CHAPTER 12

Body colour and local interactions

Introductory

This Chapter concerns the phenomenon of ***induced colour*** *with a particular emphasis on two intimately related manifestations of it, known as* ***simultaneous colour contrast*** *and* ***simultaneous lightness contrast****. Although these have had an enormous amount of exposure in both artistic and scientific books, there is much to say about aspects of them which might be difficult to find. In particular, relatively little is normally said about the importance of* ***viewing conditions*** *on appearances. It is on this subject, which has been of particular interest to me, both as an artist and as a scientist, that this chapter will concentrate.*

The origins of the phrase "*simultaneous colour-contrast*"

The French equivalent of the phrase "*simultaneous colour contrast*" was originally coined by the French Chemist Eugène Chevreul (1786-1889). He published his observations in 1838,[1] half way through his unusually long and distinguished life, while employed at the celebrated Gobelins fabric-printing works (founded in the fifteenth century and destroyed by fire in 1871). The directors of this company, in keeping with the spirit of the *Industrial Revolution*, wanted to find what science could do to help them improve their product. Chevreul's main job was to investigateof new dyes with regard to permanence and to chemical reactions with other dyes. However, he also became interested in the perception of colours and, in particular, in interactions between the strongly contrasting, neighbouring colours that sometimes appeared in the Gobelins designs. He summed up his observations as follows: "*In the case 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 lightness. We have then… simultaneous contrast of colour.*" Significantly for the part his ideas were to play in art

1 Eugene Chevreul, 1838, T*he Principles of Harmony and Contrast of Colours and their Applications in the Arts,* First English translation by Charles Martel, London 1872

history, he called particular attention how his rule applied to are juxtapositions of colours that are *opposite* each other on the colour circle (later to be known as "*complementaries*").

Chevreul's work very quickly came to interest artists. Amongst the most enthusiastic was Eugene Delacroix (1798-1863) who began to juxtapose complementaries in his paintings. The results greatly influenced the young *Impressionists*, who honoured Delacroix as a precursor of what they saw as their "*Modern*" ideas.

In the 1880s, Chevreul's discoveries gained a new importance when they were taken up by Georges Seurat, who is said to have first studied them in a book entitled "*Grammaire des Arts du Dessin»,* by Charles Blanc,[2] a critic, an art historian and an acquaintance and admirer of Delacroix. One of Blanc's observations was that, "*separate touches of (contrasting) pigment will tend to form more pure and vibrant colours in the observer's eye than would be formed by the more traditional mixing of pigments on the palette*."[3]

Learning about colour.

So much has been written on the topic of *simultaneous colour contrast* that it might be supposed that there is little point in adding more. However, recent research has given new insights into the subject that provide artists with a number of new considerations. Since some of these relate to my own history, what follows will contain a certain amount of autobiography.

During my first term at art school I attended a colour course given by the artist Michael Kidner.[4] This was very much influenced by ideas taught by Johannes Itten at the *Bauhaus* in Germany around 1920[5] and preached in Britain during the 1950's by various people. Perhaps the most influential of these on Michael was Harry Thubron,[6] whose course he had attended in 1959. Thus, it came to pass that our first project was *very Bauhaus,* and found us making displays rather like the one illustrated in *Figure 1*.

Our task was to find nine pairs of colours (a disc and a surround) that

2 Charles Blanc, 1867, "*Grammaire des Arts du Dessin*".

3 Much will be said about the phenomenon of *optical mixing in "Painting with Light".*

4 A monograph on the work of Michael Kidner was published in 2007 on the occasion of his 90th birthday retrospective exhibition at Flowers East gallery, London.

5 Johannes Itten, 1974, *The Art of Color*, John Wiley & Sons Inc.

6 https://en.wikipedia.org/wiki/Harry_Thubron

"*worked*" especially well together. At the end of the project, we had to decide who within the group had made the best sets of pairings. My art education having been confined to a Polish context, I did not even know what was meant by the word "*work*", but I soon learnt that, in this case at least, it referred to the generation of a kind of electric energy which on occasion suffuses colours, particularly at their edges, giving them something of the *vitality of a primary light-source* and the *quality of pure, surface-less colour*.

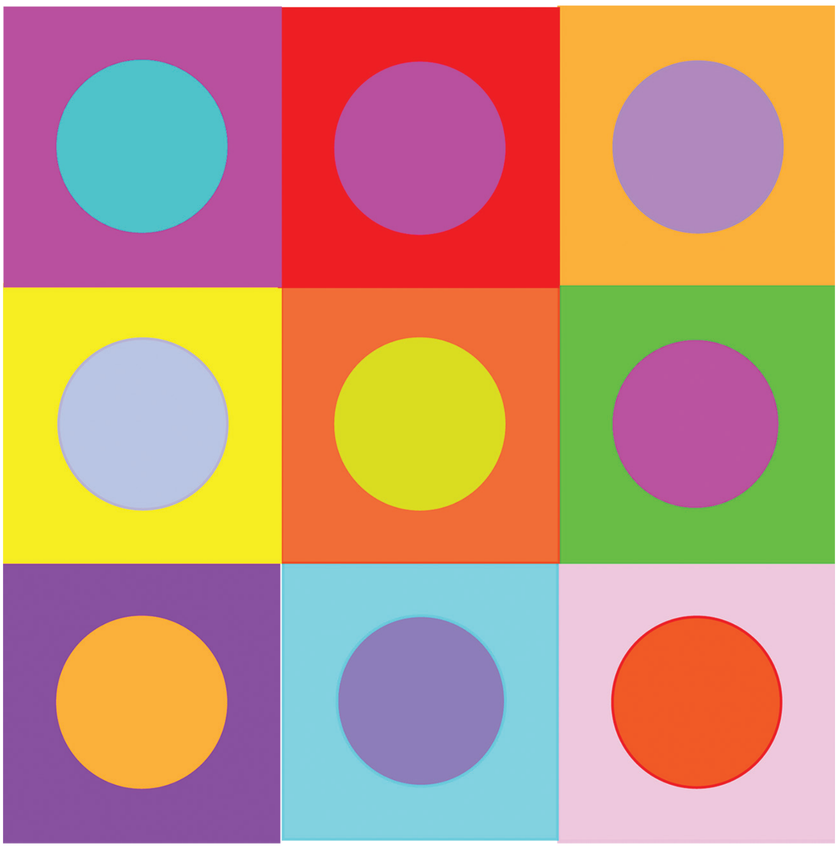


Figure 1:My art school project

Michael told us that the desired effect would only occur if the pairs of colours concerned were atonal or, as I prefer to say, "*equal lightness*" and our experiments proved him to be right. This will be hardly surprising for anyone who had any acquaintance with the literature on the subject.

All might have seemed straightforward if a puzzle had not emerged. As I had no way of solving this at the time, it was to remain a mystery for many years, until explained by research done at the *University of Stirling*.[7]

The difficulty came at the end of the day when we all gathered to discuss each others productions, a process that took a long time and led to no very clear conclusion. Even our expert tutor seemed to hum and haw an incredible amount and never seemed to come up with definite pronouncements. How could something so apparently straightforward as equal-lightness be so hard to agree upon? To answer this question we need to know more about the phenomenon simultaneous colour and lightness contrast.

A journey of discovery

Figure 2: A page from my children's book

7 See next two chapters and the remainder of the book for the momentous consequences this was to have for me.

The beginning of my journey into the less well-known aspects of *colour-contrast effects* came when I took a course on silk-screen printing, while still at art school. It was my great luck that this was run by Stephen Russ from whom I learnt more about the spirit of true craftsmanship in its best sense than from any other source. It was under his supervision that I embarked on an illustrated book targeted at young children. The illustrations were line drawings of one colour on a background of another (*Figure 2* illustrates a page from it). Each pair of pages had a unique combination of colours, which gave the project the secondary purpose of testing out a largish number of colour combinations.[8] From a formal point of view, the main thing which distinguished them from most other demonstrations of *simultaneous colour-contrast*, was the thinness of the lines.

This is significant because the effects due to this phenomenon are generated by *interactions at edges* and because thin lines can be described as "*regions of colour in which the proportion of edge relative to surface area is maximised*". From the personal point of view, the power and beauty of some of the combinations awakened an interest in the *use of thin lines in paintings* which turned out to be of lasting significance in my work as an artist. It was also to open up interesting possibilities for scientific exploration.

Interim years: preparing to teach a colour course

After leaving art school, I found myself doing occasional work as a *Visiting Lecturer* in a number of different art schools. In particular, I was asked to teach *Colour Courses*. Both my personal work of that time and my teaching played a part in the development of my understanding why equal-lightness is so hard to pin down. *Figure 3* is a mock up illustrating elements of the kind I was using in my painting. As can be seen, it shows two pairs of orange, *thin-bar elements,*[9] painted on a greyish-blue background. Notice that the top pair almost touch each other, while the bottom pair are widely separated, but almost touch an edge of the grey rectangle. This use of different types of juxtaposition, either between the elements themselves or between elements and real-object edges, reflected my ongoing interest in *real-surface/illusory-space* dynamics. One thing I found was that the lightness relation between the bar and the background had an important influence on these. To get this just how I wanted them required experiment, as did the placement of the bars. One trick which proved helpful involved painting the back of a piece

8 Since the book had sixty four pages, the number of pairs of them was thirty two.

9 In my paintings they were one sixteenth of an inch thick (0.16 cm) and two and a half inches long (6,35 cm)

of masking tape with a colour (say, an orange, like the one illustrated) and cutting it into thin strips (approximately one sixteenth of an inch wide). Such strips could easily be stuck onto a previously painted background colour and, in this way, a range of different bar-colours could be tested without having to go through the time-consuming business of making a completed painting for each trial.

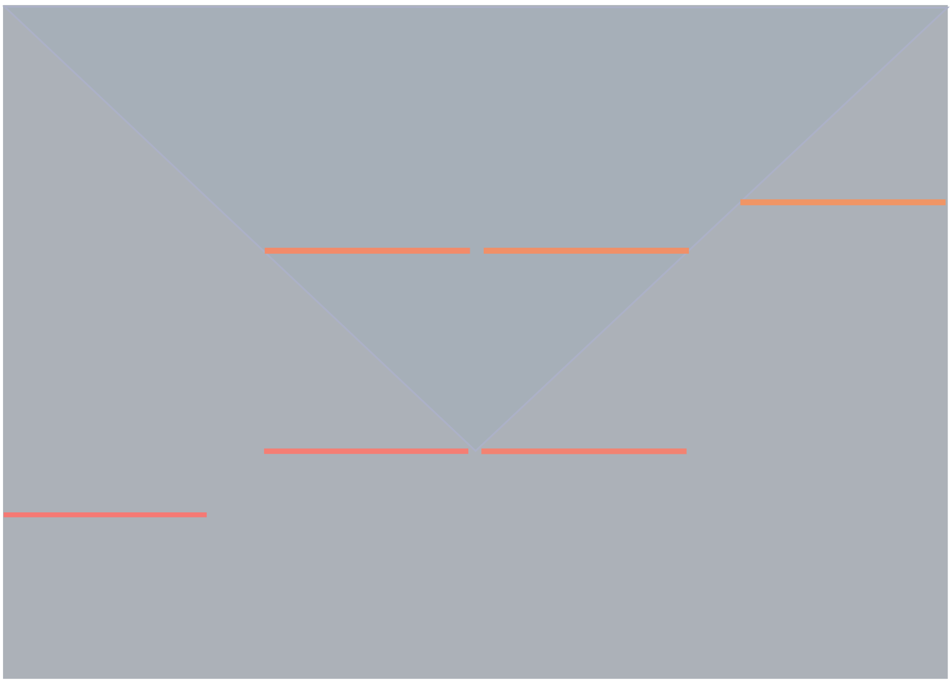


Figure 3: Elements of kind used in my "Grey Series", thin-bar paintings.

Alternating stripes

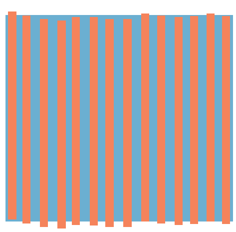


Figure 4: Example of a target of the kind used for the 'optical colour mixing' exercises

When preparing a colour course, I hit on the idea of getting students to explore similarities and differences between two ways of colour mixing: The normal *stirring-it-up* method and *optical-mixing*. Perhaps most people associate the latter with Seurat and arrays of dots of different colours placed side by side, in such a way that, whereas from close they are seen separately, from further away, they blend into one impression. As an alternative to clusters of dots is *alternating thin stripes*, an idea first suggested by Chevreul and popularized by Blanc in his influential book.[10]

Following this idea, using the masking tape method just described, the students created thin strips of colour-opposites and laid them, alternately, next to each other to produce a result along the lines of *Figure 4*. From close, these would be seen as alternating stripes of contrasting colours while, from further away, the different colours would blend into one impression. It was an ideal way of testing out *optical mixing*.

Lighting conditions

As preparation for the course, I had done much experimenting with different combinations of colours. In the process, I found myself making discoveries that intrigued and excited me. As an introduction to these, it is necessary to go back a step and return to *thin orange bars* in *Figure 3* and the "*Grey Series*" series paintings to which they relate. The choice of the *orange* for the bars is no accident. It was the outcome of discoveries which more or less obliged the use colours within this range. In earlier paintings, I had tried both *blue*, *green* and *purple* stripes but had been distressed when, in the evening, under electric (tungsten) light, the colour had drained out of them, leaving them a nasty grey.[11] It was clear that the change in the lighting conditions was having a particularly catastrophic effect on the balance of colours. I was forced to accept both (a) that there is *no way of avoiding colour transformations when paintings, tuned to daylight, are viewed under tungsten lighting conditions* and (b) that they would be particularly disappointing if they contained green, blue or purple thin lines painted on an approximately equal lightness background.

An obvious next step was to investigate the possibility that with other colours something might be gained by the exposure to a tungsten light source. What would happen if the thin-line bars were to be made of colours that would brighten

10 Charles Blanc, 1867, Grammaire des Arts du Dessin

11 The thinness of the lines accentuated the *lightness-contrast* effect.

up when illuminated by it, such as yellow, orange or red. Following this thought, I started experimenting with a range of reddish-oranges, similar to the colour illustrated in *Figure 3*.[12] The breath-catching outcome was that thin-line bars that I had managed to give the qualities I sought when illuminated by daylight, when transformed by tungsten light, became like bars from an electric fire, glowing in a scintillating void of grey. I had struck lucky.

The creative potential of changes in viewing conditions

These developments stimulated a growth of interest in effects caused by changes in viewing conditions. Thus, it is hardly surprising that I found myself noticing phenomena that I might otherwise have overlooked when experimenting with optical-mixing exercises in preparation for my art school course. In particular, when the viewing the targets, under natural lighting, at different times of day, I became aware that significant changes were taking place in the colour relativities of the stripes. Over-excited by what I was seeing, I impulsively leapt to a wrong conclusion. Luckily, my mistake did not prevent my discovery from being, not only the main catalyst to my next three years of work as a painter, but also responsible for my appointment to a post in a university. A mixture of ignorance and over-hasty judgement had changed my life.

Even at that time, I was sufficiently aware of the phenomenon of *colour-constancy* to suspect that the changes I was experiencing should not be taking place. But, in the glow of self-deception, I thought that seeing should be believing and what I told myself could not be doubted was that the appearance of my stripes were varying with changes in the lighting conditions. Not surprisingly, I soon found myself musing as to how I could exploit my discovery in the context of paintings.

Stripy paintings

The idea which emerged can be explained with the help of *Figure 5* which reproduces a detail of a painting from my "*Stirling Series*". The complete work, like all the others in the series, is only 25 cm square and it is made up of a grid of thirty six, 4 cm X 4 cm squares and thin borders around the edges of the painting. Each of these is composed of thin stripes (approximately 1/32 of an inch or 0.79 mm wide) of alternating, approximately complementary colours.

12 If the ranges had been any more yellow or more red, they would *have lacked both the required level of saturation and the necessary range of lightness*.

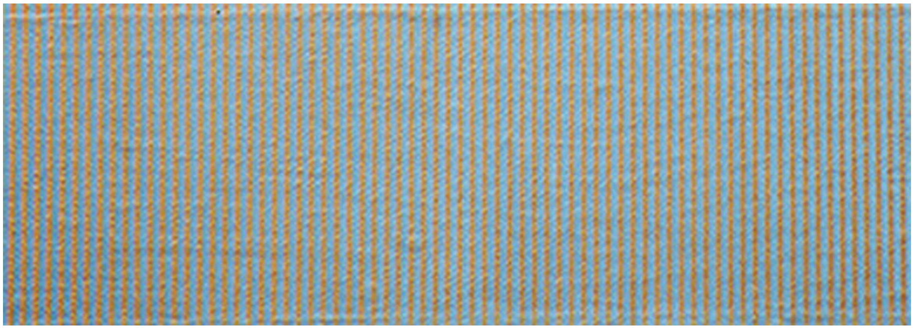


Figure 5: A detail from a stripy painting.

According to theory, alternating stripes of true complementary colours, when viewed from a certain distance, will be seen as a neutral grey. This being the case, it should be possible to make a uniform grey painting even though the thirty six squares were each made from a different pair of alternating complementaries. In addition, unless the *colour-constancy system* scuppered everything, any changes in lighting conditions would differentially upset the balance between the colour pairs within each and every square. The result should be a painting capable of coming alive in the sense that it would appear different with every variation in lighting conditions.

Although hesitant about the idea, I was encouraged by the pilot paintings. They did indeed change over time and in most exciting ways. It was in the consequent state of excitement that I went for my interview for the post of *Cottrell Memorial Fellow* at the *University of Stirling* and it seems that my interviewers were taken in by my enthusiasm. I felt I was the luckiest person in the world.

The set-back

Two years and twenty-eight paintings later, despite the many unforeseen difficulties I had encountered, I was still full of enthusiasm. Indeed, along the way, many new exciting possibilities had emerged. However, before I could start on the twenty-ninth painting, the house of cards had come tumbling down.

Influenced by my contacts with members of the *Psychology Department* and my exposure to the idea of properly controlled experimentation, I was persuaded that it would be a good idea to have some stable lighting conditions for looking at my paintings. The sequence of events that followed led, I cannot remember precisely how, to my being whisked off to Eindhoven in Holland, the headquarters of *Phillips Electrical*, the multinational giant, where I was furnished, as a gift, with the required equipment.

Back home, I was in for a shock for, with the new lighting system in place, the colours in my paintings changed as much as ever. There was only one conclusion to be drawn: The theoretical underpinning of my project was flawed. The idea that the variations in colour which I had been observing were due to changes in the spectral composition or the intensity levels of the light illuminating the paintings was simply wrong.

It was a devastating conclusion. But every cloud has a silver lining. I soon realised that if it was not variations in the lighting conditions that caused the colour changes that I had observed, it must be something else. The process of discovering what this might be was a transforming experience. As well as bringing about a great leap forward in my understanding of colour, it enabled the resolution of the puzzle dating back to Michael Kidner's colour course. Through experimentation I was to learn that there is a whole battery of reasons to explain the inability of Michael and his students to agree with respect to equal lightness judgements. It is to these we now turn.

The "*Pratt Effect*"

The first inkling of what was to come was the discovery that the colours in my paintings altered as a function of *viewing-distance*. As I moved away from them, the relative lightness of paired stripes always changed, in some cases, quite dramatically. Since I had never heard of such an effect of viewing distance on appearances, I went to my colleagues in the Psychology Department to ask for information. Although there were no specialists on colour vision as such, there were several with a good general knowledge of it, and I expected no problem in finding the required explanation. To my surprise, no one seemed to be aware of the phenomenon I was describing. Ranald MacDonald, the department statistician, kindly went to the trouble of doing a computer search. When this came up with nothing, he himself became very interested in my discovery. Rather precipitately and to my embarrassment, he insisted on describing it as the "*Pratt Effect*".

An expert's explanation

Despite Ranald's enthusiasm and his confidence in the thoroughness of his computer-search, I could not really believe that the viewing-distance effect I had discovered was unknown to the experts in the field of colour vision. How could it have been overlooked?

The event that made me begin to wonder whether Ranald might be right took place after a talk I had given about my paintings.[13] I was approached by an undoubted authority on colour perception who announced with apparent confidence that my observations were due to *small-field tritanopia*, a phenomenon totally unknown to me. However, when he explained in detail why he had reached his conclusion, there were various reasons why I felt that what he was proposing could not be right, but who was I to argue with an expert?

Fortunately, my doubts refused to go away, particularly since I could not help realising that the expert's confidence in one explanation suggested the possibility of ignorance of others. When I confided this thought to Ranald, he suggested that the only way to clarify the situation was by means of experiment.

The outcome was that Ranald and I were able to show conclusively that there is indeed a clear effect of viewing-distance on colour appearance and that it is most evident in comparisons between blues and reds, whether seen as separate colours[14] or as mixtures (that is to say, purples).[15] We also concluded that the main explanation for this phenomenon is almost certainly *chromatic aberration*, but there were almost certainly other contributory factors, including *small-field tritanopia*. One by-product of the experimental results of particular importance for me was that they provided an explanation as to why Michael Kidner and the students in his class found it so difficult to reach a consensus when making equal lightness judgements.

Below, the story of our experiments is told in more detail. In gratitude to our expert, it starts with *small-field tritanopia*.

Small-field tritanopia

One of the findings of researchers into the structure of the retina is a total absence of blue receptors in the central one degree of a normal retina. As a result, this tiny region cannot mediate perceptions of blueness. Consequently, the image of any blue stimulus completely encompassed within it will appear as a neutral

13 At a conference organised by The Colour Group of Great Britain, at the Royal College of Art, London, in 1977.

14 Pratt, Francis and MacDonald, Ranald R, 1981, 'Effects of distance on heterochromatic matching'. Perceptual and motor skills, Vol. 50, pages 1127-1138

15 MacDonald, Ranald R., Pratt, Francis and Beattie, Martin E., 1982. 'Effects of viewing distance on metameric matches'. Perceptual and motor skills, Vol. 54, pages 119-126

grey. In effect, the outcome is a highly circumscribed kind of *colour-blindness*. Furthermore, as the retinal images of stimuli get smaller with viewing distance, it is obvious that a stimuli of the appropriate size could change from blue to being not blue as a function of viewing distance.

Our question was, can this type of colour blindness explain the colour changes observable in my paintings? As already indicated, I felt sceptical. It seemed obvious that the regions of colour at which I was looking when investigating the viewing-distance effect in my paintings subtended visual angles of considerably more than one degree, even if the individual stripes were very thin. However, speculation is one thing and experiment another. Fortunately, it was not difficult to work out as way of checking out this matter. Ranald and I simply got people to compare large red and equally large blue discs at different viewing distances. The results showed that the distance effect was still in operation. Clearly, small-field tritanopia could not be the explanation we were looking for. Though it just might contribute to the viewing-distance effect, it could not explain it.

Other possibilities

With the only suggestion coming from an expert having been undermined, I began to entertain slightly more seriously the idea that I might have stumbled upon a hitherto unrecorded visual phenomenon. It was time to look into it more seriously.

As it turned out, we were never to find a reference in the scientific literature to a generalised viewing-distance effect of the sort we had discovered. However, we did find a number of studies directed at a particular and limited manifestation of it. These relate to a gadget known as an *anomaloscope*, which is used for detecting red/green colour-blindness (the most frequently found manifestation of anomalous colour vision). We also found Dr. Millodot who was aware of our distance effect and who had done detailed experiments that were to help us greatly in coming to our own conclusions concerning the main explanation for it.

More on these below. But first, as an aside, I would like to mention the response of another accredited expert who dismissed our findings. He was the reviewer employed by the highly respected journal to which we submitted a paper on thbe distance effect we had found. In his letter of rejection, he declared that he could not take seriously the idea that anyone could paint a painting with stripes of 0.79 mm wide. How could he have confidence in researchers who start their exposition with such a palpable nonsense! Significantly, this narrow minded reviewer did not dismiss our paper on the grounds that the effect was well known and this gave us encouragement to persevere.

The anomaloscope

The principal upon which the anomaloscope works is that red/green colour-blind people will not match a standard yellow light with the same red/green combination as colour normals. In 1947 two researchers, Horner and Parslow,[16] reported that the matches made by colour-normals varied with the viewing-distance from which they made the comparison. Various explanations were proposed for this state of affairs. Horner and Parslow suggested that it was due to a combination of chromatic aberration and pupil size. Later researchers disagreed and proposed an alternative explanation. Concentrating on the fact that the size of the anomaloscope image decreased with increases in viewing-distance, they explained the changes in colour appearance either in terms of the distribution of the *macular pigment* which fills the interior of the eyeball or in terms of the lay-out of receptor types in the retina.[17]

Our own researches came down firmly in support of the Horner and Parslow chromatic aberration based hypothesis, while recognising the potential relevance of all the other explanations in certain particular circumstances.

Chromatic aberration, viewing-distance and focus.

As is well known, different wavelengths of light are bent different amounts by a prism. The same phenomenon effects the light that passes through the eye's lens, making it impossible for all the different wave-lengths to be in focus on the retina at the same time. In the present context, the significance of this differential focussing becomes evident in the light of the experimental finding that there is a direct relationship between focus and lightness: the more fuzzy the focus, the less bright will be the appearance.

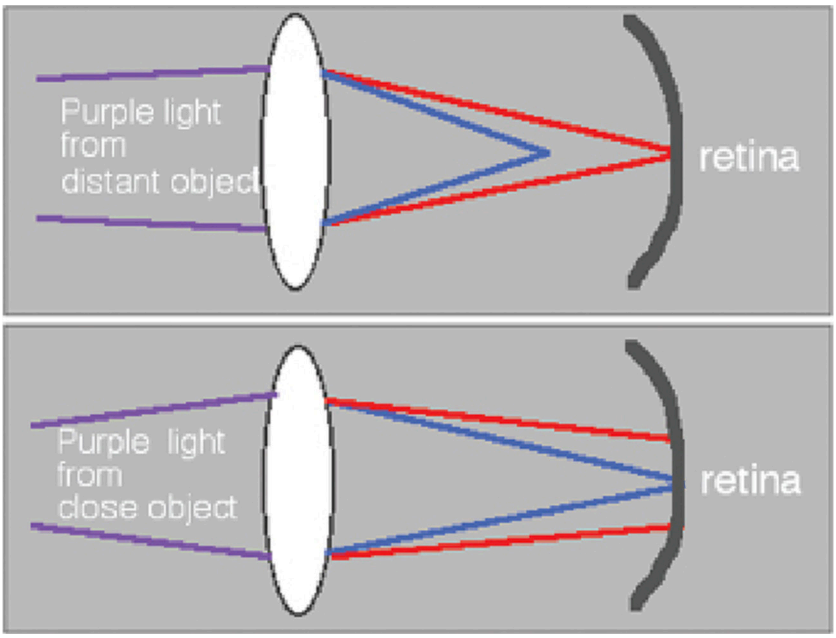
Figure 6 illustrates the nature of the relation between viewing-distance and the wave-length in focus. It is inspired by a paper by Millodot & Sivak,[18] whose comprehensive findings can be briefly summarised. Thus, they found that the eye

16 Horner , R.G. & Parslow, E.T., 1947,

17 In other words, similar to the explanation for small field tritanopia

18 Millodot, N. & Sivak, J.G., 1973, Influence of accommodation on chromatic aberration of the eye. Brit.J.Physiol. Opt, Vol. 160, pages 169-174

always focuses on the longest wave-length of light available. From most normal viewing distances, this will correspond to red light (higher diagram). However, whenever a viewer approaches a target reflecting a range of wave lengths, there will be a point at which the longest wave-lengths can no longer focus on the retina. From this point inwards the wave-length in focus will be shorter and shorter until, at very close viewing distance, it will be the shortest, that is to say the wave-length which corresponds to blue light (lower diagram). From this close-up viewing position, the focal point of all the remaining visible wavelengths will e behind the retina and, therefore, out of focus, with the longest (red appearing) wavelengths being the most out of focus of all.



0

Figure 6: Effects of viewing-distance on focus

When related to alternating orange and blue stripes in my stripy paintings, the results of Millodot and Sivak's tell us that anyone approaching a surface covered with them will discover that their relative focus will change: The red will be in focus from further (two or more paces) and the blue from nearer (within a 30 cm of the target). In view of the correlation between focus and lightness, these results predict the viewing-distance effect which I had first seen in my stripy painting, namely that on approaching an orange/blue pairing, the orange stripes change from lighter to darker and the blue ones in the opposite direction. The reader is invited to confirm this prediction for themselves by testing it on *Figure 4*. Analogous shifts occurred in all pairings I had tried out in the paintings

We also found that the distance effect worked for *colour-mixtures*. The biggest shifts occurred in purples, since they comprise a mixture of red and blue, the two extremes in relation to chromatic aberration. From closer viewing-distances purples become relatively bluer and from further away they become relatively redder. Some degree of colour-shift occurs with all colour-mixtures and this is always in the same direction. Thus, oranges viewed from nearer become more yellow, yellows become more green and greens become more blue.

Cones and rods and changes in levels of illumination

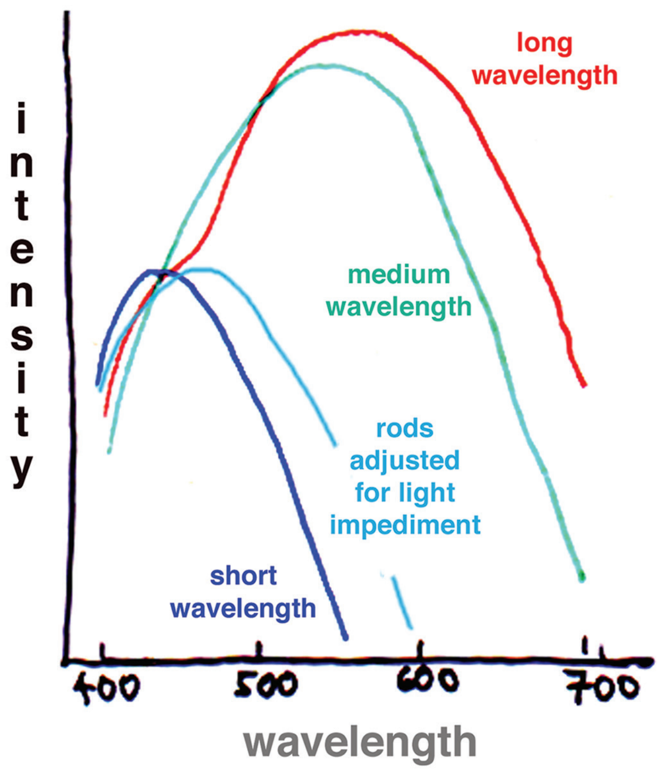


Figure 7 Showing the differential sensitivity of rods and the three cone types to different wavelengths of light.

Meanwhile we had come across other reasons which might contribute to colour shifts in certain circumstances. One of them concerns interactions between the relative sensitivity of rod receptors and cone receptors in the retina and level of intensity of the light illuminating the colours concerned.

Thus, the rods are much more sensitive to the intensity of light than the cones. As a result, under normal daylight conditions, the few rods left in the fovea are "*bleached out*" and cease to function as sources of information. It is for this reason that classical colour theory ignores the rods as sources of colour experience. Nevertheless, it is generally accepted that, under some circumstances, the rods do play a part in colour vision. The best known of these being when the levels of illumination are low, as at evening time. *Figure 7* explains why this should be so, by showing that the rods like the cones are differentially sensitive to different wave-lengths of light, with their region of greatest sensitivity being half way between those of the green and the blue cone receptors. From the experiential point of view, what all this means is that as dusk settles in and the overall level of illumination in the environment decreases beyond a certain point, the rod receptors start to play a part in colour vision. Thus, for example, whereas, at midday, a comparison between a red and a blue flower might show the red as the brighter of the two, a comparison at dusk may favour the blue. Similarly a red-violet flower may be transformed into blue-violet one with the reduction in the level of illumination as evening approaches.

There is also evidence that the wave-length sensitivity of the rods may play a part in perception at higher levels of illumination. Thus, Graham showed that four primaries are needed to match large regions of colour[19] and, evidence from red/green colour-blind people leads to a number of intriguing possibilities, which are discussed elsewhere.[20]

Changes in pupil size

It is well known that the size of the eye's pupil changes with the intensity of the light impinging upon it and does so according to the principle that the less the amount of light, the larger the pupil becomes and the greater the spread of light entering the eyes. Since there is a correlation between focus and lightness, this means that, relative to a red, a blue will get darker with increases in the level of illumina-

19 C.H. Graham, Editor, 1965, Vision and visual perception, Wiley, London
20 Appendix B

tion. As Horner and Parslow pointed out, this phenomenon will enhanced when targets are much brighter than their surroundings (as is the case with the targets provided by an anomaloscope). This is because, the greater the distance from which the target is viewed, the greater the relative influence of the dark background. Since a diminution of light causes both an increase in pupil size and poorer focus, a colour shift in the direction of blue will reslt from increases in viewing distance.

Ageing eyes and spectacles

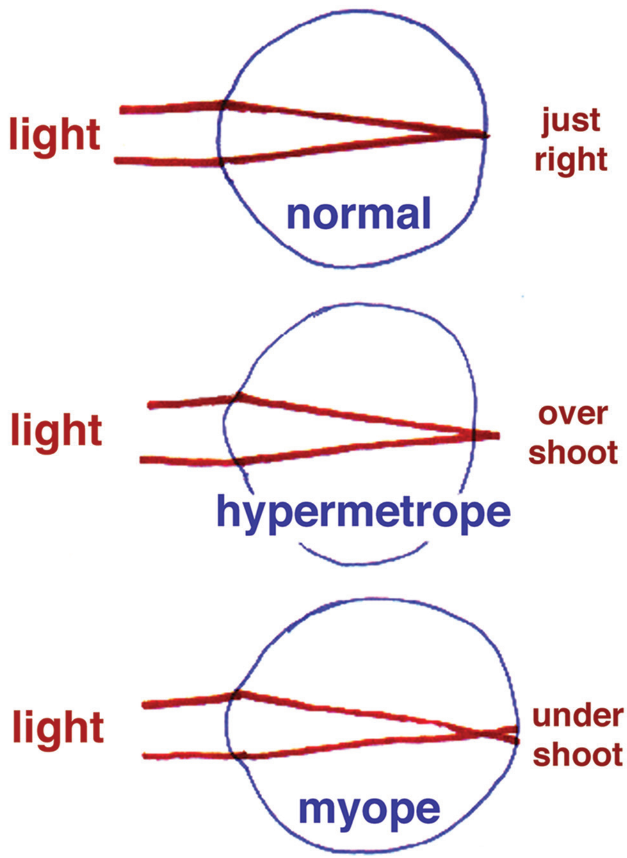


Figure 8: Focusing profiles of normal, hypermetropic and a myopic eyes

In young people the eye's inner lens (known as the *"crystalline lens"*) is flexible. As explained earlier, this flexibility allows the eye to make fine adjustments in focus. *Figure 8*, middle diagram, show how, in the absence of an inner lens, a hypermetropic eye (long sighted - short distance between corneal lens and retina) would be unable to focus light on the retina under any circumstances and how the situation would get worse as the eye approached the object being viewed. This is the unsatisfactory situation that the flexible crystalline lens ameliorates.

However, its flexibility diminishes with age. Accordingly, at a certain point in their life *"hypermetropes"* (long sighted people who can focus on close up objects) become *"presbyopes"* (long sighted people who cannot do so) and need spectacles. Until the arrival of the possibility of variable focus, lenses lacked flexibility, with the result that different lens prescriptions were required for different viewing-distances (for example, for reading, for driving or for painting). In view of the connection between focus and colour appearance explained above, it is not surprising to find that big changes in colour perception can occur when presbyopes remove their spectacles.

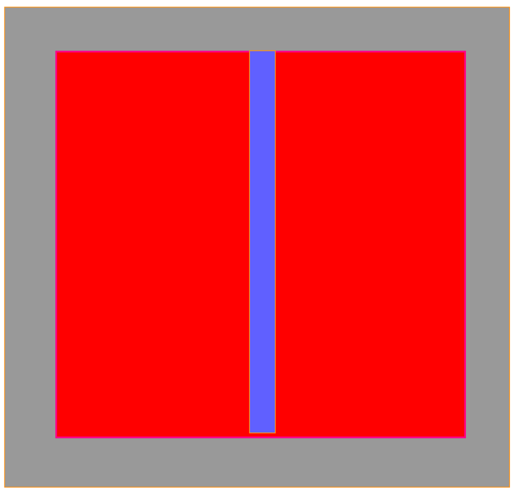


Figure 9 : Experimental target used to test effects of spectacles on colour appearance.

Figure 8 (bottom diagram) also shows that, though the details are a different, the general picture is similar for myopic people (short sighted - long distance between the lens and the retina). Thus, for them also, the flexibility of the eye's inner lens has the function of enabling them to see more clearly at a greater range of distances. For example, they can read comfortably at a variety of distances from the eye. However, when they get older and the lens becomes inflexible, the range of reading distances will be reduced, until there will only be one distance remaining capable of bringing the page of writing into focus. This will always involve going closer to it, possibly so close that the short sighted person will no longer be able to take in a whole line of writing at a glance.

If the reader is a *presbyope*, old enough to need spectacles for distant vision, he or she is invited to experiment with *Figure 9*, by looking at it from two or three paces away, alternately with and without the aid of the spectacles. The effect of wearing the spectacles should be to bring the longer wave-lengths into focus and thus, relatively speaking, favour the red parts. Taking them off should remove this advantage by bringing the long wavelengths out of focus and, thus, relatively speaking favour the shorter ones. As a result, without spectacles, the blue may seem the brighter of the two colours and, with them, the red.

It may be easier to demonstrate the reverse effect when the target is seen from close-up.

Avoiding equal-lightness

It would seem that the human visual system abhors equal-lightness colours. The explanation we were given at art school was that lightness-contrast is important for making sense of the world, since it is necessary for the operation of a number of visual systems. Certainly, this hypothesis gives us the following way of explaining the instability which many people experience when looking at near equal-lightness colour pairs. The argument goes that since there is a relation between focus, chromatic aberration and the relative lightness of colours, it is evident that the eye's inner lens, merely by changing its shape, can transform equal-lightness into unequal lightness. This being the case, if the visual system really does abhor equal-lightness pairs, the young eye would be able to avoid it by modifying the shape of its inner lens until the pairs are no longer equal. However, at the moment the desired imbalance is achieved, the stupid brain could be expected to be comforted and, seeing no reason to continue the effort of holding the lens in its new position, relax the ciliary muscle. Unfortunately, for its comfort, doing so would restore matters to lightness equality and abhorrence. In this way a cycle of changes from equal to unequal lightness would be set in motion, creating a highly unstable situation. The result will be one that many people have experienced, involving a certain kind of kinetic energy between the colour pair in question, capable of giving some people a buzz and others a headache.

Back to the Art Class

From the above, we can now see why Michael Kidner and we students in his class found it so difficult to agree: Michael was about fifty years old and, therefore, must have lost the flexibility of his inner lens. Some of the students were no doubt myopic and others hypermetropic, some were wearing spectacles and others were not. And, it never occurred to any of us to consider our viewing-distance as a variable, any more than it occurred to us to monitor changes in the ambient level of illumination. In all, we were a disparate and ignorant lot, which did not mean that we did not get much of interest and visual enjoyment out of Michael's project. Quite the contrary.

Taking the third dimension into account

So far we have only considered colours displayed on a flat surface. But when we depict nature, we are doing our best to analyse them in the context of a three dimensional world. This extends the number of context dependent visual effects we will find ourselves confronting. Although the demonstrations which follow concern relativities of lightness and darkness and not to the other dimensions of colour as such, it cannot be emphasised too often that all colours look different in all their dimensions if any of them are changed.

The constraints imposed for laboratory experiments can reveal some dramatic effects that might never be noticed in the everyday world. This is partly because the conditions are arranged to maximise the effect in question. It is also because in everyday life we virtually always manage best by believing our eyes. This leaves us off our guard when an exception arises, with the result that we can only too easily overlook occasions on which our eyes deceive us. This is certainly true of the four experiments that follow. Although they make a splendid job of surprising our eyes, their main significance is to those who want to understand how the eye/brain make sense of the visual world. Most importantly, they highlight the need to understand the computational basis of cognitive cues.

Everyone will have noticed that a window-bar, even though painted white, when contrasted directly against a bright sky outside, will appear to be black. Some people seem to find it hard to believe that the light scattered back from a surface that appears to be so black is as intense as the light being scattered back from a neighbouring white wall. If so, they may have an even greater difficulty in believing the description that follows of how an experimenter named Gilchrist discovered that a white surface can be turned black either, simply, by closing an eye or, more mysteriously, by a sort of conjuring trick which deceives viewers' preconscious visual systems into believing that a target that they are asked to look at is further away from them than it really is.

The bent-card illusion

However, though providing the most dramatic demonstrations, Gilchrist was by no means exploring virgin territory. He was very consciously following in the footsteps of Hochberg and Beck, who had managed to make a significant change in the lightness of a surface by waving a pencil up and down. And they, in their turn, were much influenced by the well known "*Bent-Card Illusion*", which is associated with the name of Ernst Mach, of "*Mach-Band*" fame.

The bent-card illusion requires a light source, a rectangular piece of white card and, possibly, some perseverance. The card should be bent in half and placed with the fold pointing towards your eyes, making a convex corner. This arrangement is illustrated in the left hand side image in *Figure 10*. The light source should be arranged so that it illuminates one side (in this case the left hand side), leaving the other side in shadow (the right hand side).

Figure 10 : The bent card illusion

The illusion is created by deceiving the eye into thinking that the fold is perceived as pointing away from your eyes, making a concave corner (the right hand drawing). The perseverance is needed to arrive at the deception. The other requirements will almost certainly be a combination of de-focussing the eyes and a sustained effort of blank-minded concentration. With reasonable luck, sooner or later, the brain will do what is required of it and jump to the false conclusion that the fold is now nearer, making a convex corner (left hand drawing). If it does, simultaneously with the switch in interpretation, the shaded side of the card will suddenly become significantly darker. To account for this dramatic change it is necessary to hypothesise that the brain is using knowledge of the direction of the light in making its interpretation of the dark half of the card. Thus, when the fold is falsely perceived as being further away, the dark side can only be interpreted as facing the light source: in which case, it could not be a shadow. The brain is left with no alternative but to perceive it as black pigmentation. As so often in visual perception, preconscious knowledge precedes interpretation.

The question arises as to how the brain computes this knowledge. It is one of many as yet unanswered fundamental questions, although ideas in the chapter on the colour constancy algorithm (*Chapter 12*), may well point in the direction of an answer.

Hochberg and Beck's demonstration

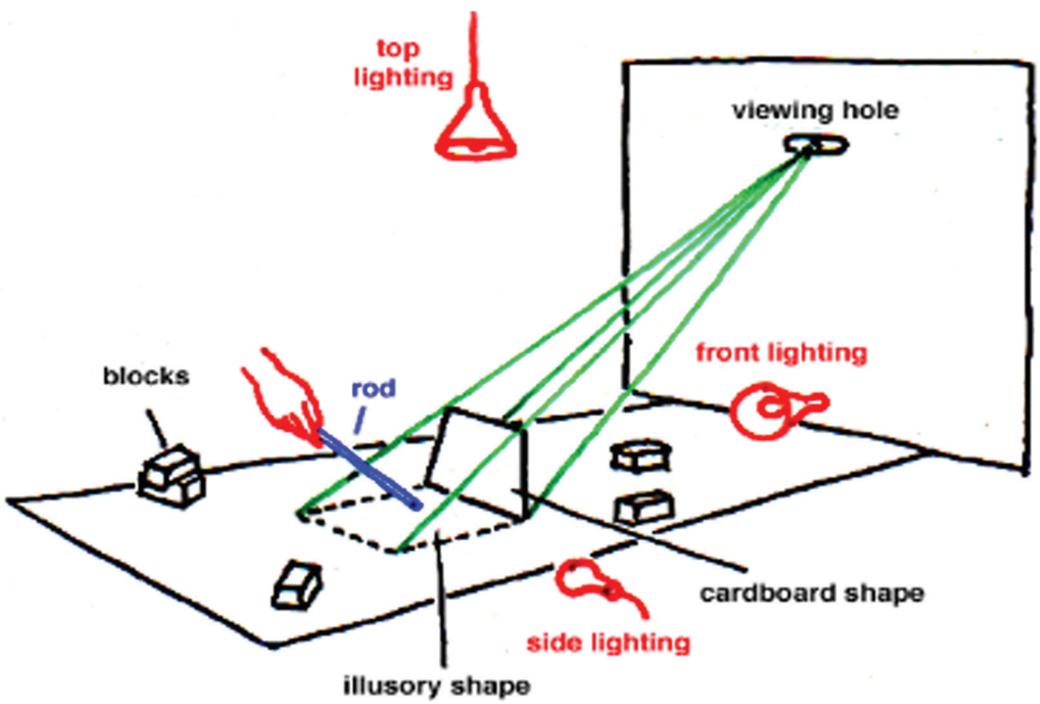


Figure 11 : Hochberg and Beck's demonstration

Hochberg and Beck's experimental set-up makes it possible to examine further the eye/brain's capacity to include assumptions about the direction of the light source in its calculations relating to the perceived lightness of surfaces. However, relative to the bent card illusion, it reduces the effort necessary to bring about the changes and makes what happens seem both more natural and, if anything, more miraculous. Once again, everything depends on creating an illusion. In this case, it is created by exploiting the phenomenon of shape-constancy, whereby foreshortened rectangles are perceived as having right-angle corners, despite the image on the retina being subject to well known perspective-induced distortions.

Thus, in *Figure 11*, the cardboard shape, when viewed monocularly through the viewing-hole, has two plausible interpretations: First, as upright, in which case it appears its actual shape, having a longer base and a shorter top; and, second, as lying flat on the table-top, in which case it appears as a receding rectangle. Normally, it is perceived as the latter (the various blocks, placed nearby are expressly there to support this interpretation). However, the simple act of waving a pencil in the space behind the card renders this interpretation impossible. Immediately, the card is seen as both upright and its actual shape. Nor is the shape alteration the only transformation that takes place. Simultaneously there is a distinct change in lightness, the direction of which is determined by the location of the source of the illumination. As illustrated in *Figure 12*, if lit from in front, the target shape appears darker, when thought to be horizontal, and lighter, when thought to be vertical. When lit from above, the situation is reversed.

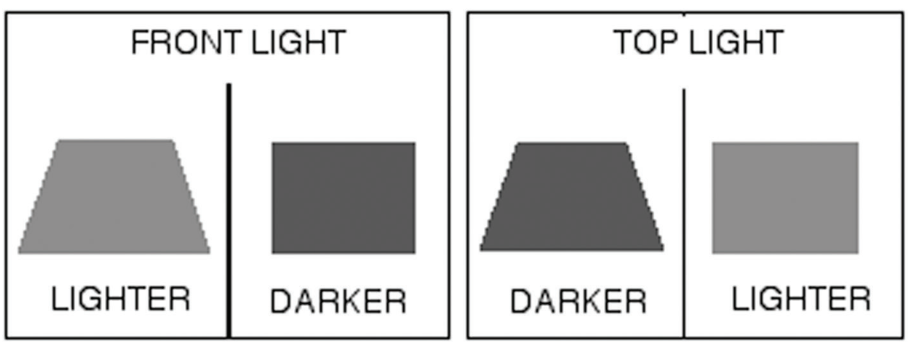


Figure 12 : Hochberg and Beck's results

Hochberg and Beck's experiment provides four interesting findings, all of which confirm the deductions from the bent card illusion. The first is that the eye-brain can determine the direction of the main light source. Of the other three the third is perhaps the most theoretically surprising and challenging. They all concern the basis of eye/brain computations. Thus the eye/brain:

- Uses knowledge of the direction of the light source in constructing perceptions of relative lightness
- Takes illusory spatial orientation into account when computing appearances.
- Takes overlap information into account when computing appearances.

Gilchrist's demonstrations

One could say that all Gilchrist did was to dramatise phenomena already demonstrated by Hochberg and Beck. However, the effects which his experimental arrangements produced are both more spectacular and easier to relate to actual analyses of colour relationships in the natural world. There are two different experiments: the first of these depends on comparing monocular and binocular observations and, the second, on tricking the observer, by means of misleading overlap information, into seeing a surface as further away than it really is. In both cases, as with both the bent-card illusion and Hochberg and Beck's demonstration, it is preconscious processing that determines what is perceived.

The first demonstration

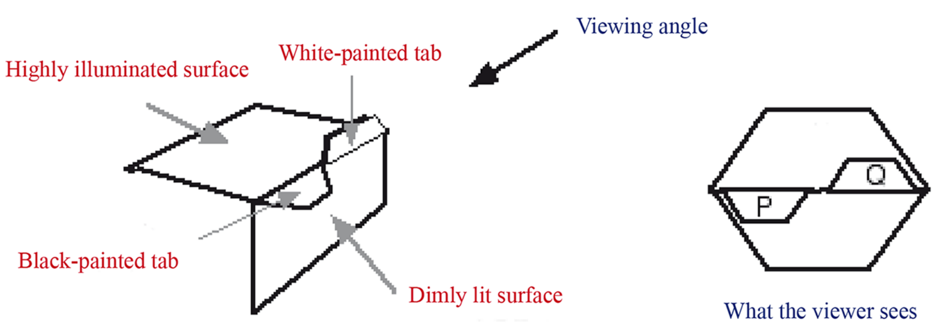


Figure 13: Targets for Gilchrist's first demonstration

Gilchrist's first experiment uses a target display constructed as illustrated in *Figure 13 (left)*. It consists of a piece of card bent at right angles and placed such that one surface is horizontal and the other vertical. From the corner of these surfaces project two tabs, a black-painted one ‘P’ which is coplanar with the horizontal white-painted surface ‘X’ and a white-painted one (Q) which is coplanar with the vertical grey-painted surface ‘Y’.

Figure 14 shows a cross-section of a large cabinet in which the display is placed. The base of the cabinet is almost a metre square and the height, just less than two metres. Matters are arranged such that a light source situated on the ceiling of the cabinet shines directly down onto the horizontal surface, but does not directly illuminate the vertical one. The only light arriving at the latter is reflected from the grey sides of the box.

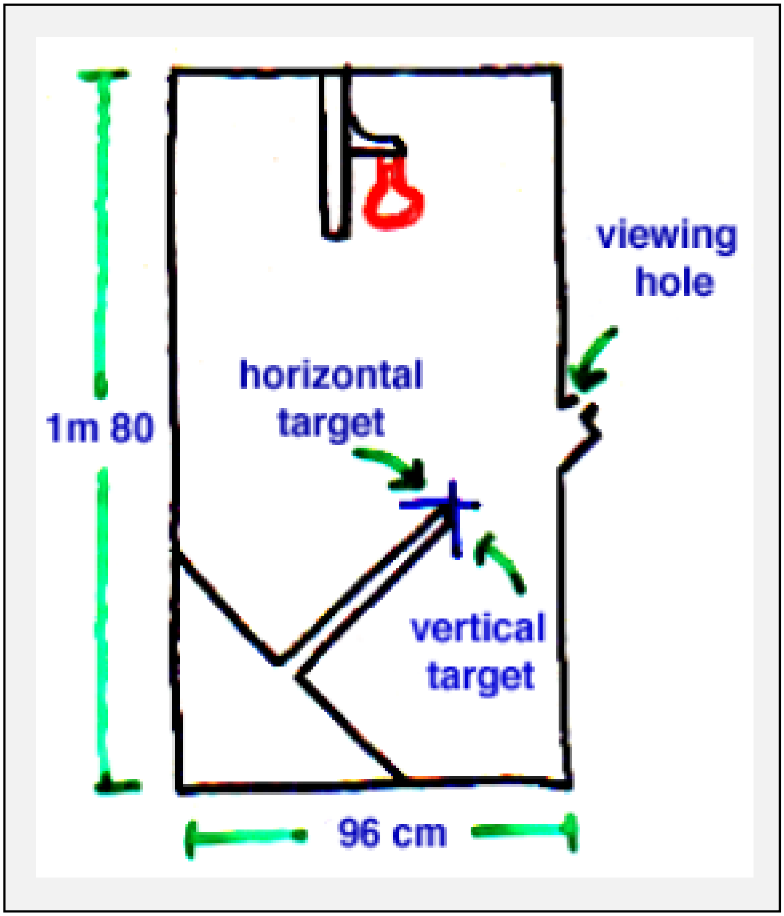


Figure 14: Set up for Gilchrist’s first demonstration

Using this equipment, Gilchrist was able to create an enormous intensity difference between the light source illuminating the horizontal surface and that illuminating the vertical one (a ratio of 900:1). In the side of the box that is facing the vertical target there is a slit from which the display can be observed such that both of its main surfaces are at an identical angle to the line of vision. As a result they are affected in the same way by the laws of perspective. The observation slit is long enough to allow for either monocular or stereoscopic vision. For the experiment itself, the experimental subjects were asked to look at the display either with both eyes or with one eye closed. This meant that:

1. When both eyes are being used *stereopsis* occurs and gives strong 3D spatial information with the result that the tabs are perceived as being in their actual orientations. Thus, the brightly illuminated black-painted tab is seen as coplanar with the brightly illuminated white-painted horizontal surface and the dimly lit white-painted tab is seen as coplanar with the dimly lit black-painted vertical surface.
2. When only one eye is being used, the tabs are seen as rectangular shapes lying on the surfaces behind them. Thus, the brightly illuminated black-painted tab is wrongly perceived as being coplanar with dimly lit grey-painted surface while the dimly lit white-painted tab gives the impression of being coplanar with brightly illuminated white-painted surface.

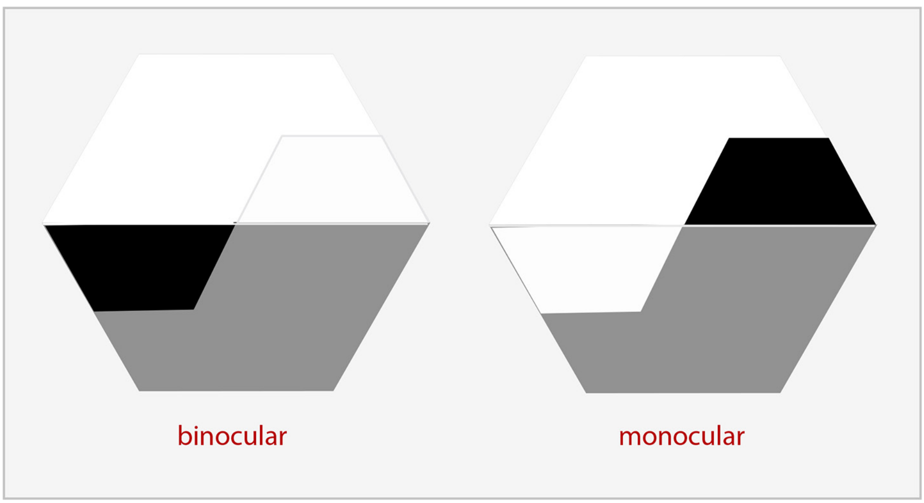


Figure 15: The display and the results

Figure 15 also shows the results which depend on the fact that the appearance of the tabs is influenced by the lightness contrast between the tab and its perceived background. Thus:

1. When stereopsis is in operation, the brightly lit black-painted horizontal tab is seen in contrast to the similarly illuminated and actually coplanar white-painted horizontal surface. Consequently it appears as its painted colour.
2. When *stereopsis* is inhibited by the closing of one eye, the brightly illuminated, black-painted horizontal tab is compared with the dimly illuminated grey-painted vertical surface, relative to which it looks white. Similarly, the dimly lit white-painted vertical tab, which is now seen as lying on the brightly lit white-painted horizontal surface, appears as a black reminiscent in appearance to the colour of white window bars seen against a brilliant sky.

In summary, black has been turned to white and white to black.

Gilchrist's second demonstration

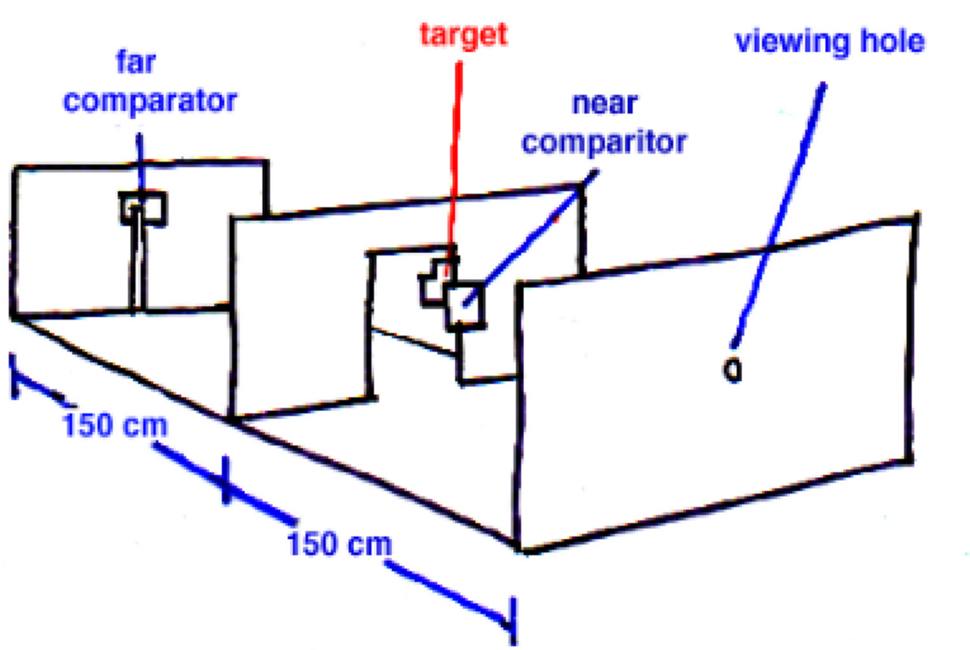


Figure 16: Gilchrist's second demonstration

Gilchrist's second experiment depends on tricking the eye by means of *overlap cues*. *Figure 16* shows the set-up. This time, instead of a single cubicle, there are two, miniature rooms (both approximately one and a half meter square) with a opening between them. The nearer room, along with a white-painted target in the doorway, is dimly illuminated, while the further room along with the white-painted comparator target is very much more brightly lit (the intensity-difference ratio being 220:1). The experimental subjects viewed this set up *monocularly* through a small hole in the wall of the nearer room. Their task was to judge the lightness of the target concerned. Once more, the outcome depends on what is perceived as its context. Thus, if compared with a dimly illuminated, black-painted panel in the near room, it is seen as white, whereas, if compared with the brightly illuminated, white-painted panel in the far room, it appears as a black. As in Gilchrist's first experiment, this is reminiscent in appearance to the colour of white window bars seen against a brilliant sky.

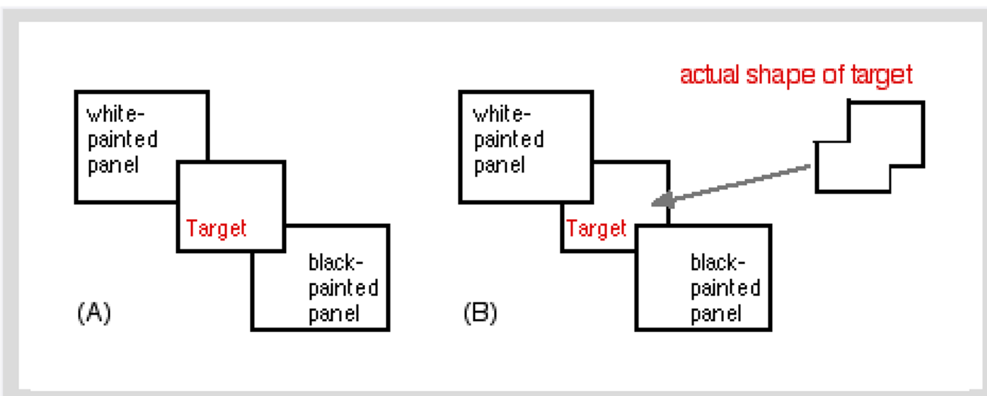


Figure 17: The target is made to appear behind the distant white-painted panel solely by means of overlap cues.

The ingenuity and much of the additional interest of Gilchrist's arrangement is shown by how he tricked the eye into making the second of the two alternative interpretations. *Figure 17* shows he did it. It will be seen that the only difference between the two experimental conditions is the shape of the target and it is this that determines its perceive spatial location. One one case (A) it is a rectangle and in the other (B) a rectangle shape but with right-angled segment cut out of each corner. Thus, as illustrated on the left, in the first experimental condition the dimly lit white-painted rectangular target is perceived as a rectangle in its actual location, that is to say, just in front of the adjacent, coplanar, dimly lit black-painted comparator panel. However, as illustrated on the right, in the second experimental condition, the specially designed shape of the dimly lit white-painted target deceives the eye into seeing it as behind both of the comparator panels and as being illuminated by the two hundred and twenty times more intense light source in the further room. In this circumstances it is perceived as being as black as the window bars seen against the bright sky. As there were no changes in either the actual location of the target or in the wave-length combination of the light being reflected from it, the dramatic change in appearance can only be due to the brain's interpretation of the location of the target, based on *false overlap information*.

In summary, both Gilchrist's experiments give potent support for what had already been indicated by the bent-card illusion and the Hochberg and Beck demonstration, namely that appearances can be radically changed by what the brain assumes it is looking at. The three interrelated and fundamentally important lessons that are being rammed home are the same as those that came from the bent card illusion and the Hochberg and Beck demonstration. The are that:

1. Priority is given to perceived context over actual context with respect to colour appearances.
2. Appearances can be determined by the eye-brain's choice as to which visual system it believes.
3. Conscious appearances can be significantly influenced by preconscious processing.

All these factors can contribute to the factors that decide the nature of the visual experience of artists when analysing scenes that they are in the process of drawing or painting from observation. Of particular interest is the difference between the colour perceptions produced by monocular and binocular vision. Colourists have many good reasons for keeping one eye closed while they are working.

Implications

Ever since Chevreul first described the phenomena of simultaneous colour and lightness contrast, knowledge of them has had a great impact on the practice of painting. Their importance to the artistic community is reflected in the regularity with which they appear, treated with varying degrees of thoroughness, in "how to do it" books on painting.

They have also has been the focus of excellent scientific studies, which have explained it in terms of lateral inhibition, none of which is more impressive than that of Tom Cornsweet.[21]

In this chapter, I have tried to avoid tedious repetition of what is already extremely well known. Rather, I have concentrated on aspects of the subject which are difficult to find out about. All of these concern viewing conditions. They explain how colours can be effected by:

1. *Viewing distance (near or far)*
2. *Viewing context (as neighbours on a flat surface or in an in front/behind relationship)*
3. *The number of eyes used (two or one)*
4. *The type of eyesight (short or long),*
5. *Whether or not spectacles are being worn*
6. *Knowledge of the location of the main light source.*
7. *Cognitive cues and in particular overlap and other sources of information about spatial layout.*

For the scientist wishing to model the eye/brain, the last two of this list should be of particular interest.

21 Cornsweet, T. N., 1970, Visual Perception, Academic Press, New York: NB. Other possibilities are discussed later in this book.