colour harmony (Figure 2).

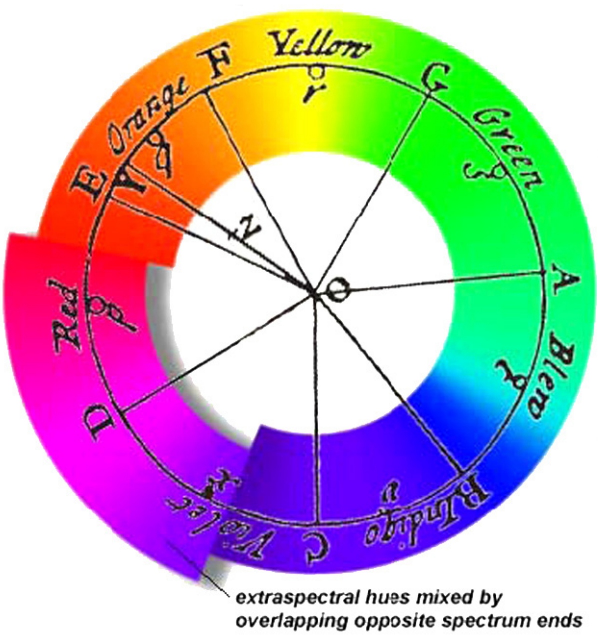

Figure 2 Newton's colour circle

Newton's circle was incomplete because certain hues cannot be generated by individual wavelengths. Purple, for example, is one of the non-spectral colours; it can be created when blue and red lights are mixed together. That the circle is the logical arrangement of hues is evident even just by looking at the spectrum. In Figure 1, for example, the two ends of the spectrum are more similar in appearance than either is to the green hue in the centre. It was this observation by Newton that the two ends of the spectrum are similar in colour that led him to introduce the notion of hue as a circular phenomenon [11]. This circularity of hue is related to perception rather than physics and stems from the opponent processing of colour signals in the human visual system [12]. Newton also understood that this circular nature of hues provided a geometrical method that could be used to predict the hue and saturation of light mixtures. Newton's hue circle can be used to show, for example, the now well known phenomenon that yellow results from mixing red and green light.

Newton was also very interested in pigment mixing and explored this at length using carmine (red), orpiment (yellow), verdigris (green) and bremen blue (blue) pigments. However, it is interesting that Newton stated clearly that the hue circle only applies to light mixtures; that is, that pigment mixtures would not depend on the proportional weights or quantities of the pigments in a mixture, but on the quantities of light reflected from them.

An important aspect of Newton's work was that he refuted the colour theory inherited from Aristotle in which light and dark were the two antagonistic primitives that mysteriously combined, like an oil slick on water, to create colour. Aristotle had supposed that all colours derived from black and white; the idea was widely accepted until the 18th century and even finds supporters in the present day [13]. During the Enlightenment in Europe in the 18th century there was a fresh search for rational, rather than mystical, explanations of all kinds of natural phenomena. In particular, people sought a perfect colour-order system and associated laws of harmony. Newton showed that, far from being a fundamental primary, white can be created from many different mixtures of three or more spectral colours and that black is related to the absence of light. Frantisek Kupka (1871–1957), the Czech painter and graphic artist, created a series of paintings (see Figure 3) as homage to Newton's colour circle using an array of spectral hues but emphasising the painters' primaries red, yellow and blue. Newton's work was not universally accepted however; Johann Wolfgang Goethe (1749–1832), the German poet and philosopher, was vehemently opposed to Newton's theories and believed that science and mathematics had no role to play in the theory of colour [14].

Figure 3 Disks of Newton by Frantisek Kupka (1912)

Complementary Colours and Primaries

In a quest to discover basic laws of colour harmony Newton proposed various hypotheses about the relationships of colours to musical sounds. However, it was his work on complementary colours – latent, if undeveloped, in his work – that came to have the greatest resonance in the history of painting [9]. Although the majority of Newton's work was with light (and additive mixing) rather than with pigments (subtractive mixing) the mathematician Brook Taylor (1685–1731) pointed out in his *New principles of linear perspective* (1719) that 'the knowledge of this [Newton's] theory may be of great use in painting', and then explained in general terms how to apply Newton's circle to the mixing of paints. This confusion between additive and subtractive mixing may have been a factor for why there has been such a proliferation of different colour wheels [15].

Before the properties of colour wheels are discussed it is useful to clarify what is meant by complementary colours and primary colours. Whilst Leonardo da Vinci (1452–1519) was probably the first to notice that, when observed adjacently, colours will influence each other, it was Goethe who specifically draw attention to these associated contrasts in the early part of the 19th century and described them with such emphasis that they have continued to be borne in mind [16]. Goethe conceptualised what are now called complementary colours, though he called them completing colours [17]. In 1854 Eugène Chevreul (1786–1889) published his 'Principles of harmony and the contrast of colours and their application to the arts' and noted that 'where the eye sees at the same time two contiguous colours, they will appear as dissimilar as possible, both in their optical composition and in the height of their tone'. However, even in his earlier work Chevreul had demonstrated that a colour will lend its adjacent colour a complementary tinge (of hue). As a result, opposing complementary colours will brighten (whereas when pigments are mixed or blended together they darken), and non-complementary colours will appear 'contaminated', for example, a green next to a yellow receives a blue-violet tinge.

By 1730 the German engraver Jakob Christof LeBlon (1667–1741) had discovered that the colours red, yellow and blue are primary in the mixture of pigments. Their combinations produce the so-called secondary colours orange (red + yellow), green (yellow + blue), and violet (red + blue). When a primary colour is mixed with the secondary created from the other two primaries, a chromatically neutral colour results. Colours (inks or paints, for example) that when mixed together produce a neutral colour are said to be complementary. However, this is a very different meaning of the term complementary to that used above with respect to observations by Goethe and Chevreul.

We are now able to distinguish three different meanings of complementary colours [18]:

1. Subtractive complement is a pair of colours that when mixed together as paints or inks produce a grey or chromatically neutral colour
2. Optical complement is a pair of colours that spin to grey on Maxwell disks (essentially additive colour mixing)
3. Afterimage complement is a colour and its afterimage that results if the colour is stared at and then removed.

The subtractive complementary pairs are often listed as yellow–violet, blue–orange and red–green [19]. However, yellow and blue lights can be mixed together to create white and therefore are optical complements. Thus it can be seen that a question such as, 'which colour is complementary to yellow?' needs to be more precisely defined before it can be uniquely answered.

To return to LeBlon's discovery that red, yellow and blue are the subtractive primaries, students of colour often have the misconception that this means that all colours can be generated from a mixture of the three primary colours. Of course, this is not the case. Indeed, no matter how pure or saturated the three primaries are it is impossible to match all possible colours using a mixture of those primaries. Not only it is not possible to match all colours using a mixture of red, yellow and blue colorants, these three primaries do not even give the largest colour range (gamut).

The ideal subtractive primaries have now been shown to be cyan, magenta and yellow. The painters' primaries of red, blue and yellow were derived partly based on the availability of pigments that could yield saturated colours [20], and have now been shown to be non-optimal in terms of the subtractive gamut. For additive mixing, however, the greatest gamut can be generated using the primaries red, green and blue and for this reason digital display devices such as televisions and LCD monitors use these three colours as the primaries. The red in the additive system is not the same red as in the subtractive system; the use of the same colour term illustrates the limitations of colour communication using language. The additive primaries are red, green and blue and they produce in binary mixture the secondaries yellow, magenta and cyan. The subtractive primaries are cyan, magenta and yellow and they produce in binary mixture red (yellow + magenta), green (yellow + cyan) and blue (magenta + cyan).

Modern digital printing devices use the optimal subtractive primaries cyan, magenta and yellow inks (sometimes called process colours). It is interesting to note that primary colours (additive or subtractive) are neither fundamental properties of light nor even of matter; rather they are biological constructs based on the physiological response of the human visual system to light. The nature of the additive primaries results from properties of our visual systems. The subtractive primaries (CMY) are now reconciled with the additive primaries (RGB) because in their purest forms each subtractive primary would absorb either red, green or blue light. However, the idea of the subtractive primaries being red, yellow and blue introduced by

LeBlon in the early part of the 18th century became firmly entrenched in the world of artists, and therefore the confusion between additive and subtractive mixing and between various primary systems remains.

Colour Wheels

Moses Harris (1731–1785) produced the first printed hue circle in 1766 [20]. He believed that red, yellow and blue were the colours most different from each other and should be placed at the greatest possible distances apart, separated by 120 degrees, on the circle. Harris was certainly influenced by LeBlon who discovered the primary nature of red, yellow and blue while mixing pigments for printing. This circular organisation was taken up by Goethe. Although Goethe hypothesised that there were two primary colours (blue and yellow) and that all colours derived from them, he was also strongly influenced by LeBlon's red–yellow–blue primary system, and his six-colour hue circle reflected this. Figure 4a shows a classic six-colour hue circle with red–yellow–blue primaries.

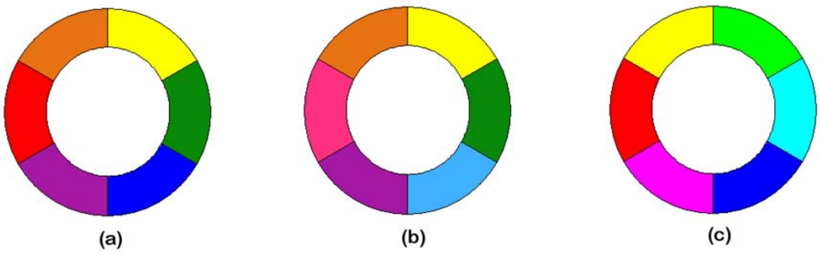

Figure 4 Pigment colour wheel (a), process colour wheel (b) and the light colour wheel (c) according to Feisner [20]; it is possible to create 12-colour versions of each of these wheels that show tertiary colours

The Harris colour wheel was based on subtractive colour mixing and can be used to predict the result of colorant mixing. Such predictions are of course limited in their accuracy because of the phenomenon of metamerism. Two yellow colours, for example, may have identical colour appearance when viewed under daylight but possess very different spectral reflectance factors. The consequence of this is that when mixed with another colour, blue, say, the resultant mixture colour would be different depending upon which of the yellows was used. Clearly colour circles cannot account for this complexity of colorant behaviour, but nevertheless can be a useful teaching aid as to the 'rules' of colorant mixing.

Feisner identifies five different types of colour wheel [20]:

1. Pigment wheel
2. Process wheel
3. Light wheel
4. Visual wheel
5. Munsell wheel.

The first three of these wheels are illustrated in Figure 4. The process colour wheel is based on the cyan, magenta and yellow primaries. However, the secondaries in Feisner's process wheel are the same as in the pigment colour wheel whereas binary mixtures of cyan, magenta and yellow are known to produce red, green and blue (see Figure 5b). The light wheel is based

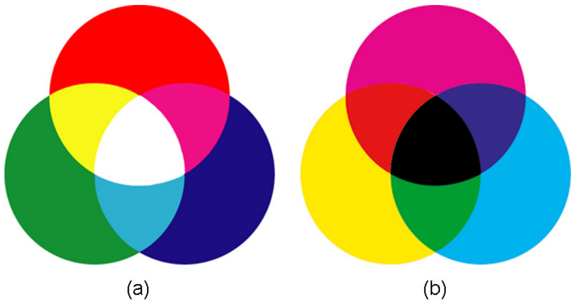

Figure 5 Additive (a) and subtractive (b) colour mixing

on additive colour mixing and is, of course, analogous with Figure 5a. The visual wheel grew out of da Vinci's observations about complementary colours and is based on four primaries: red, green, yellow and blue [20]. This arrangement owes much to Ewald Hering's work on opponency. These four colours are sometimes called the psychological primaries, relating to the opponent nature of red and green and of yellow and blue. Thus red and green are complementary and yellow and blue are complementary in the afterimage-complement sense mentioned earlier.

Harkness described four colour wheels using the Natural Color System of colour notation [14]. These were colour wheels of art, perception, science and physiology. The colour wheel of art was Itten's wheel (Figure 6), which is similar to the pigment wheel in Figure 4a in that it uses red, green and blue primaries. The colour wheel of perception was based on opponent colour theory and shows the psychological relationships of the red–green and yellow–blue opponent colours. The colour wheel of science was based on modern colour spaces such as CIELAB, which were themselves related to the Munsell colour wheel. The colour wheel of physiology placed afterimage complements opposite to each other. Harkness concluded that no one perfect or ideal colour wheel could be identified and noted that successful use of the various colour wheels requires an awareness and understanding of the different philosophies behind each wheel [14].

The last hundred years has seen a profusion of colour wheels that attempt to reveal harmonious relationships. Complementary colours are deemed to be opposite each other in the hue circle, but such a definition of 'complementarism' is seldom based on colorimetric measurements [6]. This means that the representations of colour wheels produced in textbooks, for example, are subject to the vagaries of colour reproduction and may, from time to time, be misleading.

Figure 6 Itten's colour wheel

Colour Harmony Theory

The previous section on colour wheels was necessary because these arrangements of hue have been particularly prominent amongst theories of colour harmony. Early systematic concepts of harmony in the Western world were based on Pythagorean number symbolism and specific colour scales. Theories of colour harmony since the Renaissance include the following common themes: changes in chroma and brightness within the same hue, neighbouring colours and opposing colours. Various colour wheels have been helpful to represent such relationships.

Figure 7 'Sunday afternoon on the Island of the Grande Jatte' by Georges Seurat (1884–86)

Chevreul, who was particularly concerned with colour harmony, equated maximal contrast of the complementaries with maximum harmony, and promoted red–green, orange–blue, and yellow–violet as complementary pairs. Neo-impressionists such as Georges Seurat (1859–1891) and Paul Signac (1863–1935) were strongly influenced by Chevreul's writings. Later, Odgen Rood (1831–1902) also experimented with contrast and complementary colours and agreed with Chevreul that an abrupt contrast between complementary colours had a pleasing effect on the eye. However, Rood argued that such a contrast in a small space would enhance the effect. It is possible to see the influence of both Chevreul and Rood in works such as *Sunday afternoon on La Grande Jatte* (Figure 7) and *Woman at the well* (Figure 8), and indeed the writings of both Chevreul and Rood seem to have had a great impact on the French impressionists.

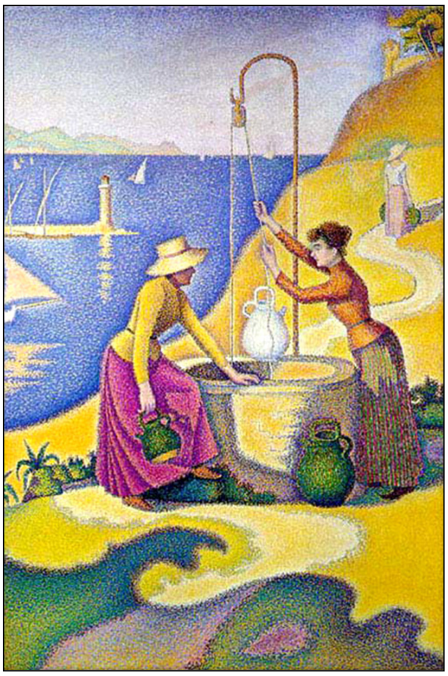

Figure 8 'Woman at the well' by Paul Signac (1892)

Three of the most important contributors to colour harmony in the early 20th century were Ostwald, Munsell and Itten. A common factor in all three views of colour harmony was the use of a colour solid or colour-order system to represent the relationships between colours. An early colour solid was developed by Philipp Otto Runge (1777–1810), who used a 12-hue colour wheel in relationship to a central core of a middle-value grey. The hues were gradated in tones towards the grey core whose upper point was white and whose lower point was black. This sphere predates the solids later produced by Munsell and Ostwald by almost a century [10]. The colour circle of Wilhelm Ostwald (1853–1932) consisted of 24 hues arranged, as in the Runge colour solid, around a spine of achromatics. In the Ostwald colour circle yellow and blue were opposite each other as were red and green. Although the Ostwald system was popular for several decades, it was largely superseded by other systems (such as the Munsell system), partly because the arrangement of colours was such that it could not accommodate the subsequent development of pigments and dyes of greater saturation. Ostwald developed some ideas about colour harmony based upon his colour solid which can be summarised as:

1. Colours harmonise if they are located at the equal white and equal black circle in the solid
2. Colours harmonise if they have equal white content
3. Colours harmonise if they have equal black content
4. Colours harmonise if they have equal hue content.

The American art instructor and painter Albert Munsell (1858–1918) developed a novel system for describing and communicating colour. Munsell's system, first published in 1905 as *A color notation system*, was based upon the perceptual attributes value, chroma and hue. Munsell arranged his samples in the form of a tree with the trunk representing the achromatic colours black through grey to white, and with each branch representing a hue. The further away from the trunk samples were, the greater their chroma. The samples were presented in a book so that each page contained samples of the same hue whose value increased up the page and whose chroma increased away from the spine of the page. The Munsell system had several key attributes. Firstly, each sample could be notated by three numbers that specified its position in the book. Secondly, although the notion of a spherical colour solid with the most saturated colours on the equator was not novel (Munsell himself attributed this idea to Runge), the spacing of the samples was designed so that the perceptual distance between samples was constant. Thus, moving around the hue circle would involve a progression through the hues with steps of equal visual magnitude.

Interestingly, the Munsell system was based around five basic hues: red, yellow, green, blue and purple. Like other practitioners at the time, he conjectured that an image would look harmonious if it produced an overall impression of being 'centred' on grey, preferably middle-value grey [21]. In order to ensure this, he calculated the colour strength of a colour region as the product of its area, lightness and saturation. Thus, a small area of high colour strength would balance a large area of low colour strength. In the balance of colour areas, a strong colour should occupy a smaller space to balance a weak colour. To do this, the areas should be inversely proportional to the product of Munsell value V and Munsell chroma C. Mathematically this gives Eqn 1:

$$\frac{A_1}{A_2} = \frac{V_2 C_2}{V_1 C_1} \qquad (1)$$

where A denotes area and the subscripts refer to two different colours.

Munsell's practical principles of colour harmony were based on the idea that colours can harmonise only when they are located on a specific path in the Munsell colour space [22]. These paths include:

1. Colours on the grey scale
2. Colours of the same Munsell hue and chroma
3. Complementary colours having the same value and chroma
4. Colours of 'diminishing sequences', in which each colour is dropped down one step in value and chroma, and
5. Colours on an elliptical path in the Munsell space.

The strength of Munsell's contribution was that, unlike much of the work of his contemporaries and even successors, all three attributes of colour are taken into account in a visually spaced colour system. The Munsell system became internationally successful as a method of colour communication and is still very popular today. The commercial success of Munsell's system for colour communication somewhat eclipsed the contribution he made to colour harmony. Alternative colour-order systems have been proposed as tools for colour harmony including, for example, the Coloroid system [23].

Johannes Itten (1888–1967) took Chevreul's idea of contrast further and in a 1916 essay wrote, 'All perception takes place in terms of contrasts: nothing can be seen on its own, independent of something else of different quality' [24]. Itten, who was one of the first masters of form at the Bauhaus, proposed that all visual perception is the result of seven specific methods of colour contrast [11]. These contrasts are of:

1. Value
2. Saturation
3. Hue
4. Extension
5. Warm/cool
6. Complements
7. Simultaneous contrast.

The first three refer to contrasts in the three perceptual dimensions of colour and the fourth concerns contrast in size for different colours. Goethe had earlier noted that different hues were different in their intensities and produced the following light values: yellow (9), orange (8), red (6), violet (3), blue (4) and green (6). Itten used the reciprocals of these values as proportional to area (noting that the stronger a colour, the less area it should occupy) so that, for example, the area proportionalities for the complementary pairs were given as yellow:violet = 3:1, orange:blue = 2:1, and red:green = 1:1.

Itten's fifth contrast refers to the notion that certain colours (red, yellow) are associated with warm feelings whereas others (blue, green) are associated with cool feelings or emotions [25]. The sixth contrast relates to the relationships of the aforementioned complementary pairs. Finally, Itten was concerned with simultaneous contrast. According to him, the simultaneous effect occurs between any two colours that are not precisely complementary. Each of the two will tend to shift the other towards its own complement, and generally both will lose some of their intrinsic character. Under these conditions, colours give an impression of dynamic activity. It is now understood that simultaneous contrast encompasses contrasts of hue, brightness (value), and colourfulness (saturation) and is a ubiquitous phenomenon in colour vision [26]. Furthermore, in certain situations colours will assimilate with each other rather than contrast [27].

Itten produced a 12-colour wheel to illustrate his ideas based upon the red, yellow and blue primary system (Figure 6). Indeed, he wrote that 'One essential foundation of any aesthetic color theory is the color circle, because that will determine the classification of colors' [25]. In Itten's colour circle, subtractive complements were placed opposite each other. Itten believed that all complementary pairs (presumably he meant subtractive complements), all three-colour combinations whose colours form equilateral or isosceles triangles, and all four-colour combinations forming squares or rectangles are harmonious.

In addition to Itten and Munsell, several other artists made important observations about colour harmony. The contributions to colour-harmony theory of artists such as Henri, Kandinsky and Pope, for example, have been reviewed [28]. Robert Henri (1865–1929) developed the Maratta system that used red–yellow–blue as primaries and orange–green–purple as secondaries. The Maratta system was a fixed palette of available pigments which, if properly understood, would assure harmony. Wassily Kandinsky (1866–1944), who joined the Bauhaus in 1922, associated colours with shapes and even with motion. Yellow was a 'spreading' colour and associated with the triangle, red with the square and blue with the circle. Thus the three primary colours were logically associated with the three main shapes. However, Kandinsky reportedly experienced sound–colour synesthesia and whether the relationships of Kandinsky's colour–shape relationships have meaning for others is less clear. Kandinsky was interested in the contrast between yellow and blue; the 'second great contrast' was that between white and black, and the third was that between red and green. The fourth great contrast was orange and violet. Arthur Pope (1880–1974) taught in the fine arts department at Harvard for over 30 years and believed in an orderly approach to colour harmony. He designed colour scales, worked with fixed palettes, and pursued systematic and methodical colour expression.

Contemporary Colour Harmony

A recent review of software that attempts to assist in the generation of harmonious colour schemes reveals that most of these systems focus on the harmony of hue and express rules for creating colour harmony in terms of a hue circle [29]. One widely available software tool states incorrectly in its help file that 'Color theory analyzes only the relationships of pure colors, it does not take color lightness and saturation into account. While your color scheme can use any tints, shades, and tones, color theory pays attention only to the hue component.' This is despite the modern understanding of the three-dimensional nature of the colour perception and seems to ignore earlier theories and schemes proposed by workers such as Munsell and Itten. The ideas of balance and the relationships between chroma and size, and between hue and chroma, seem to have been largely forgotten in design software.

The harmony of hues is also represented in many art and design textbooks with reference to hue circles. Figure 9 illustrates four ubiquitous schemes:

1. Monochromatic colour harmony (where colours are chosen with the same or nearly the same hue)
2. Complementary colour harmony (this is always represented as referring to opposite colours on a hue circle)
3. Analogous harmony (where colours are chosen with similar hues)
4. Split-complementary harmony (where there are basically three colours, with two being either side of the complement of the third in the hue circle).

Other examples (not illustrated in Figure 9) include triadic colour harmony (three colours whose hues are each separate by about 120 degrees in the hue circle) and tetradic colour harmony (basically a double complementary scheme). However, many educators are aware that lightness (often termed value) and chroma (often termed saturation) have an affect on the harmony of a hue palette.

For example, Holtzschue notes that any hues used together can be harmonious [17]. By this she does not mean that any hues used together will be harmonious but, rather, that there are no inherently good or bad hue combinations; contrast of lightness and chroma also need to be

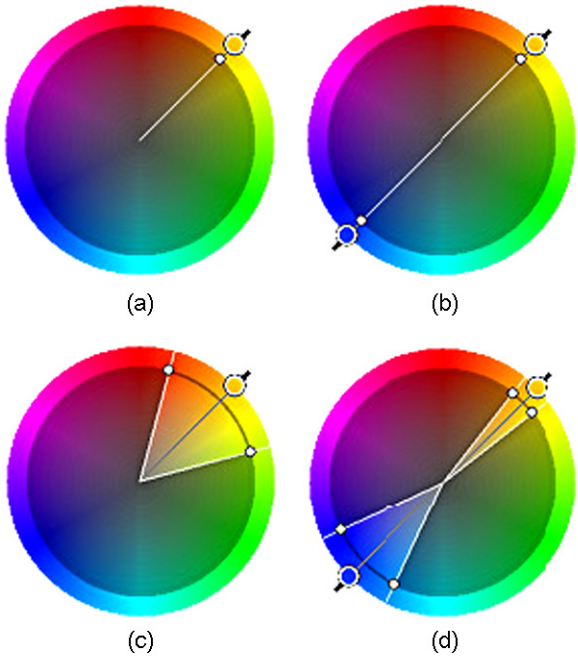

Figure 9 Four typical geometric relationships: monochromatic (a), complementary (b), analogous (c), split complementary (d)

considered. When considering that hue relationships alone are incomplete ideas about colour harmony, Holtzschue offers three ideas about value and harmony:

1. Even intervals of value are harmonious
2. Intermediate values are harmonious, and
3. Equal values in different hues are harmonious.

In the first statement Holtzschue argues that a range of values does not have to extend from the extremes of dark to light to be pleasing. Intervals of value will be harmonious as long as each step is well distanced from the next. She calls this the harmony of even intervals. The second statement implies that hues at the extreme of light or dark are not pleasing. Colour combinations that are similar in saturation or have similar saturation are also described as being harmonious.

The importance of lightness and chroma in a harmonious colour scheme is highlighted by Wong [30]. Feisner describes the classic hue relationships (analogous, complementary, etc.) but also pays attention to ideas such as rhythm, balance, proportion and scale in terms of whether a particular colour composition is harmonious [20]. Koenig outlines three different classes of colour harmony: simple, contrasting, and balanced [10]. According to Koenig, simple harmonies are based on a small number of neutrals or hues. Contrasting harmonies have their foundation in the concept of either complementary hues or hue temperature contrasts. A balanced colour harmony is a colour palette with hue selections that are well spaced apart on the colour circle.

In the 19th century and the early part of the 20th century artists and scientists worked closely together to develop ideas about colour harmony. However, in the latter part of the 20th century we have seen a divergence of views between artists and scientists. One of the earliest scientific attempts to model harmony was the work of Moon and Spencer who proposed a quantitative model based upon colour difference, area and an aesthetic measure [31]. Although the model has subsequently been shown to perform quite poorly [32], the work was generally welcomed by the scientific community [33]. The Moon and Spencer model was recently used in a Kansei approach to colour harmony in townscape evaluation [34].

More recently, experimental psychologists have sought to ground theories of colour harmony in the empirical study of responses to single and paired coloured samples by subjects. However, this empirical work has done little to either substantiate or replace any of the traditional theories [9]. For example, based on categorical-judgement data for Chinese observers, a quantitative model of colour harmony was developed for two-colour combinations [35]. Ou and Luo's quantitative model can be used to derive several rules for colour harmony including:

1. Two colours that differ only in lightness will appear harmonious
2. Small lightness differences between two colours may reduce the harmony of the pair
3. The higher the lightness of each component in a binary pair, the more likely it is that they will appear harmonious
4. Blue is the most likely hue to create harmony in a two-colour combination, with red least likely to.

The latter point may indicate a confusion between colour harmony and colour preference (many studies report that blue is more preferred than red). However, another study by Ou *et al.* demonstrates that although there is a strong relationship between colour harmony and colour preference, they are different concepts [36]. A very recent study has sought to develop a model similar to that of Ou *et al.* but for three-colour combinations [37]. Shen *et al.* argue that colour harmony from an engineering perspective has received limited attention because its successful evaluation requires the development of pleasure-related features [38]. They argue that there are two categories of colour harmony studies: speculative (absolute/relative harmony, mood, similarity, fashion trends) and operational (area, order, hue, power spectrum), and that the former lacks implemental procedures. In their study a new pleasure-related function of colour linguistic distribution was proposed.

Mahyar *et al.* have taken a somewhat different approach and have sought to use psychophysical methods to explore whether opposite colours as defined in CIELAB space are harmonious and have revealed several anomalies [39]. The current gulf between the artistic and scientific views of colour harmony is described by Granville [6], who wrote that 'Scientific theory does not lend itself to understand the creative process. One can analyse a harmonious colour scheme in terms of the relationship to paths in colour space, but the analysis does not enable the creative process to be understood.'

Discussion

Many different ideas have been put forward to explain or predict why certain colour combinations are harmonious or pleasing. Goethe and Chevreul attributed importance to particular colours and their combinations, with the complementary relationships recognised as being ideally harmonious. Chevreul developed more systematic laws of harmony to include laws of contrast and analogous colours. Munsell and Ostwald, however, attributed importance to sequential organisation, balance and mathematical order. No single one of these theories seems to be complete or fundamental, and all have been criticised for a lack of explanation (to support the theory) and a lack of evidence to support the claims [40]. Although colour harmony is a multifarious concept that is represented by a range of meanings [41], a recent analysis of a number of books on colour revealed the prominent contemporary understanding of colour harmony to be one of order, referring to uniformly spaced points in a colour classification system [42,43]. However, it is impossible to separate colour from design, with the consequence that fashion and personal preference are primary arbitrators of colour harmony [6]. Colour atlases are therefore useful for selecting harmonious colours only in that they sample colour space in an orderly way that permits one to find easily the colours one has in mind.

Wong states that 'Because tastes change from generation to generation and according to an individual's age, sex, race, education, cultural background, etc., it is difficult to establish specific rules for creating effective colour combinations' [30]. This is a commonly found view in the literature. For example, Nemcsics claims that colour is dependent on colour preferences within a given group of people at a given time [44]. It seems likely therefore that there are no universal laws of colour harmony; rather, ideas about colour harmony shift over time and between cultures and are application-specific. This idea is elucidated by Holtzschue who suggests that colour harmony is the pleasing effect of two or more colours used together, and visual impact is the effect of colour combinations on the power of a design or image. She also suggests that instead of thinking of combinations as being harmonious or dissonant, they can be thought of as successful or unsuccessful [17]. Nevertheless, Heddell argues that there is a continuing need in the arts for practical applications of colour theories [45].

It is evident that, despite the fact that colour harmony is predominantly about successful art and/or design, certain concepts seem to have remained intact over time. The value of using complementary-colour relationships, for example, has been established by numerous advocates over the centuries. The clearest statement on this topic is perhaps provided by Kuehni who writes, 'It is quite evident that there are no universal laws of (colour) harmony' [7].

It could be argued that although the theories put forward by physicists (e.g. Moon and Spencer) and cognitive psychologists (e.g. Ou and Luo) at least provide empirical evidence to support their ideas, they still lack any fundamental explanation as to why certain colour combinations are harmonious [40]. Furthermore, the recent scientific approaches seem to be increasingly disconnected from the context of art and design. Thus the preferences that are empirically determined in the laboratory may bear no resemblance to the preferences and choices made by art and design practitioners in the context of an expressive idea or in response to a design brief.

The last hundred years have seen a divergence in view between artists and scientists on the topic of colour aesthetics, and we suggest that this trend needs to be reversed if significant progress is to be made in terms of understanding colour harmony. A similar sentiment has been expressed for art and design in general [46].

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