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REVIEW ARTICLE

Research on the Visual Psychology of Colour and Its Influence on Art and Design

Lifang Wan[1,*], Yuan Xiang[1]

[1] *School of Art, Nantong University, Nantong 226007, Jiangsu, China*

Corresponding author: Lifang Wan, E-mail: lifang.wan@ntu.edu.cn

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Abstract

Objective: To study colour constancy and related visual-psychological phenomena under illumination of different colours, and their influence on art and design. The cerebral cortex forms colour vision from its perception of chromatic adaptation, colour constancy, colour saturation and hue; colour perception is bound up with human psychology and brain activity, and many phenomena in art and design involve a knowledge of colour visual psychology. Methods: An experimental-psychology method of asymmetric colour matching was used, combining optics and colour psychology. Spectral information from the Munsell colour chips was used to simulate different colours on a computer, composing visual stimuli against red, green, blue and yellow illumination. Observers viewed the stimuli in a dark room and performed colour-matching tasks against the differently coloured illumination. Results: After a change of illumination, a person's response to an object colour shifts in chromaticity along the direction of the new illumination, so that the object colour re-establishes a harmonious chromatic relationship with its illuminated background. Conclusions: The psychology of colour perception is widely applied in art and design — architectural colour, interior design, film, environmental lighting, painting, fashion design and display. Understanding the visual psychology of colour affords deeper insight into how colour is represented in the brain, the psychological impressions colour produces, and the effect of illumination on colour, enabling designers to apply the laws of colour change to their environment, to gauge the audience's response, and to achieve harmonious colour schemes. Through visual experiments on hue, colour saturation, chromatic adaptation and colour constancy, and through the study of colour in art, visual science and art are found to form a holographic whole, deeply influencing and connected with one another.

Keywords: colour, constancy, visual psychology, art and design

1 The Visual System

The human eye can capture information about light. Light passes through the eye, falls upon the retina, and is transmitted to the brain by the optic nerve. The retina contains large numbers of photoreceptors — the cone cells and the rod cells — of which the cones operate mainly in bright conditions. There are three kinds of cone, the L, M and S cones, which principally distinguish the three wavebands of red, green and blue light. The trichromatic cone system was slowly established in the course of biological evolution, initially to distinguish the colours of fruit or of natural enemies. The rods operate mainly in dim light; they cannot distinguish colour, so in dark surroundings people normally see a scene without hue. Roughly 1.26 billion photoreceptor cells are distributed across the retina, of which six million cones lie in the fovea. The signals generated by so many cones and rods cannot be delivered to the brain in full within a short interval, for the brain is like a CPU whose capacity to process signals is finite; visual signals are therefore compressed at the optic nerve fibres before transmission. The signals of individual cone cells are recombined by addition or subtraction, and the compressed information is processed by the opponent-colour mechanism, emerging at the perceptual stage as *light–dark*, *red–green* and *blue–yellow* and delivered to the visual cortex [1].

With the advance of science in the early twentieth century, artists of Symbolism, Expressionism and Cubism questioned the validity of academic naturalism. Through psychological and X-ray-like analysis they sought to make their painting reveal an essence beneath the surface [2]. The painter Cézanne once advised young painters to observe nature in terms of the sphere, the cone and the cylinder, and never to forget those basic solid forms when composing a picture. The working of the brain appears to accord with Cézanne's theory of painting: the visual system decomposes a complex figure into simple shapes, reducing it to line segments in different orientations and to different colours. In fact the processing of human visual signals is carried out by different regions of the cerebral cortex. Contrary to what one might imagine, visual information is not delivered to the brain as a whole and then displayed there; it is decomposed into separate information about an object's

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shape, colour, motion and orientation. These streams have different oscillation frequencies and are processed in different locations in the brain, and the image a person finally sees is the synthesis of the information from those locations. How the brain assembles information from these different locations has not yet been thoroughly investigated. The visual cortex lies roughly at the back of the head. Colour information is initially processed mainly in areas V1, V2 and V4 of the cerebral cortex; motion information is processed in V1, V2 and V5/MT. The hue and saturation of a colour arise in V4. In the end the brain synthesises shape, motion, colour and texture into the appearance of the real world that people see. The visual system thus completes the process from the deconstruction of an image to its synthesis.

Picasso's celebrated oil painting *Violin and Grapes* decomposes the violin into numerous disconnected, hybrid shapes — structures of differing form, texture and colour — depicting the simultaneity of multiple viewpoints. With the advance of visual brain science, it has been found that Picasso's artistic practice and manner of thinking closely resemble the working mode of the human brain, which likewise first deconstructs an image into separate information and then reassembles it. Looking closely at the history of art and of science, art and technology have in every age mirrored one another. From the Renaissance to the Industrial Revolution, painting moved from realism and naturalism towards abstraction and stylisation, while science underwent a parallel passage from phenomenon to essence, from macroscopic mechanics to microscopic quantum mechanics. The development of science and of art may therefore be said to occupy a single holographic whole.

2 The Response of Chromatic Adaptation, Hue and Colour Saturation in the Brain

Chromatic adaptation is an important factor in colour vision. After gazing for a long time at a vivid colour, one feels its vividness slowly decline; this phenomenon is visual chromatic adaptation. When the eye has adapted to one coloured light and then observes the colour of another object, it cannot immediately obtain an objective impression of that colour but retains a complementary component formed by the preceding adaptation. With the further development and refinement of neuro-molecular cytology, Johnson (2008) identified in area V1 of the monkey's visual cortex certain bipolar and unipolar neurons sensitive to colour, and these visual cells produce the effect of chromatic adaptation. When a unipolar cell responds to red light, it induces a response to green — green being precisely the complement of red — and the amplitude of the green response is lower than that of the red, indicating that the energy of the complement is weaker than that of the original colour. Chromatic adaptation is present at every instant, and the adaptation colours of different moments superpose upon one another; when a person sees an object colour, its complement is generated in the brain at the same time. The brain contains unipolar cells sensitive to colour which respond to one pure colour only. Most bipolar cells, however, are orientation-selective (Johnson, 2008) and can identify the shape and boundaries of a colour. Under ordinary illumination the object colour and the adaptation colour superpose on the retina at the same time, and the complement serves to cancel part of the original object colour, which indirectly achieves the effect of filtering and neutralising the background illumination. The function of chromatic adaptation is to draw the eye's sensation of colour back towards the white point of daylight, preserving the sensation of colour constancy.

Object colour and the chromatic-adaptation complement correspond exactly to the theory of yin and yang in ancient Chinese thought: object colour represents yang, the adaptation complement represents yin, and only when yin and yang are in balance can human colour perception remain balanced. The use of complementaries in art and design is in fact an important means of restoring balance to the response of the brain's visual cells. History affords many artists skilled in the use of complementaries — Van Gogh, Matisse, David Hockney. A complementary scheme is a law of beauty and equally a law of balance; it can give a person a sense of serenity and comfort, and it accords with the response pattern of the brain's visual cells.

In recent years researchers have performed many visual experiments on monkeys, whose genes are the closest to those of humans and through which the production of colour in the human brain may therefore be indirectly understood. The researchers seated a monkey before a monitor, drinking as it watched different colour stimuli, while an electrode inserted in its brain recorded its response to each colour. The study showed that different colours are arranged in sequence across the monkey's visual cortex according to the oscillation frequency of the light. It further found that when colour saturation rises, the discharge rate of visual cells in area V4 of the monkey's cortex increases, and when saturation falls the discharge rate in V4 decreases. This research can explain the difference in the brain's response when people view the work of Van Gogh and of Morandi. The highly saturated colour of Van Gogh's work raises the discharge rate of the viewer's visual cells and readily produces excitement and visual fatigue, whereas Morandi preferred low-saturation colours, which make a picture feel calm and restorative; present-day interior and fashion design accordingly makes frequent use of Morandi palettes.

Colour can regulate the excitability of the brain's visual cells and affect the viewer's mood. Fast-food restaurants, for instance, favour bright red decoration to hasten their customers' eating; hospitals, to relieve patients' despondency, avoid black as far as possible and may add cheerful colours to lift their mood; and children prefer highly saturated, bright colours, which more readily hold the attention.

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3 Colour Constancy

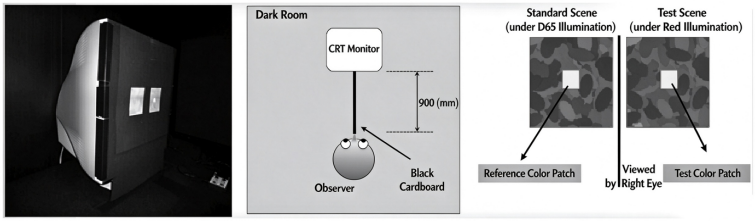
Colour constancy is a human capacity for perceiving colour, one that does not vary with changes in illumination but remains constant — that is to say, people can normally recognise the colour of an object without being influenced by the ambient light. Colour constancy was slowly formed in the course of human adaptation to the living environment, and it keeps people from being unduly sensitive to the colour changes brought about by ordinary illumination. Chromatic adaptation and the higher colour-computational capacity of the cerebral cortex are generally regarded as the principal causes of colour constancy. Research has found that when the colour of the illumination changes, the corresponding brain cells in areas V1, V2 and V3 of the visual cortex change with it, whereas some colour-correlated cells in V4 do not; because these cells do not respond to the change of colour, scientists conjecture that they may be one reason why colour can remain constant.

Colour constancy concerns the perception of colour change under different illumination, and because it involves the illuminated environment it is frequently connected with artistic creation. Many painters, in order to achieve harmony in the picture, unify the image by means of the colour of the light source: Balthus and Morandi, for instance, harmonised their colours with the illuminant colour, giving the picture a unified dominant tone, while the ambient colour reflects the colour of the source and forms a harmonious and unified image.

4 Experiments on Colour Constancy

To understand how people's sensation of colour differs under different illumination, how colour constancy operates and by what laws, the author, building on experimental colour visual psychology and combining it with optics, conducted an interdisciplinary study of colour matching under different illumination. The experiment was carried out with observers in a dark room, seated before a monitor with a black divider between the two eyes, so that the left and right eye could each see only the visual stimulus on the corresponding side, as shown in Figure 1(b). The experiment employed the method of asymmetric colour matching; Figure 1(c) shows the visual stimulus under a D65 source and under a red source — on the left the colour effect under standard D65 daylight, on the right the effect under red light. The procedure was as follows: on the basis of the colour of the small central square (the reference patch) on the left under daylight (D65), the observer was asked to adjust the small central square on the right under red light (the test patch) to the colour that, in their imagination, it ought to have under red illumination.

The twelve reference colours were selected from Munsell chips: 5R 5/6, 2.5YR 5/6, 10YR 5/6, 7.5Y 5/6, 5GY 5/6, 2.5G 5/6, 10B 5/6, 7.5PB 5/6, 5P 5/6, 2.5RP 5/6, 10RP 5/6, and grey. The illuminated background pattern consisted of three hundred randomly superposed ellipses whose colours were drawn at random from the Munsell hue circle at chroma 6 and value 5. These colours were displayed on the monitor through simulation from the standard Munsell spectra; the monitor was calibrated with a colorimeter and the chromaticity error did not exceed 3%. Fifteen observers with normal colour vision took part, aged between 18 and 25. The experiment simulated background illumination in five colours — red, green, blue, yellow and D65 — and observers, taking the colour of the reference patch under D65 daylight as their basis, imagined and adjusted the colour of the test patch under each of the four coloured illuminations.



(a) (b) (c)

Figure 1 (a) shows the monitor used in the colour-constancy experiment. Figure 1(b) shows the experiment conducted in a dark room, with the observer seated 900 mm from the monitor viewing the visual stimulus. Figure 1(c) shows the visual stimulus under D65 (left) and red (right) illumination.

5 Experimental Results

In the course of the colour-matching experiment, the governing principle was first to preserve colour harmony: the brightness and colour of the central test patch, when set against its surroundings, must not appear too abrupt, and the colour must be made to merge into the larger background. Harmony of brightness, of hue and of saturation had all to be considered at once, and the process of matching a colour is in essence a complex computation of the brain. After a month of daily two-hour colour-constancy matching, the observers were generally more sensitive to the change of colour under different

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illumination and had gradually become familiar with the laws of matching. It was apparent that when adjusting a colour under red light, observers shifted the original colour in a definite direction along the red axis, so that the newly adjusted colour inclined towards red; and under green, yellow and blue illumination they likewise deflected it through a particular angle in the direction of the corresponding illuminant colour. Colour constancy under different illumination is affected not only by chromatic adaptation but also by the higher colour-computational capacity of the brain. The results show that a person's capacity for colour-constancy computation differs with the illumination, the measured order of constancy being green > red > yellow > blue. This indicates that under red and green illumination people more easily distinguish the colour of the light and compute the change of colour, whereas under yellow and blue illumination the colour difference is hard to discriminate.

6 Discussion

Colour constancy is always bound up with illumination, and painting, film, architecture and interior design frequently take the influence of different illumination into account. The French Impressionist Monet was the first to lay emphasis on the change of light and shadow under different illumination. Before Impressionism few painters attended to the play of light and shadow that the same scene presents at different hours; people lived habitually in the state of their own colour-constant perception. Monet broke with that convention, holding that colour changes with the sunlight from moment to moment, and painted the same subjects repeatedly — water lilies, the cathedral, haystacks — in different seasons and under different illumination.

The colour a design presents under different illumination differs in lightness and darkness, in warmth and coolness. In architecture, for example, the designer must take local illumination into account when designing a building's colour; the same colour observed in a region of frequent rain and in a region of frequent sunshine gives a different impression. In a rainy region, where colours tend towards dullness, some bright and vivid accents may be added in compensation [3]. Interior design must likewise consider the colour of the light source: a restaurant whose source is of warm colour temperature readily produces an impression of romance and warmth, whereas the lighting of a shopping mall needs to approximate the colour of daylight so that customers may better distinguish the colours of garments. To express different emotions, film directors also light with sources of different colour temperature: in *Corpse Bride*, for instance, the whole film uses a blue-grey lighting to create the terrifying, chilling atmosphere of the zombie.

In the practical teaching of colour composition at university, students commonly cannot render an object's reflected colour correctly under a given illumination; they tend to ignore the influence of light and set down directly the object's local colour as held in the mind. Such colours lack a unified source colour, are usually disconnected and unrelated, and cannot form a harmonious effect when combined. Colour training can therefore use the colour-constancy experiment to adjust students' cognition of colour: by repeatedly comparing the colour response under different light sources, it helps them establish a sound sense of colour order and better integrate light, art and design with psychological sensation.

7 Conclusion

Art is created by the mind, and the links between mind and mind then produce resonance; every level of the mind is connected with art, including individual perception and the social and cultural dimensions. The sensation of colour is a shared characteristic of the human mind, and it also exerts an influence on art and design. This paper has studied the visual-psychological experiment of colour constancy: spectral data were used to simulate colour backgrounds under red, yellow, blue and green illumination, and observers performed a constancy experiment matching colours against differently coloured backgrounds. It was found that after a change of illumination a person's response to object colour undergoes a chromatic deflection through a certain angle in the direction of the corresponding new illumination, so that the object colour re-establishes a harmonious chromatic relationship with its illuminated background; and that a person's colour constancy differs among the four illuminations, the eye being less able to identify the change of colour under blue illumination, which is close to daylight. After training in the colour-constancy experiment, observers were more sensitive in mixing colour and more readily obtained a harmonious scheme. The experiment is limited in that the monitor's gamut could not cover the whole range of colours the eye can identify; a wider-gamut monitor should be used in future.

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