

COLOUR VISION : NORMAL AND ABNORMAL, FOR PHYSICISTS.

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(Read March 25, 1937.)

In the past the subject of colour vision was one of the most difficult with which the medical student had to deal. Doubtfully could the subject be called a science because the student of it found that he could do little more than consider a mass of incompatible theories, each of which seemed equally as valid as any other, and select from them some one which pleased him best. Workers in this field also had their scope limited. They might find new facts, but, having found them, their aim seemed to be to find the already existing theory with which the new facts seemed best compatible.

It now appears that the difficulties of this subject were not provided by the facts, but by certain preconceived notions with which the facts were expected to conform. Those who dealt with colour vision presumed that the natural stimulation by light of the nervous elements in the retina was a process exactly similar to that of exciting a piece of excised nerve by an electric current. In addition, none of them knew how a beating heart, and with this rhythmically active structures generally, behave when they are stimulated. The scientist who has this knowledge, however, can immediately recognize that the behaviour of the nervous elements of the eye on stimulation is similar to that of a beating heart. And such a recognition so completely transforms the subject of colour vision that, instead of elaborating complicated theories about it, an elementary knowledge of physics enables one to predict its chief phenomena. We can use, in fact, the known phenomena of sound to teach us something about colour.

From what we know about sound, a rhythmically active living nervous structure could be expected to possess the capacity to provide two types of sensation, the one provided by the intensity of each individual effort, the other by the rate of repetition of those same efforts. That is to say, we should expect a rhythmically active nervous structure to provide one sensation mediated by amplitudes and corresponding to loudness, and another mediated by rates and corresponding to the musical note. The phenomena of vision corresponding to loudness and tone are brightness and colour. Hence we conceive the possibility that colour is dependent on the rate of beat of living rhythmical structures.

Acceptance of this possibility makes coloured light an external force which is capable of altering the rates of the rhythmical changes that take place

in the structures of the eye reacting to light. These living rhythmical structures, however, have a normal rate of beat which is determined by their own intrinsic forces. It is this normal rate which the external forces may alter. Further, only two types of change are possible, namely, quickening and slowing.

Now, if one of these external forces quickened a normal rate, n , say, to $(n+x)$, it is likely that among the slowers there should be one which slowed the rate to $(n-x)$. If things were so, then the combined action of these two forces should give no change of rate at all, though they might augment amplitude.

These simple calculations, expressed in terms of colour, imply that every colour may have an opposite such that the two acting together neutralize each other's action on rates. Many of such pairs of colours could conceivably exist, but their admixture should give a common result.

These deductions are realized. For every colour has an opposite or complementary colour such that the admixture of each pair gives the common result of grey or white according to strength. Hence we find that the neutral colour is grey, and that this can become white by amplitude increase. Further evidence in support of this is derived from the behaviour of hearts. Drugs which can alter both rate and amplitude have been found by me to alter amplitude only when they are employed in weak concentrations. If this rule held true for rhythmical structure generally, then feeble light should exhibit variations of brightness of the neutral colour only. This is also true, for dim light gives us variations of grey.

The next expectation derived from what is known about sounds is that every colour should be mediated by a range of rates and not by a single rate. If we take as the standard for C a vibration rate of 256, say, there will be a range of vibrations on either side of this which we must still call C. Some of these we cannot directly distinguish from our standard, others we shall still call 'C' but declare that they are somewhat flat or sharp as the case may be. If, next, rates are gradually quickened from the standard, we shall eventually reach a pitch which is more than a sharpened C, but is instead a new note, C sharp. Similarly on the other side C will gradually flatten to C flat.

The expectation from such facts is that grey through quickening should gradually sharpen into a colour, grey sharp, and by slowing should flatten into a colour, grey flat. These two colours should possess the property of mutual decolourization to grey without the intermediate production of any other colour, because grey flat can only flatten grey sharp to grey and vice versa. Two colours with these predictable properties actually exist. They are red and green. Up to the present, however, their capacity to decolourize one another has been simply inexplicable. In this case, therefore, we actually progress from the inexplicable to the predictable.

We may now progress to drawing the colour scale given below (see fig. 1).

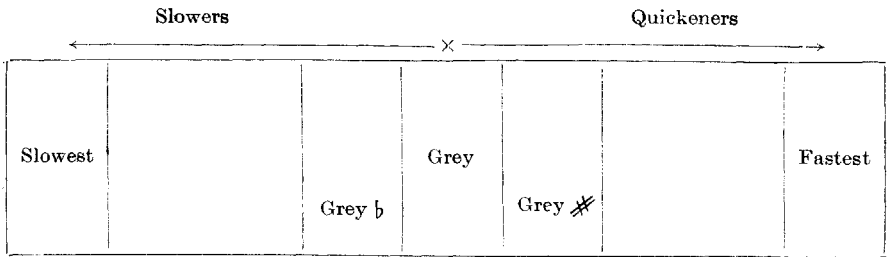


FIG. 1.

The scale is given to indicate the existence of two other peculiar colours lying at the extremes of the scale. Their existence is predictable from the fact that our capacity to perceive movement is limited. The limitations are definite, things may move too fast or too slow. There should therefore be at one end of the scale a colour mediated by the slowest rate perceptible to us, and at the other end a different colour mediated by the fastest perceptible rate. These two colours are of opposite nature and in combination with red and green should provide all other colours.

The next task, then, is to search among colour vision theories for one which divides the colours into two pairs of opposites with red-green as one pair. The theory we require is that enunciated by Hering, and from it we find that the other pair is blue-yellow.

These colours require now to be placed in position. Help towards this is provided by the artists who divide colours into the warm and cold. Their actual division has been strongly criticized, both by physiologists as well as physicists, on the basis of spectrum findings with the thermopile. Such criticism has actually been unscientific. If artists do not feel what someone argues from the spectrum that they ought to feel, it is not to be deduced from this that they feel wrongly. One can only deduce from the differences that further investigation is required. An entirely new light is thrown on these matters when one appreciates that the artists have obtained their sensations of warmth and cold from rhythmical structures. In such structures warmth quickens, and cold slows. Consequently we place red and yellow among the quickeners, and blue and green among the slowers. This gives the colour scale below (see fig. 2).

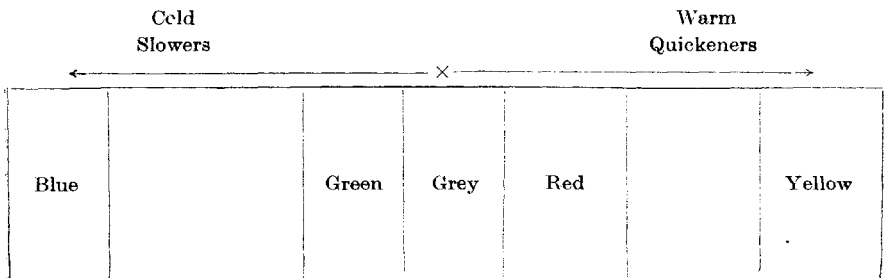


FIG. 2.

It is to be observed that the 'slow' division of the scale is made longer than the 'quick'. That is done because a mixture of blue and yellow yields green, i.e. blue slows more than yellow quickens.

On looking at the scale we appreciate the possibility that colours may also possess a property corresponding with what musicians term 'pitch'. Hence we look for another inherent property of colours, and find what we want in their intrinsic brightness.

The colour scale above represents the normal state of affairs. From this normal or average only two variations are possible, it may either be harder or easier for rate changes to be effected. The limit of hardness would imply an inability of those external forces, which normals call colour, to quicken or slow rates beyond the range which gives grey. The possessor of such insensitive end-organs would therefore see variations of grey where others see colours, and he would be termed completely colour-blind.

A milder degree of hardness would not permit the weaker external forces, those which normals call red and green, to quicken or slow enough to give a colour distinct from grey. The possessors of such end-organs would therefore exhibit varying degrees of red-green colour-blindness. Some, for example, would confuse all reds with grey, others would be able to distinguish 'sharp' reds from grey, but not the 'flat' reds, and so on. The converse would hold for green. These predictions are in general fulfilled.

A quite different type of colour-blindness would arise from the possession of unduly labile end-organs. In such, the rates would be quickened and slowed so much by yellow and blue, respectively, that the rates actually produced by these forces would be either too fast or else too slow for the existence of motion to be perceptible. The individuals possessing such labile end-organs would consequently be 'blind' to yellow and blue. The normality of the end-organs at the periphery of the retina is the possession of this degree of lability.

The main facts of colour vision and colour blindness are thus predictable from the standpoint that the end-organs which give rise to visual sensation have an inherent rhythmical activity. Conversely, of course, the facts lead to a theory that the end-organs possess this inherent rhythm. In the past, however, every scientist who thought on these matters started out with a presupposition that the end-organs of the retina had an essentially different character from that which they actually possess. This presupposition placed the science of colour vision in a position analogous to that of astronomy in the days when it was presupposed that the earth was stationary and flat.

If we could imagine a group of intelligent scientists speculating on the phenomena of sunrise from the bases of a stationary and flat earth, is to be appreciated that seemingly satisfactory explanations would be forthcoming. We could even expect the three schools of those who are suggested that the sun was pushed from behind, of those who suggested that it was pulled from the front, and of those who suggested that it had an inherent power of movement. It would further be impossible to make definite choice between these different

schools. Each one's theory would be as valid as that of any other, a point to which we would draw special attention.

When any false theory is accepted as a fact, it becomes possible, by correlating it with other facts, to build up a number of other false theories each of seemingly equal validity with its fellows. Such has been the character of the divers theories hitherto elaborated around the phenomena of colour vision. Their seeming equal validity is in itself the evidence that they each treat as fact some fundamental false theory. The fundamental theory which we have found to be false is the one that presupposes that the stimulating action of light on the retinal end-organs is the same as the action of electric currents on a piece of excised nerve.

But even if we still believe in this fundamental proposition, the advance of the science of muscle and nerve shows that traditional colour vision theories are faulty. It was good physiology, for example, in the days of Helmholtz to believe that an individual nerve or muscle fibre gave graded responses when it was excited by graded strengths of electric current. Now we know instead that such responses have an all or nothing character. Each individual element gives either its full response or none at all. Such responses, it should be noted, are similar to those of a gun cartridge.

The sensitive layer of the retina consists of individual nervous elements. Consequently, if their condition and stimulation were as hitherto presupposed, their responses to stimulation should possess an all or nothing character similar to that of a gun cartridge. This would make all vision consist of areas of dazzling brightness interspersed by areas of complete blackness. Our vision obviously is not so, but it only 'ought' to be so if the presuppositions were true.

If anyone, then, makes this assumption of partial stimulation, he must either reconsider his fundamental proposition or provide still another adjustive hypothesis. In contrast with this, response graded according to the strength of stimulation is a typical character of the responses of rhythmical structures. The grading of response that actually occurs is, in fact, another line of evidence that rhythmical structures are being stimulated.

The final point to be noted about colour vision is that the past science was founded on what the psychologists call an error of projection. Everyone believed at one time that grass is green. We now know instead that the green is in us. But when it came to putting the green inside us, the existence of a special green sensitive structure was imagined to exist in the retina. This supposition now appears to have been as much an error of projection as was the supposition of the presence of the green in the grass. Colour appears instead to be our interpretation of rhythmical activity arising from a particular source just as the musical note is our interpretation of the same type of activity arising from a different source. The interpretive instrument is common to both and provides that fundamental relation between music and colour which is realized in the Moonlight Sonata.

