THE RELATION BETWEEN EYE-COLOUR AND DEFECTIVE COLOUR-VISION

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IN an early paper in the EUGENICS REVIEW* dealing with inheritable characteristics in man, I cited as suitable instances where systematic study might throw new light on the relations between physical and mental constitution, the pigmentation of the iris, on the one hand, and defects of colour-vision, on the other. Many psychologists have believed that differences in hair- and eye-colour are connected, though no doubt indirectly, with differences in mental and temperamental qualities; and among the latter, differences in sensory discrimination are the easiest to detect and assess.

In conformity with these suggestions, during inquiries on backward and subnormal children carried out for the London County Council and other authorities, I have endeavoured to secure records of the more obvious inheritable physical characteristics and to apply systematic tests of colour-vision, in addition to the usual tests of more complex abilities and traits. In nearly every survey I found consistent indications of a correlation between pigmentation and colour-discrimination; but the size of the correlation was too small to be accepted as conclusive without a far more extensive inquiry. The results, however, more recently obtained during the examination of recruits for the fighting services provide material which well repays analysis from this particular standpoint.

It is the object of this paper to summarize the evidence so far available, and to review the possible hypotheses which that evidence suggests, in the hope that readers may be sufficiently interested to submit further data, in the shape of pedigrees, family records and individual cases for psychological investigation.

* 1912, **4**, 36-50.

Defective Colour-Vision among Children; School Surveys

In my earlier surveys of school children,* I relied mainly on Stilling's pseudo-isochromatic charts; these can be used as a group-test, and borderline cases thus detected were examined individually by wool, bead or lantern tests, and in the more doubtful instances by tests of colour mixture. Among the boys I found 3·1 per cent suffering from a defect of colour-vision sufficiently pronounced to be regarded as "partial colour-blindness" (nearly all instances of red-green colour-blindness, with darkening of the red end of the spectrum in about one-third of the cases). In addition there were another 3 per cent suffering from milder deficiencies of colour-vision of various degrees and types —e.g., less pronounced forms of red-green confusion and various anomalous deviations.† Among the girls only 0·2 per cent were found to be suffering from "partial colour-blindness"; but cases of weak or anomalous colour-vision were not uncommon (1·3 per cent), and appeared disproportionately frequent among relatives of colour-blind boys. Altogether, it will be seen, defects of colour-vision, innate and probably inheritable, and often severe enough to constitute a grave handicap in practical life if they pass unrecognized, are far more fre-

* Cf. *The Backward Child*, p. 217.

† The large proportion of defective cases included in Table I is due to the fact that many were referred by teachers and that additional efforts were made to investigate the brothers and sisters of cases of deficiency found in the survey. I should like to emphasize what I have said elsewhere (*l.c.*, p. 217), that, in addition to the more familiar types of colour-blindness, there are a number of deficiencies "difficult to classify under the usual headings"; some of these may be regarded as extreme deviations in the normal distribution of ordinary trichromatic vision; but others—the "red weak," the "green weak," and other anomalous forms (as well as definite red-green blindness)—differ qualitatively as well as quantitatively.

quent and far more various than has commonly been supposed. The total figure for males cannot be far short of 8-10 per cent.

For colour of hair and eyes, a grade was assigned on a sevenfold scale, the various degrees being roughly defined in accordance with a normal distribution, with the probable error as unit (giving frequencies in round figures of 5, 10, 20, 30, 20, 10, 5 per cent). The numbers observed are shown in Table I. The figures after eye-colour denote the specimens in the Martin scale corresponding to each grade.*

seven categories for eye-colour to a twofold classification (dark and not dark), and apply the tetrachoric method, we obtain much the same figure, namely 0·193. The correlation would therefore seem to be of the same low order as correlations between other physical and mental characteristics, such as body-type and temperamental tendency.

For hair colour the correlation with defective colour-vision was somewhat smaller, 0·104—a figure which in a group of this size is well below the level of statistical significance. Here and elsewhere, on partialling out

TABLE I

DISTRIBUTION OF EYE-COLOUR AMONG CHILDREN WITH NORMAL AND DEFICIENT COLOUR-VISION

Eye-Colour		Colour-Vision					
Grading	Martin Scale	Normal		Deficient		Total	
		Number	Per cent	Number	Per cent	Number	Per cent
Blue-Grey	16, 15, 14	24	4·6	2	1·6	26	4·0
Light Grey	12	48	9·2	7	5·6	55	8·5
Light Mixed	13, 8	122	23·2	21	16·9	143	22·0
Medium Mixed	11, 10, 9	164	31·2	39	31·5	203	31·3
Dark Mixed	7, 6	89	17·0	28	22·6	117	18·0
Medium Brown	5, 4	60	11·4	18	14·5	78	12·0
Dark Brown	3, 2, 1	18	3·4	9	7·3	27	4·2
Total		525	100·0	124	100·0	649	100·0

In the first three categories (light-eyed) there are decidedly fewer colour-blind children than we should expect; in the last three (dark-eyed) decidedly more. Applying the usual test for statistical significance, we find $\chi^2 = 11 \cdot 8$; with 6 degrees of freedom this gives P = 0·068. In non-technical language that means that the odds are only 14 to 1 against such a set of differences arising by the chances of random sampling; so that the relationship cannot be accepted as conclusively established.

It is instructive to estimate the probable amount of correlation, supposing it to exist. For purposes of calculation we may assume that both pigmentation and variations in colour-discrimination are distributed more or less in accordance with the normal curve. With the biserial method we find a correlation of 0·174; if we prefer to reduce the

* Prof. Riddell has drawn attention to the fact that the various sets issued by the manufacturers are not quite the same ("Classification of Eye Colour," *Ann. Eug.*, 1942, **11**, 252).

the correlations of both hair-pigmentation and colour-vision with eye-pigmentation, that between colour-vision and hair-pigmentation is reduced virtually to zero. So far as the present data go, therefore, any association between defective colour-vision and dark hair-colour is apparently due simply to the fact that both happen to be associated with dark eye-colour.

Defective Colour-Vision among Adults

(*a*) *Regional Surveys*. During the present war, results obtained with the Ishihara tests, when applied to naval candidates, have exhibited remarkable differences at different centres. The investigators inferred that there must be "genuine geographical differences in the distribution of colour defect, analogous to differences in the distribution of blood groups or intelligence"; and the data were referred to me with an inquiry for a possible explanation. On plotting a map to show the relative frequencies in various regions of Great Britain, I found that they at once displayed a striking correspondence with the known distribution of hair- and eye-colour. The proportions ranged from 4 per cent in S.E. Scotland to 10 per cent in Mid-Wales. Grouping the figures by counties, and correlating the percentages in each county with the best available estimates for pigmentation, I found a correlation between defective colour-vision and dark eye-colour of 0·73, and between defective colour-vision and dark hair-colour of 0·62. A correlation of 0·73 based on *groups* might easily be produced by correlations of about 0·15 to 0·20 among *individuals*.* In passing it will be observed that the high percentage reported for the country as a whole (7 per cent) confirms what was noted during the school surveys—namely that defects of colour-vision are far more numerous than the figures usually quoted for colour-blindness might lead one to suppose.

(*b*) *Individual Surveys*. From the Royal Air Force, data are available for over 3,000 individuals. Every candidate was first examined with the Ishihara tests; and those making more than a few slips were subjected to two lantern tests.† The distribution of eye-colour and visual deficiency is summarized in Table II. "Dark-eyed" includes all whose irises show a "medium grey" or "dark grey" background together with "medium brown" or "dark brown" colouring; "light-eyed" includes the remainder.

TABLE II

ASSOCIATION OF DEFECTIVE COLOUR-VISION WITH EYE-COLOUR: ADULTS

Eye-colour	Colour-Vision Normal	Colour-Vision Defective	Total	Percentage Defective
Light-Eyed ...	2,461	322	2,783	11·6
Dark-Eyed ...	368	80	448	17·9
Total ...	2,829	402	3,231	Diff. 6·3

It will be seen that among the dark-eyed the number of colour-defectives is more than half as many again as among the light-eyed. The difference observed (6·3 per cent) is nearly four times its standard error ($\pm$ 1·69) and therefore fully significant. The odds against such a difference arising from the fluctuations of sampling are about 50,000 to 1.

To compare the amount of correlation with that obtained for children, I have re-classified the records into seven grades for eye-colour (Table III); but, since the method of recording eye-colour differed somewhat from my own, it was not always possible to make each grade exactly identical with the corresponding grade in Table I. With the larger numbers now available, we can here calculate not only the percentage from each grade found among the normals and the colour-defectives, but also (what is far more suggestive) the percentage of colour-defectives found in each grade; with one exception, the increase is steady and striking.

A biserial correlation based on the seven-fold classification yields a coefficient of 0·134: a tetrachoric correlation based on the fourfold table above yields a figure of 0·162. The correlation for adults is thus of the same order as that found for children.

For hair-colour the correlation is much lower, and statistically non-significant. To some extent it appears to be reduced by the fact that, in these islands, dark hair is not

* Burt, Cyril, *Local Differences in Defective Colour Vision* (Memorandum to Senior Psychologist's Department, Admiralty, Aug. 31st, 1943). For help with the estimates of pigmentation, I am much indebted to Dr. Bowen, Lecturer on Anthropology in the University College of Wales, Aberystwyth, and to one of my research students, Miss Crawford, who has also assisted in the calculations: a more detailed analysis of the data, with map, is contained in her thesis on the subject (Psychological Laboratory, University College, London). Through the kindness of the Editor of *Man* I have recently received more up-to-date figures for pigmentation for certain parts of the country; and we should be most grateful to receive data on this point from readers of this journal.

† The data were obtained by Dr. J. Grieve, who was good enough to send me the figures for statistical analysis. Since, in individual studies, such as the present, the grading for hair- and eye-colour is dependent on the investigator's judgment, and the reader may suspect the possibility of unconscious bias, it may be noted that Dr. Grieve's expectations differed from mine. He himself had formed "the clinical impression that defective colour-vision was more common in red-haired candidates"; but from an inspection of his data at a later stage he concluded, not only that this "clinical impression was ill-founded," but also that "there was no relationship between the presence of poor colour perception and the nature of the pigmentation of the iris." Our more detailed tabulations of the results, with a full statistical analysis, will be found in an article on "Defective Colour Vision in relation to Pigmentation" (*Man*, 1945, **82**, 103 f.).

TABLE III

DISTRIBUTION OF EYE-COLOUR AMONG ADULTS WITH NORMAL AND DEFECTIVE COLOUR-VISION

Eye-Colour	Colour-Vision: Normal Number	Normal Per cent	Defective Number	Defective Per cent	Total Number	Total Per cent	Percentage Colour-Defective
Blue-Grey	362	12·8	35	8·7	397	12·3	8·8
Light Grey or Mixed	814	28·8	90	22·4	904	28·0	10·0
Moderate Grey or Mixed ...	888	31·4	138	34·3	1,026	31·7	13·4
Dark Grey or Mixed	397	14·0	59	14·7	456	14·1	12·9
Medium Brown	313	11·1	65	16·2	378	11·7	17·2
Dark Brown	55	1·9	15	3·7	70	2·2	21·4
Total	2,829	100·0	402	100·0	3,231	100·0	12·4

infrequently accompanied by light or bluish eyes. With the present data it is not easy to allow for this with any exactitude; but, when an approximate deduction is made, there are indications of a small but just significant relationship. What slight correlation exists, therefore, could be fully accounted for as an indirect consequence of the correlation of hair-colour with eye-colour.

Genetic Linkage

In view of the agreement between these three independent inquiries, there can, I think, be no question about the existence of some kind of correlation between defects of colour-vision, on the one hand, and pigmentation of the iris, on the other. Since the same correlation is discernible from comparatively early years, and since (apart from slight changes with increasing age) eye-colour remains almost unaffected by post-natal factors, it would seem that the relation must either be itself innate or else rest on some innate characteristic of the individual constitution. The simplest explanation would be to postulate some kind of genetic linkage. Evidence has already been found for linkage between colour-blindness and one or two other characteristics (chiefly those for which the genes are supposed to lie on the non-pairing portion of the X-chromosome, e.g., hæmophilia); and more than one writer has suggested that eye-colour may itself be in some small degree sex-linked.

Among my cases there were eighty-eight pairs of brothers whom I could classify as definitely normal or deficient in colour-vision and also as definitely light-eyed or dark-eyed. If linkage is present,* we should expect the number (*a*) of those who were *similar* in both colour-vision and eye-colour and (*b*) of those who were *dissimilar* in both to be disproportionately large. The numbers actually observed are shown in Table IV.

TABLE IV

NUMBER OF BROTHERS SIMILAR OR DISSIMILAR IN COLOUR-VISION OR IN EYE-COLOUR OR IN BOTH

	Colour-Vision: Similar	Colour-Vision: Dissimilar	Total
Eye-Colour: Similar	35	22	57
Eye-Colour: Dissimilar	14	17	31
Total	49	39	88

$\chi^2 = 2 \cdot 15$ $P = 0 \cdot 14$

The chi-squared test shows that it is quite possible, though perhaps not very probable, that these slightly excessive numbers have arisen by chance. Four out of the five pairs that included a case of definite colour-blindness are in the doubly similar or doubly dissimilar sub-groups. If, therefore, we could separate out certain types of colour deficiency instead of being forced by lack of numbers to pool all types together indiscriminately, we might eventually obtain clearer and more cogent evidence. But the most pressing need is a collection of relevant pedigrees, giving precise indications about both characteristics for three or more generations.

Physical and Bio-Chemical Explanations

It seems clear, however, that, even could it be demonstrated for certain special types, genetic linkage will not cover all the phenomena. For these, alternative interpretations

* The statistical test here adopted is that used by Penrose for testing linkage between eye-colour and blood-grouping (*Ann. Eug.*, 1935, **6**, 133).

must therefore be sought in the more direct effects of pigmentation (or its underlying causes) on colour-perception. To determine the possible explanations we may briefly summarize what is known about the chief pigments present in the eye.*

(i) A small area on the retina, in the neighbourhood of the part of clearest vision, is somewhat pigmented, and on this account is known as the *macula lutea* or "yellow spot." Except when the translucent tissues are discoloured by jaundice or old age, the yellow-brown pigment of the *macula* is the only pigment through which the focused light-rays pass. Its intensity is known to differ widely in different individuals and in different races. Clerk Maxwell believed that such differences in macular pigmentation would account for certain anomalies of blue-vision†; and Hering invoked them to explain the distinction between the two main forms of red-green blindness.‡ Hering's theories, on this and other points, were strongly opposed by McDougall, in whose laboratory I myself received my training; and it occurred to me that, since the macular pigment is apparently related to the melanin pigment of the hair, iris, and skin, light would be thrown on the problem by examining the colour-vision of dark-haired and dark-eyed persons. This, in fact, was one of the original motives which led to the investigations here recorded.

The yellow pigment of the macula chiefly absorbs spectral rays from the blue region of the spectrum. We should therefore expect blue-vision to be chiefly disturbed; and the disturbance would be confined to the central part of the visual field. Both these effects are noticeable in test results from dark-skinned foreign races§; but they do not explain more than a small proportion of my own colour-defective cases.

(ii) The photochemical substances responsible for colour-vision in daylight are almost certainly pigments; but their existence has not as yet been definitely established. Unfortunately, therefore, their chemical nature remains unknown.

(iii) The only retinal pigment about which much is known is the photo-sensitive pigment of the rods, usually called "visual purple," or "visual yellow" when acted on by light. It is a pigment of the carotenoid group, and is essential to the colourless vision of the dark-adapted eye. Before the war, researches on individual differences in dark-adaptation were carried out in my laboratory by Lythgoe and Phillips. However, no correlation was found between such differences and variations in eye- or hair-colour.*

(iv) The outer stratum of the retina, which is continuous with the posterior pigment layer of the iris, contains a pigment (fuscin) related to melanin; and, like melanin, is also acted on by sunlight. It appears to play a part in the regeneration of the rod-pigment and possibly in that of the cone-pigment.

(v) The pigment which mainly determines differences in the visible colour of the iris is identical with, or at any rate closely related to, the melanin pigment responsible for dark hair- and skin-colour. Melanin is a pigment of the indol group: dopa, its precursor, appears to mark a stage in the conversion of tyrosine into adrenalin. Its formation appears to be affected by disturbances of the adrenalin glands and (like that of rod-pigment) by deficiency of vitamin C.

From these various facts we may infer that differences in eye-colour might conceivably be related to differences in colour-vision in at least two ways—physical or chemical. The physical effects are more likely to influence blue-vision than red- or green-vision. And, if we prefer a chemical explanation, two slightly different theories are still conceivable: first, the amount of pigment present in the iris might prove to be a rough but comparatively direct indication

* I am much indebted to personal communications from Sir John Parsons and Dr. Katherine Lythgoe, who have been good enough to check my statement of present knowledge on these matters.

† *Phil. Trans. Roy. Soc.*, 1860, **150**, 57.

‡ *Lotos*, 1885, **6**, 142: cf. Trendelenburg, *Klin. Med.*, 1939, **102**, 769.

§ Cf. Parsons, *Colour Vision*, 1924, 160. For summaries of more recent work, cf. P. Clements, "Racial Differences in Colour-Blindness," *Am. J. Phys. Anthrop.*, 1930, **14**, 4, and T. H. Garth, "Incidence of Colour-Blindness among Races," *Science*, 1933, **77**, 333.

* Phillips, *Proc. Roy. Soc.*, 1938, **127B**, 405.

of the amount of pigment present in the related epithelial layer of the retina ; second, and more indirectly, differences in the amount of pigment produced in all the visible tissues—skin and hair perhaps as well as iris—might indicate differences in the general chemical metabolism of such pigments in the body as a whole and therefore in the retina in particular. In either case, if, as some writers have argued, the chemical substances responsible for red and green vision are the latest to be evolved, we might expect these to be the substances that would most readily be affected by individual variations.*

It seems evident, therefore, that the chains of causation must be far more complex than might at first have been supposed ; quite possibly we have to deal not with one, but with several different influences. Consequently, pending further knowledge of the underlying physico-chemical processes, the most profitable line of study will consist in an endeavour to discover with greater precision what is the nature of the various deficiencies in colour-vision, which are at present, in a more or less indiscriminate fashion, picked out by the tests in current use.

Factor-Analysis of Colour-Vision Tests

With a view to learning more about the reliability, the mutual consistency, and the differential effects of the simpler tests of examining colour-vision, I have employed a number of different methods with groups of children and young adults. In addition to the usual mosaic and wool tests, I have used size-, speed-, and colour-mixture tests, for nine standard colours about equidistant on the colour-circle. The observations* were made upon 146 school children (boys aged 11-14) and 81 students (men and women aged 19-25). Owing to slight differences in technique, the correlations were calculated separately for the different groups and then averaged. With a total number of 227 any correlation below 0·134, and any factor-saturation below 0·366, will be of doubtful significance.

The intercorrelations are shown in Table V. They have been factorized first of all by simple summation (Table VI,A).† With this method the first factor has positive saturations for all nine colours, and thus suggests the existence of a single "general factor" for colour-discrimination entering into every test ; roughly speaking, this conclusion means that, if a person fails badly in discriminating (say) yellow, he is likely to be poor at discriminating most other colours, e.g., red, green, and (in a lesser degree) blue. However, the contribution of this factor to the total variance (see foot of table) is only 22·5 per cent, and consequently this "general factor" must here play a smaller part than general factors usually obtained from testing other cognitive processes.

TABLE V

CORRELATIONS BETWEEN TESTS FOR COLOUR-PERCEPTION

Colour	C	R	O	Y	YG	G	GB	B	V
Crimson	(·276)	·162	·089	·256	·043	−·018	−·005	·261	·286
Red	·162	(·710)	·502	·489	·120	·013	−·147	−·050	·125
Orange	·089	·502	(·443)	·496	·226	·212	·004	−·006	·109
Yellow	·256	·489	·496	(·705)	·294	·340	·063	·214	·277
Yellow-Green	·043	·120	·226	·294	(·402)	·462	·253	·096	·052
Green	−·018	·013	·212	·340	·462	(·598)	·377	·118	·015
Blue-Green	−·005	−·147	·004	·063	·253	·377	(·298)	·191	·021
Blue	·261	−·050	−·006	·214	·096	·118	·191	(·438)	·301
Violet	·286	·125	·109	·277	·052	·015	·021	·301	(·292)

* It is conceivable that the evolution of the fair-skinned, light-eyed races of the ill-lit North have been accompanied by a further evolution or stabilization of colour-perception. In the older races of the South the darker pigmentation of the retina, like that of the iris and skin, may have served in part as a protection against the intenser light of the southern sun.

* For help with the earlier experiments I am indebted to Mr. W. J. Williamson. Mr. P. Chatterji had planned to repeat the inquiry with improved methods, but his work was interrupted by the war. The investigations reported above were intended merely as a preliminary trial ; but in view of the increasing interest in the whole subject they are briefly reported here.

† For the method used, see *Factors of the Mind*, pp. 461-6, 477-82. On the applicability of such methods to problems of colour-vision, cf. *ibid.*, pp. 20, 84. I am indebted to Miss M. Cast for checking my calculations.

On the other hand, the bipolar factors play a larger part than usual. The first divides the colour-tests into two main groups —those concerned with the warmer end of the spectrum (including violet) and those concerned with the cooler end, with red and green respectively as the most dominant colour in positive and negative portions. The second (less marked) introduces a cross-classification, with blue or blue-violet as most dominant in one part and yellow as the central test of the other.

Secondly, the factors thus obtained by simple summation were "rotated" to eliminate the negative saturations. The rotation was effected in the usual way by making a preliminary group factor-analysis, and then introducing allowances for overlap by an orthogonal transformation. The final results are shown in Table VI,B.

display a marked overlap in the case of yellow. They are by far the most important elements in the analysis of defective colour-discrimination.* The third group-factor appears chiefly concerned with differences in bluish tints (including crimson); there is a small but doubtful overlap on yellow.

It was hoped that the two modes of factorization might throw light on the controversy between the rival theories of colour-vision. It will be noted that the results of the group-factor analysis—three specialized factors, each displaying for the most part positive effects, with red, green, and blue respectively giving the largest factor-saturations—is in keeping with the three-colour theory of Young, Helmholtz and McDougall; nevertheless, with the wide margin allowed by the probable errors, the observed correlations can be accounted for almost as well

TABLE VI

FACTOR SATURATIONS

	A. Bipolar Factors			B. Group Factors			
Colour	General	Red-Green	Blue-Yellow	General	Red	Green	Blue
Crimson	·331	·175	·351	·149	·245	−·103	·427
Red	·473	·613	−·264	·121	·821	−·134	−·094
Orange	·501	·274	−·313	·221	·580	·161	−·151
Yellow	·769	·229	−·145	·342	·689	·265	·176
Yellow-Green	·478	−·299	−·230	·025	·248	·574	·078
Green	·520	−·492	−·288	·082	·127	·751	·053
Blue-Green	·259	−·473	·017	·172	−·149	·474	·137
Blue	·384	−·157	·501	·389	−·040	·091	·520
Violet	·363	·130	·371	·194	·158	−·061	·455
Percentage of Common Factor Variance	50·8	28·3	20·9	10·5	40·6	30·5	18·4
Percentage of Total Variance	22·5	12·6	9·3	4·8	18·6	13·9	8·4

With the elimination of negative saturations the general factor (as usual) is greatly reduced in importance; it is now a "basic" general factor rather than an "average" general factor. Could we take its low saturations at their face value, they would suggest that, if we wanted only one or two tests for general discrimination, the best would be tests of blue and yellow discrimination. The bipolar red-green factor of Table VI,A is now split into two group-factors in Table VI,B, with red the most dominant in the one, and green in the other; but the two factors

by the bipolar analysis, where each factor comprises two antithetical or antagonistic tendencies, on the lines of the Hering theory. However, it is doubtful whether the factors as they stand can be taken as representing simple causal agencies.

The immediate practical use of the fac-

* The fact that the red-factor contributes more to the variance than the green-factor appears to mean (i) that individuals differ more widely in their sensitivity to red than in their sensitivity to green, and (ii) that these individual differences affect a larger range of colours. Variations in sensitivity to green appear commoner, but more restricted in degree and in effect.

torial analysis is this. It enables the investigator to re-weight the several tests, so as to obtain a measure for each of the chief components. These measurements we can then correlate with degree of pigmentation. With the final form of the analysis the correlations are as follows: (i) general factor, 0·218; (iia) red factor, 0·169; (iib) green factor, 0·086; (iii) last factor, 0·127. Only the first two coefficients are large enough to be statistically significant. The factor most affected by pigmentation is the factor for general colour-discrimination; in this factor the largest factor saturations are for blue and yellow, which we might suppose to be most disturbed by yellow-brown pigmentation. But the factor for red discrimination also shows a significant, if somewhat smaller, correlation. The last two coefficients are too small to be significant. On correlating the factor-measurements obtained by members of the same family, we get the following figures for family-resemblance: (i) 0·124, (iia) 0·332, (iib) 0·278, (iii) 0·098. Here it is differences in the red- and green-factors which alone are statistically significant; and the small correlation for the first (or general) factor is reduced practically to zero, when the influence of pigmentation is partialled out.

Conclusions

We may sum up the main results as follows. (1) There is a small but well-established correlation between deficiencies of colour-vision and dark pigmentation of the iris. The correlation is discernible even during childhood. (2) Defects of colour-vision, however, appear to be more numerous and more various than geneticists have commonly assumed. Previous statements about inheritance of colour-blindness have too readily supposed that such defects consist of only one or two sharply distinguishable types, such as might be accounted for by the presence or absence of a single sex-linked gene. In addition, it is essential to recognize the existence of intermediate and anomalous types. (3) The cases responsible for the correlations with pigmentation are not so much the severer and restricted defects that would usually be classified as red-green blindness, but (at any rate in a large degree) the milder and more anomalous defects. And it seems probable that the correlation revealed by the statistical examination of groups is due to more causal processes than one. (*a*) A tendency towards weakness in red-green discrimination appears to be to some extent of genetic origin and (so far as my pedigrees go) is rather more common among relatives (including female relatives) of the definitely red-green blind; some of these may therefore represent a heterozygotic form. The disproportionate frequency of dark pigmentation in such cases may be due either to genetic linkage or to the fact that exceptional pigmentation (or some characteristic underlying it) may aggravate these latent tendencies. (*b*) In other cases the correlation with pigmentation seems best explained as an effect of differences in pigment-metabolism. (*c*) Defects in blue- and possibly in yellow-discrimination seem to be due, not to innate peculiarities in the photo-chemical reactions, but rather to the absorption of certain light-rays by the more densely pigmented macula. (4) Pending further knowledge of the biochemical processes involved, factor-analysis may usefully be employed to distinguish the chief classes or types. Owing, however, to the comparatively small number so far tested for this purpose, and the somewhat crude technique employed, the inferences drawn must be regarded as tentative only. (5) There is an urgent need for more detailed studies of such cases and their relatives by a wider variety of laboratory tests. Relatives whose vision is apparently normal require as intensive an examination as the so-called colour-blind. And it is hoped that readers who may be acquainted with such families (which are far commoner than is usually supposed) will bring them to the notice of a competent psychological investigator.