Journal of the

Colour Group

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Colour Rendering

The main purpose of the meeting of the Group held on 3rd February, 1965, at Imperial College was to provide a comparison between the Spectral Band and the Test Colour Shift methods of measuring the colour rendering of a light source. The Test Colour method was proposed as an official C.I.E. recommendation and circulated to National committees for comment by December, 1964. The only comments received which raised serious objections were from the British national committee, and these were discussed by a panel consisting of some of the members of C.I.E. committee E-1.3.2 at Aix-la-Chapelle in January, 1965. Most of the British work on colour rendering has been concerned with the spectral band method.

The first two speakers at the Colour Group meeting outlined the history and main features of the two methods. Dr. Crawford (National Physical Laboratory) spoke on the Spectral Band Method, and Dr. Ouweltjes (Philips Gloeilampenfabrieken) described the Test Colour method. Written versions of these talks are published here, and Group members will be able to compare the methods from these.

The third speaker, Dr. D. A. Palmer (National Physical Laboratory), described experiments relating the predictions of the Test Colour method to the data available on the Band system, so providing a bridge linking the work of the other two speakers. It is hoped that Dr. Palmer's paper will be published in a future issue of the Journal.

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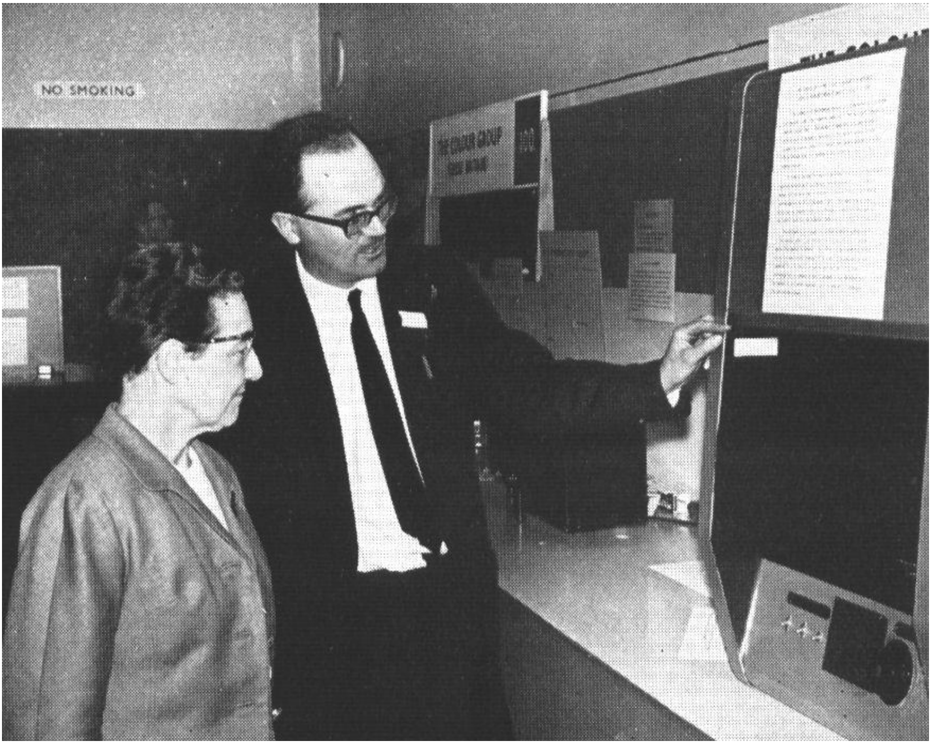


Mr. R. W. Brocklebank describing an exhibit on the Colour Group's stand at the 1965 exhibition of the Institute of Physics and Physical Society to Dr. A. C. Stickland.

COLOUR RENDERING: Assessment By the Spectral Band Method

B. H. Crawford

The colour appearance of an object depends upon three factors: the colour perception properties of the eye, the spectral reflectance pattern of the object and the spectral composition of the light illuminating the object. It is the third of these factors which is the concern of colour rendering.

Many light sources are an imitation of some standard source, in particular of a phase of daylight, and in such a case the user wishes to know how good the imitation is and whether the approximation of the actual source to the ideal is good enough for his purpose. The basic importance of daylight probably lies in the fact that it is the quality of illumination under which vision has evolved and under which, therefore, the eye is at its best in recognizing and judging colours.

A little thought will show that it is impossible for one light source to imitate another exactly unless it is of the same type; the precise imitation of daylight by artifice is thus practically impossible, but many approximate imitations have been produced. These can be compared by determining their spectral power distribution curves, but this method gives almost too much information, so that the broad assessment of suitability is obscured by fine detail. It has been found very helpful to simplify the spectral distribution by transforming it to a relatively small number of spectral bands; various numbersfrom 5 to 10 have been suggested. The deviation of the light source under test from the accepted standard may then be expressed by a percentage for each band.

There now arises the question of what quantity to use for the band values—power, luminosity or some other weighted function of power. There is little doubt that a special weighting function for colour rendering can be determined; several, in fact, have been determined or suggested, but the use of the-luminosity function has been found to give results approximating sufficiently closely to those from a special function. As the band luminosity values have usually to be determined for other reasons, their use for colour rendering assessment is an obvious practical convenience.

We now come to consider the most difficult part of the colour rendering assessment problem : how great can be the deviations from an accepted standard before they are noticeable or significant? It would seem to be a logical necessity to determine these tolerable deviations (or tolerances) by direct experiments on colour rendering appearance. The so-called tolerances suggested by some workers, especially in connection with the Test Colour Shift method of colour rendering assessment, have been derived from the standard deviations of colour matching determined by MacAdam. Their applicability to the case of colour rendering cannot be assumed. Extensive experiments were therefore carried out at the National Physical Laboratory to determine colour rendering tolerances directly in the framework of a Spectral Band method of assessment. The principle followed in these experiments was, briefly, to make controlled, continuous changes in the various spectral bands of a light source, to observe various objects illuminated by the source and to note the stage at which a change in the appearance of the objects was apparent. The objects included pictures, both natural and impressionist coloured patterns, faces and foodstuffs. The spectrum was divided into six bands and these were varied separately and in various combinations. Care was taken that spectral composition was changed without altering the colour of the light source; the latter being the factor of particular importance in practice.

From this experimental work a simple system of colour rendering assessment was derived which sets forth both the detailed and the over-all performance of a light source in respect of colour rendering. The system rests on the following four rules which express the experimental results:

(i) The tolerance for a band is the same for excess or deficit relative to the standard if expressed as a proportion or percentage.

(ii) Bands separated by not less than the width of another band behave as if independent of one another.

(iii) Any pair of contiguous bands is subject to half the tolerance of either band alone if both are deficient or both in excess.

(iv) If the bands_ of a contiguous pair vary in opposite directions they behave independently and are both subject to the normal tolerance.

Finally, a tolerance of ± 10 per cent. for single bands was found to be acceptable to 95 per cent. of the population (as tested in the NPL experiments). Table I gives an example of the application of the NPL spectral band method to a fluorescent lamp of a type often used for general illumination, and having an equivalent colour temperature of 4100/ K. The result shown is an average performance for a lamp of this type; a few are better, many are worse. A wider survey and suggestions for presentation of results will be found in a review paper by the author in *Brit. J. Appl. Phys.*, 1963, vol. 14, pp. 319-328, where there is also a bibliography of the subject.

TABLE 1

	band luminance			deviation from unity			
spectral band limits (mμ)	test source	reference source	ratio of luminances	single bands	double bands	excesses outside tolerances	
400-455	0.567	0.457	1.24	+24		14	
455-510	6.42	8.24	0.78	–22	+1	12	0
510-540	15.9	20	0.8	– 20	– 21	10	16
540 -590	51.3	44.7	1.15	+15	–3	5	0
590-620	16.5	17.5	0.94	–6	+5	0	0
620-760	9.27	9.18	1.01	+1	–3	0	0
					sum of excesses = 57		

The C.I.E. Test Colour Method

J. L. Ouweltjes

Although the possibility of using the apparent change of test colours under different light sources as a measure for the colour rendering properties had been mentioned before, the first important paper on the Test Colour Shift method was by Barr, Clark and Hessler[1] in 1952. They compared two sets of three fluorescent lamps by means of the shifts of test colours selected by drawing a circle in the Breckenridge-Schaub R.U.C.S. diagram with the point corresponding to equienergy white in the centre. This circle corresponded to colours of medium brightness and medium saturation, similar to the Munsell 6/6 colours. Twenty test colours were taken, lying evenly spread on the circle. The colour shifts were calculated and also estimated by visual comparison. These observed colour shifts were reported to show satisfactory agreement with the calculated ones.

AMERICAN WORK

In the same year the American I.E.S. Light Sources Committee established a Sub-Committee to deal with Colour Rendering problems. With Miss Nickerson as chairman, this committee has done a vast amount of work, and has been the main contributor to the final form of the Test Colour Method. The first thing to do was to make a thorough study of the colour differences observed under different light sources of the same colour. In general there was a satisfactory agreement between observed and calculated colour shifts. The next questions to be studied are how many test colours should be taken and how should the colour differences he evaluated.

THE OSRAM GROUP

An important contribution to the development of the Test Colour Method was presented by Miss Hennicke in a paper delivered at the C.I.E. meeting in Brussels in 1959[3]. In her work also the colour shifts were evaluated both visually and by computation. A number of test colours was shown, illuminated by six light sources of varying spectral power distribution, to a group of 12 observers. All lamps were of the Warm White type and of the same colour as the incandescent lamp which served as a reference source. The test samples were shown on a neutral grey background. The observers were asked to assign a number 0 to 5, according to the colour difference estimated between the sample illuminated by the source to be tested and the reference source. Forty-four test objects were studied, including natural objects such as human skin, red beets, cheese, butter, lettuce, coffee and sherry.

The average value of the number for the 44 test colours was taken as a colour rendering index. In the next step, a selection of seven test colours was made from these 44. The colour rendering index derived from the average colour difference of these seven samples was compared with that based on the 44 samples. The same was done with the 10 natural objects used in the experiments. It was found that in both cases a very high correlation existed, indicating that a number of 7 to 10 test colours should suffice for calculating an average colour shift that may serve as an overall measure for general colour rendering properties.

THE AUTHOR'S WORK

The next step was to extend the work to a large number of light sources. In the past, methods for specifying colour rendering properties had often been evaluated simply by comparing standard fluorescent lamps with a de luxe lamp. 1 he latter is invariably found to have the better colour rendering, but this can hardly be considered to offer adequate proof of the reliability of the method. The difference between these illuminants is such that any method will show it. In this respect the six light sources used by Miss Hennicke were already an important improvement, but even these six sources could not be considered to be representative for all kinds of light sources that may be found in practice.

Since the main field of application at that time seemed to be the fluorescent lamp, a large number of spectral power curves was calculated, starting from the emission curves of current lamp phosphors'. A total of 165 lamps was calculated, divided over the most important lamp colours; daylight 6500/ K, Cool White 4100/ K and Warm White 3000/ K.

As test colours a group of 19 was taken, including colours of medium saturation as well as more saturated ones, and colour differences were calculated in terms of the Nickerson–Stultz and Saunderson – Milner formula. Lamp ratings were derived based on the average colour shift for these colours, using both formula;. The correlation was very high.

The next step was to narrow down the number of test colours, and the lamp ratings based on five and eight test colours were calculated and compared with the ratings based on 19 test colours. For eight test colours the agreement was very good; for five it was clear that the correlation was getting poorer. This result confirmed the work by Miss Hennicke; that 7 to 10 well-chosen testcolours should suffice to derive a meaningful single number rating.

The reference illuminants were blackbody radiators, and, at higher colour temperatures, phases of natural daylight.

THE C.I.E. RECOMMENDATIONS

The final choice of test colours was a set of eight of medium saturation. Using colours of medium saturation allows variations in brightness to be neglected, so simplifying calculations of colour differences. The calculations are made in terms of the C.I.E. U.C.S. u, v diagram.

The C.I.E. method recommends the calculation of a General Colour Rendering Index, comprising the following steps:

1 From the spectral power curve of the light source to be tested and the reflectance curves of the test colours, the C.I.E. tristimulus values for the test light source and the colours are calculated.

2. The tristimulus values are transformed into the u, v co-ordinates of the 1960 C.I.E. uniform chromaticity scale, both for light source and test colours.

3. The various u and v values are compared with those obtained for the reference radiator and the differences Δu and Δv evaluated. If necessary, Δu and Δv for the test colours are corrected by the Δu and Δv for the light sources.

4. Take the average value

$$\Delta\overline{E}_i = \sqrt{\left(\Delta u_i^{\,2}\right) + \left(\Delta v_i^{\,2}\right)}$$

for these corrected Δu and Δv values, of all test colours. From this average value

$$\Delta\overline{E}_i$$

the general Colour Rendering, may be read from a table or calculated from a formula.

Apart from the General Colour Rendering Index based on the average value of ,vpu2 ± pv2, it is possible to calculate the separate values, to give a "Special Colour Rendering Index" of the individual test colours. These may be averaged, and then, of course, will yield the General Index.

TOLERANCES

So far, the C.I.E. has refrained from publishing tolerances, not because it could not be done; but publishing tolerances is a matter of considerable economic consequence and should not be done until sufficient experience is available. It is not difficult to specify tolerances in such a way that all light sources complying with them are satisfactory. the problem is to ensure that acceptable lamps should not fall outside the tolerances.

There is no reason, however, why tolerances could not be set with the C.I.E. method. The colour shifts, on which the Indices are based, have a direct physical meaning. In the adopted scale, about five units correspond to 1 N.B.S. unit of colour difference. However, under normal lighting conditions, differences of 2 N.B.S. units are unlikely to be discovered, and one may estimate that light sources with a colour rendering index of about 90 will turn out to be satisfactory for colour inspection purposes and other applications where the requirements on colour rendering are stringent.

Practical experience more or less confirms this expectation. Xenon lamps, having an Index of 92-94, are found satisfactory. The same applies to Philips fluorescent lamps with an index of about 92, and there is no reason to believe that other firms' lamps with the same index should be less satisfactory. It is interesting to note that, with Crawford's 6-band system, the 10 per cent. tolerance limit corresponds more or less to these 90-95 indices, as was found by means of a comparison for a large number of calculated light sources.

ACCURACY

It is recommended that the colour coordinates should be calculated to four decimal places. At first sight, this seems to invalidate the whole method, for at the moment there is no instrument that permits the measurement of spectral energy distributions with the accuracy required for this. Still, it is found thatthe measurements on production lamps of the same type, although there are variations in the spectral energy distribution curves, lead to the same index within one or two units. Similar variations are repored by Dr. Henderson when the same lamp is measured in different laboratories. It is the feeling of those with whom I have discussed the problem that the difference between two lamps should be at least three to four points before it becomes detectable. Therefore, variations of one to two units do not matter very much. The fact that the index is relatively little affected by variations in the spectral energy distribution curve is probably due to the adjustment made for the difference in colour co-ordinates for the light source and the reference. This tends to minimize the effect of systematic errors in the measurements.

CONCLUSION

Although the General Colour Rendering

Index cannot be said to give complete information concerning the colour rendering properties of a light source, it may serve as a reliable indication as to what we may expect. This is especially true for the higher values of the index. For the lower values, it will be increasingly useful to study the colour shifts of the individual test colours. Establishing tolerances will be largely a matter of accumulating experience. From the index, it is easy to see what kind of colour differences can be expected. Whether these colour differences are tolerable or not is entirely dependent on the purpose for which the light sources will be used.

REFERENCES

1 A. C. Barr, C. N. Clark and J. Hessler, Ill. Eng. **47**, 649. (1952).

2 D. Nickerson, Ill. Eng. **53**, 77. (1958).

3 I. Hennicke, die Farbe. **9**, 183. (1960).

4 J. L. Ouweltjes, die Farbe. **9**. 207. (1960).

5 Interim Method of Measuring and Specifying Color Rendering of Light Sources. Ill, Eng. **57**, 471. (1962).

The Summer Visit

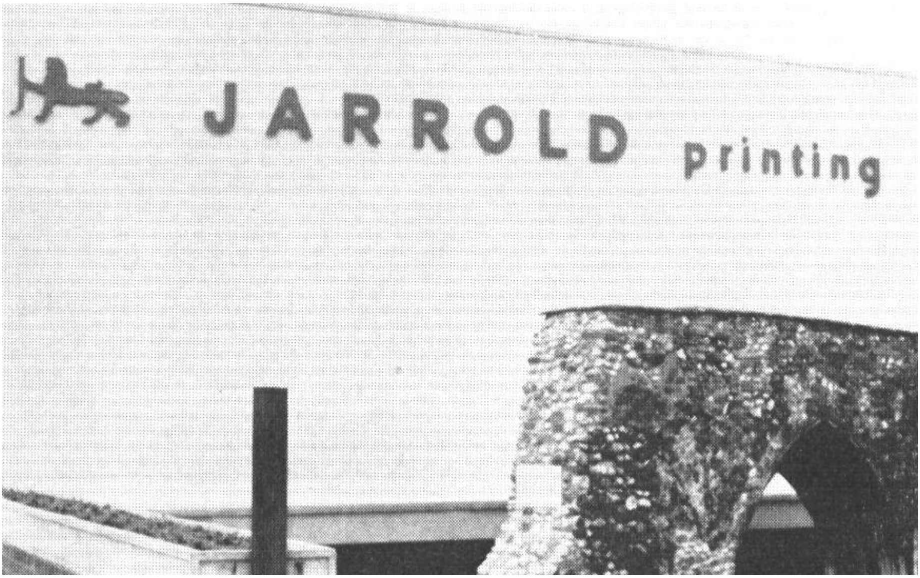
A placard publicly proclaiming "Colour Group" to all passers-by at Norwich Railway Station on the morning of Wednesday, 30th June, brought quizzical and apprehensive looks at the party gathering together. However, this was no expression of political monotone, but a party supporting a polychromatic interest, and now about to visit an old-established company of printers—Jarrolds, Ltd.

Mr. John Jarrold, Managing Director of the Company, received his guests in the refitted 19th century woollen mill which is now a printing works. Mr. Jarrold first gave a fascinating account of the long history of the firm through generations of the Jarrold family, andtheir development of printing methods up to the present day. Many samples of the high standard of printing were exhibited around the hall. Later, in the all too brief intervals between having coffee, lunch and afternoon tea, members were shown the production processes in operation.

In the letterpress shop, several flatbed machines were printing enormous sheets of paper, with their long gripper arms moving like the legs of a giant grasshopper, putting a single sheet of paper under the printing rollers about every two seconds. One of the designs being printed was a most exquisite brochure for shoes, and another part of a mathematics text book. From the layout of the pages on the sheet printed, it seemed most unlikely that a book could appear with the pages numbered consecutively, but as it was explained, and we later saw, this apparent random order achieved a perfect numerical series after the sheet was folded a dozen or more times and its edges cut to give the individual pages.

In contrast with the measured rhythm of these letterpress machines, the litho presses in the next room were printing (amongst other things) pictorial calendars, 12 months to the sheet at the rate of 2,000 years per hour. Two of the four colours being laid down on one press--wet-on-wet.

A word here about these two processes may be of interest. Letterpress is a sophisticated rubber stamp technique using a large metal plate with those areas to be printed raised above the general level. Ink is rolled on to these raised areas, and then impressed on to the sheet of paper. Offset litho uses a virtually flat plate, which is so treated that the greasy ink adheres only to a part of it; and the non-image areas are washed free of ink by water. The ink is then transferred of to the blanket (which, in fact, is more like a rubber sheet) and from there on to the paper.



The most lasting impression of the afternoon, however, was given by the Miehle web offset machine. One end of a reel of paper about 5 feet diameter and 3 feet wide was fed into the machineand printed by four units in quick succession; each unit putting down a different coloured ink and printing both side of the web. The inks were dried by gas flames. The web was then automatically cut to the correct size and folded. In this form the completed brochure, for British Rail, was packed by hand. Just before we left this modern marvel, we witnessed its real tour de force; the splicing of a new reel of paper on to the last few feet of the old one, with the machine still operating at full speed. The performance was faultless, in spite of the presence of 20 strangers, which would inevitably—as we all know too well—have incited those perverse gremlins to do their worst.

In spite of some considerable modification to the party's time schedule when we discovered the new K. & S. Paul colour separation and automatic correction unit, and also the Klishograph scanners at work, eventually we took our leave and departed our various ways. In future it is certain we shall all choose our seaside picture postcards, our calendars and our children's books with a greater purpose and understanding of the procedures which went into their production.

On behalf of the Colour Group, I would like to record our warmest thanks to Mr. Jarrold for arranging such an enjoyable and informative day for us. and for his demonstration of the excellent quality of British colour printing.

DOROTHY MORLEY

Twenty-five Years

The first science meeting of the Colour Group of the Physical Society was held in February, 1961. A future issue of the Journal will describe the 25th anniversary meeting to be held this month.

Colour Between Science and Art

M. H. Wilson

Summary of the retiring Chairman's address tc the Colour Group given 5th May, 1965, which was illustrated with demonstrations and examples from well-known painters.

In the search for objective knowledge about colour, the scientist's approach is weighted in favour of accepting observations which are repeatable and measurable in terms of space, time and energy. The artist is concerned with apprehending and conveying the quality of an inner experience. The two approaches have little in common, but it is suggested that some of the principles which arise from the study of perception may indicate an area of objectivity which is shared by both artist and scientist.

While the scientist tries to understand the systematic processes at work in the created world, the artist tries to create something new. But he has to work with available materials, and this means that he is not so much interested in isolated colours (which he cannot alter) as in their combinations and the reactions between them. He perceives the dynamic qualities of colour in terms of polarities —light and dark, warm and cool, active and passive—rather than the measurable quantities of chromaticity, luminance or physical energy.

The scientific view which regards colours as components of the light (following Newton) is of little help towards an understanding of these dynamic qualities, and indeed it does not begin to take into consideration the nature of the perceived differences between colours—redness, blueness, and so on. On the other hand, the view pioneered by Goethe-- that colours are the result of an interplay between light and dark—does pro-vide a link between the scientific facts and the qualities experienced by the artist. The spectrum experiments can be seen in terms of polarities, with the colours gradually appearing through progressive differentiation from light and dark. (Such progressions of colour are often used by a painter to give intensification and vibrant life to an area that would otherwise be dull and uniform.) The pure spectrum colours are seen as a final case, an extreme with which the artist seldom has to deal; but in arriving at them the whole world of colour is displayed, from soft atmospheric tones and deep earth colours to the brilliant and vivid ideal colours.

This approach to the subject reveals a polarity between thinking about colour as a property of light (as the physicist is taught) and thinking about it as a property of materials that darken the light (as the artist learns from his craft). A terminology of colour for universal use would have to take this opposition into account. For instance, the technology of colour printing and photography can readily be understood in terms of the opposite processes of lightening and darkening.

Studies of coloured shadows and other contrast effects show that perceived colour can only be understood in terms of the relationships between a colour patch and its surroundings and between object and illuminant. This confirms the soundness of the Goethean approach. with its concepts of complementary colours and the fundamental polarity of light and darkness. We may hope that. from such psychological studies, a science of perception will arise that includes the qualities characterizing the artist's experience of colour.

Colour Classic

This is the fourth of the reviews of "Classic Books on Colour" given at the December, 1964, meeting of the Colour Group.

COLOR-VISION AND COLOR-BLINDNESS: A PRACTICAL MANUAL FOR RAILROAD SURGEONS

J. E. Jennings (Philadelphia, 1896)

Reviewed by R. J. Fletcher

Holmgren's influence was soon felt in America among the railroads; hence this manual. The book opens with a brief historical sketch. Seebeck produced a 300 hue test in 1837, pieces of paper having to be arranged in order. A female colour defective was reported in 1864 by 1 uberville. Wilson, of Edinburgh, investigated chemistry students' colour mistakes in 1854; he anticipated the dangers to rail transport which, after 1875, brought Holmgren of Upsala into colour testing. Holmgren found that 4.8 per cent. of the 266 men on the Upsala to Gefle railway showed defective colour vision.

Several instances of extreme coloured after-images are described. Brewster experienced such after damaging his eyes by regarding the sun through a telescope. A lady worked long, sewing a red dress and suffered a "paroxysm of terror" when she looked at her child's face, apparently "a ghastly hue".

A section is devoted to theories of defective colour vision, one of which is due to Preyer (1881). He thought that colour vision is related to temperature sense, and " warm" or "cold" colours. A pair of retinal receptors, one of each variety, supplies each optic nerve fibre. Simultaneous stimulation of the two receptors, of equal amounts, frustrates the colour message of the nerve fibre. Muller's law was not related to the theory.

Sex differences have been mentioned.Women tend to develop colour sense by the frequent handling of coloured articles, hence their freedom from defects. Homer's law is quoted and an important exception is given in the form of a pedigree described by Cunier. Some details are lacking, unfortunately, and there is an initial temptation to dismiss the information given; we may guess that the tests used were inaccurate and chat the pedigree is "impossible". More mature reasoning introduces thoughts about manifesting heterozygotes and the influence of affected males.

Quaker examples are explained by intermarriage. Wilson and others described a peculiar startled look about the "colour blind". Becker's case of monocular colour defect (mentioned by Hering, 1891), is a gem; so is the suggested rule "to test each eye separately". Cures and palliatives are quoted. Favre gave children daily practice in colour naming. Many attempts have been made to assist colour recognition by using lamplight, pale orange glasses or a container of fuchsin.

Testing methods occupy a large section and include "expedients to satisfy officials, friends of the man and others". Ribbed glasses and London smokes were introduced into colour lanterns, based on Donder's model.

Acquired defects are classified. These include a colonel struck by a musket ball in the left temple. Tobacco amblyopia (subject to "secret" reversions at times) appears to have been dealt with severely: potassium iodide and strychnine were used as cures.

The Pennsylvania Railroad instructions for testing employees are given. Coloured yarns(rather than wools) were used. In one report it is suggested that "escaping steam" prevented a watch test for hearing. Some of the tests prescribed by Oliver bring to mind an assault course or the trials of Trattles.

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