



Cross-cultural differences in colour vision: Acquired “colour-blindness” in Africa

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Abstract

We report a study of the incidence of “colour-blindness” in southern and central Africa, and we compare the African data with data from various European groups. There was a surprisingly high incidence of tritan errors (yellow–blue defect). The likelihood of making tritan errors increased with age, and was greater in rural areas than in towns. In Europe, no tritan errors were made by samples from the U.K., Eire or Spain, but some tritan errors were made by a sample from southern Greece. In contrast, most of a British sample of people over sixty-five years old makes tritan errors. Although tritan errors were the most frequent, they were often accompanied by protan and deutan errors. This mixed pattern of errors is consistent with the condition being acquired rather than congenital. Many languages of southern Africa categorise blues and greens with the same term. If the tritanopia we report has been endemic, it may have reduced the “perceptual pressure” to split the blue-with-green categories into separate blue and green terms; a speculation consistent with Rivers, W. H. R. (1901. Introduction to A. C. Haddon (Ed.), *Reports on the Cambridge Anthropological Expedition to the Torres Straits*. Cambridge: Cambridge University Press). © 1998 Elsevier Science Ltd. All rights reserved.

1. Introduction

There are striking differences in how languages categorise colour: they differ in how many basic colour terms they have and in how these terms segment colour space. For instance, most southern African languages have four or five basic colour terms whereas many languages such as English have eleven basic terms. Further, colour terms in such southern African languages can cover larger

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areas of colour space than those in languages such as English. For instance, it is common for southern African languages to denote blues and greens with a single basic term, whereas the same region is segmented into two basic categories in English (see, for example, Davies et al., 1992 on Setswana the main language of Botswana).

These differences in the linguistic expression of colour were originally thought to suggest differences in colour vision, for one of two reasons. First, colour vision differences between races led to differences in colour language — the physiological differences theory (Rivers, 1901); or secondly, differences in colour language led to differences in colour vision — a version of the theory of linguistic relativity (Whorf, 1956). Although there are still proponents of both beliefs (see Bornstein, 1973 for a version of the physiological differences theory and Simpson, 1991 for a version of cultural and linguistic relativity theory), the prevailing belief has moved in the direction of colour vision being universal; that is colour vision is much the same the world over. (This universalist consensus, particularly within Psychology, is largely due to the influence of Berlin and Kay, 1969, and Heider, 1972; but see Lucy, 1992 for a counter argument.)

If we consider individuals rather than cultures, it is clear that there are differences in colour vision, because some people are “colour blind”. About 8 percent of European men and a half percent of European women have the inherited defect Daltonism (deuteranopia and protanopia) or red–green defect. The incidence of this condition varies across the world falling as low as 1 percent for American Indians (Fletcher and Voke, 1985) and 2 percent for Bugandan Africans (Simon, 1951). There is a further inherited condition — tritanopia or yellow–blue defect — but its incidence is extremely low: about five cases per hundred thousand (Pokorny et al., 1979).

Besides the inherited defects there are many acquired defects, which occur most commonly because of disease, vitamin deficiencies, and exposure to high levels of short wavelength light (Birch, 1979, Fletcher and Voke, 1985). Changes in colour vision often accompany ageing, partly because the three causes mentioned above converge in the old, particularly changes in the transmittance of the lens and the ocular media because of prolonged exposure to light (Werner, 1991). Tritan conditions, although uncommon as inherited defects, are common as acquired defects. However, acquired defects often show mixed patterns of tritan, deutan and protan errors.

Although it is well established that the incidence of Daltonism varies across the world, less is known about variations in tritan conditions. This is for two reasons. First, the likely incidence of congenital tritanopia is so small as to make it difficult or not worthwhile to estimate its variations. And second, most studies of colour vision in the field have used the Ishihara test which does not include tests for tritan errors (Fletcher and Voke, 1985, p. 191; for examples see Simon, 1951 and Reuning, 1988). We have used the City university colour vision test (Fletcher, 1980) as part of our cross-cultural work on the relationship between colour-language and colour-cognition. The City test includes tests for tritan errors, although it is not as sensitive to Daltonism as the Ishihara. Our results showed unexpectedly high incidences (at least 20%) of respondents making tritan errors in three independent samples, from southern and central Africa. Subjects made typically between one and three tritan errors out of a possible ten tritan errors.

If the high incidence of tritan-like conditions is genuine, then there are several possible explanations. First, it could be due to differential pre-retinal filtering of short wavelengths. Such a reduction in effective short wavelength stimulation could be inherited as Bornstein (1973) suggested or acquired through the effects of ultra-violet light on the lens (Werner, 1991). Bornstein suggested that people living in high sunshine areas, such as the tropics, would have a survival advantage if

they could filter out some high level of ultra-violet radiation, which would otherwise damage the retina. He suggested that such adaptive filtering could be achieved by increasing the amount of macula pigmentation relative to people living at higher latitudes. However, such a macula filter would reduce both the visible short wavelength (blue) and the ultra-violet light reaching the retinae. This reduction in the effective intensity of blue light would result in the increased likelihood of making tritan errors. Alternatively, the tritan-like condition could be due to “accelerated ageing”. During the normal life span the transmissivity of the lens reduces due to cumulative damage caused by ultra-violet light, sometimes culminating in cataract (Young, 1991). This reduction in transmissivity is greatest for the short wavelengths and produces increasing insensitivity to short wavelengths with age.

Acquired tritan-conditions can also be due to damage arising from illnesses such as diabetes, dietary deficiencies and a wide range of toxins such as the quinine derivatives, alcohol and steroids. Of these causes, the possibility of a dietary deficiency seems the most plausible candidate. The staple diet in many rural areas in southern Africa is starch based, with occasional supplements of meat. Such a diet is low in vitamin B11 and B12, and a deficiency in these vitamins can produce acquired tritan defects (Fletcher and Voke, 1985, p. 239).

The main aims of the study we report here was to check our original findings on a much larger sample, and to narrow down the possible causes of the tritan-like condition using basic epidemiological procedures. We measured colour vision on a large sample in southern Africa, stratified by age and by whether they lived in a rural or urban setting. We also made simple estimates of the typical diet of our respondents and measured their height and weight as indicators of general health. In addition, we tested several smaller samples from regions of Europe differing in the prevailing levels of sunshine. Two samples were from southern Europe, where the sunshine levels are relatively high, and two samples were from northern Europe where the sunshine levels are lower. We also tested an “old” British sample who were all over sixty-five years of age. The old sample was included to see if the pattern of errors they made was similar to the pattern of errors made by the African sample, as would be expected if the premature ageing hypothesis is true.

2. Method

2.1. Subjects

The main sample was from central and southern Africa (Botswana, Malawi and South Africa). It consisted of 597 subjects — 300 males and 297 females aged from 4 to 85 years of age, with a mean age of 31.8 years and a standard deviation of 18.1 years. Two hundred and thirty-four subjects were from rural areas and 363 subjects were from more urbanised regions. These more urbanised regions were in effect small towns — rapidly developing traditional villages — that include commercial outlets such as banks and garages. Even so, many people in the urban sample were pursuing a more or less traditional subsistence farming lifestyle. The rural samples were obtained by first asking the village head-man for permission and the participants were selected with his help, subject to the sex and age sampling constraints. The urban sample was selected by going from house to house and asking for volunteers or by asking people in the shopping areas

and arranging to visit them in their homes. All participants were given a small gift for taking part. Our field workers¹ were asked to exclude anyone with obvious symptoms of eye-disease (such as lens-cloudiness) or those who tried to view the test at less than the prescribed 14 inches. In either case, the person was allowed to complete the experiment but their data was discarded.

There were also several subsidiary samples as follows. The “standard” British sample: this consisted of 47 people from Britain with ages ranging from 20 to 65 years (mean, 45.3 years); they were from Guildford (a medium sized town). The “old” British sample: this consisted of 61 people, 15 men and 46 women, aged from 65 to 87 years (mean = 77.4 years); they were also from Guildford. The Greek sample: this consisted of 101 people from Crete, 56 males and 45 females, with ages ranging from 9 to 86 years (mean = 40.2 years); about half were from rural villages and the remainder from a large town, Heraklion. The Irish sample: this consisted of 49 people, 31 men and 18 women, with ages ranging from 18 to 73 years (mean = 33.7 years); they were all from a small rural village. The Spanish sample: this consisted of 80 people in total, of whom half were children aged 11 or 12 years (mean = 11.7 years), and half were adults with ages ranging from 16 to 55 years (mean = 25.3 years); they were all from Barcelona, a large city.

2.2. Stimuli

The City university colour vision test is based on the Farnsworth D15. It is not designed as a screening test and some instances of colour vision defect will not be detected². This relative insensitivity means that the data we report here will probably underestimate the true incidence levels. The second edition of the test consists of ten plates each with a central colour spot surrounded by four equidistant colour spots that are all the same size as the centre spot. The sizes of the spots on the last four plates are smaller than those on the first six plates: the large spots are approximately 8 mm in diameter and the small spots are approximately 5 mm in diameter, which at the prescribed viewing distance of 30 cm produces visual angles of about 1° 14' and 50' for the large and small spots respectively. The test requires the respondent to choose the surround spot that appears to be most similar to the centre spot. Of the four possible responses to each plate, one is normal and each of the other three is an error characteristic of one of three forms of colour vision defects: the “protan”, “deutan” or “tritan” defects (see Fletcher, 1980, for further details).

2.3. Procedure

In all cases data was collected by a first language speaker of the appropriate language and the experiments were conducted in that language. Instructions were standardised across languages by a successive process of translation, back translation and adjustment until the instructions stabilised. In Africa, the experiments were generally carried out close to the subjects' homes, in the open air or on a verandah, avoiding direct sunlight or deep shade. For the other samples, the test was

¹ Our field workers were Mrs Tiny Jerrett (a nurse) in Botswana where the majority of the sample came from; Dr Al Mtenje (a university Professor) in Malawi; and Mrs Lusanda Rataemane (a clinical Psychologist) in South Africa. We are very grateful for their help and advice.

² For instance, according to the Ishihara test, the first author (Davies) is a protanope, but he makes no errors on the City university test.

carried out indoors, under natural light. The experimenters attempted to maintain reasonably constant lighting conditions across subjects, but no formal measurements of the lighting were made. However, the experimenters did ensure that they could make the correct choices themselves.

All subjects did the City university colour vision test first; this took about three minutes on average. The African sample then did several other tasks that were generally variants on colour naming and colour grouping tasks; the results from these tasks will be reported elsewhere. The height and weight of 353 of the African informants were measured, and they answered questions about their diet.

3. Results

None of the standard British sample or Spanish samples made any errors. In the Irish sample there were three men and one woman who showed evidence of various degrees of Daltonism, and one man aged 73 years made one tritan error. In contrast, over a fifth (130 out of 598) of the African subjects, almost a fifth (17 out of 101) of the Greek subjects and over three fifths (39 out of 61) of the old British sample made at least one error.

Considering the African sample first, the mean number of errors for those who made at least one error was 2.4, with the mode ($n=79$) being a single error. Seven males (2.3% of the male sample) had patterns of errors suggesting either the protan or deutan version of Daltonism. Table 1 shows the number of people in the African sample who made each of the three kinds of errors, for each of the ten plates, excluding the seven people with probable Daltonism.

It can be seen that tritan errors were the most frequent overall: there were 174 tritan errors, 64.9% of the total, compared with 46 (17.2%) protan and 48 (25%) deutan errors. There is a tendency for plates seven to ten — the ones with the smaller dots — to produce more errors than

Table 1
Frequencies of types of colour vision errors for the African sample ($n=597$; 123 subjects made at least one error)

Plate	Protan	Deutan	Tritan	Total
1	3	2	7	14
2	4	4	22	30
3	5	6	18	29
4	4	4	11	19
5	6	5	26	37
6	1	1	13	15
7	4	11	17	32
8	6	4	30	40
9	8	2	19	29
10	5	9	11	25
Total	46	48	174	268

plates one to six; overall few errors were made to plates one, four and six, but this pattern is less marked for tritan errors than for the other kinds.

Logistic regression was used to see if the main demographic variables — sex, age and whether the subjects were rural or urban — were associated with the incidence of colour vision defects. For this analysis subjects were classified either as having normal colour vision (no errors) or abnormal colour vision (one or more errors). The incidence of abnormal colour vision increased with age ($p < 0.0002$); whereas only 14% of the under 25's made one or more errors, this rose to 21.3% for 25–40 year olds, and 32% of the over 40's made errors. The severity of the condition also increased with age; the correlation between age and number of errors was $r = 0.20$ ($p = 0.01$). For tritan errors alone, the correlation was $r = 0.32$ ($p = 0.01$). There was also a significant association ($p < 0.007$) between area of residence and the incidence of abnormal colour vision: a larger proportion of the rural sample (28%) fell into the anomalous group, than of the urban sample (18%). Although more men than women had abnormal colour vision (24.0% compared to 19.5%) this association was not statistically significant.

We had collected data on diet and occupation from 353 of the Botswanan sample. Respondents were grouped into those who had one or fewer meat meals per week and those who had two or more, and into those whose occupation meant most of their time was spent outdoors (generally farmers and labourers) and those who spent a good deal of time indoors. Logistic regression showed that neither diet nor occupation was significantly associated with the incidence of the condition. However, a further logistic regression on just those who made at least one error showed that diet was significantly associated with the severity of the condition ($p = 0.04$); 41% of those in the poorer diet group made more than one error compared with 21% of those on a better diet.

In the old British sample, the mean number of errors for those who made at least one error was 4.4. Table 2 shows the distribution of errors across the ten plates. It can be seen that tritan errors were the most frequent, but the difference between the tritan frequency and the protan and deutan frequencies were less than for the African sample (Table 1): there were 77 (44.5%) tritan errors,

Table 2
Frequencies of types of colour vision errors for the old British sample ($n = 61$; 39 subjects made at least one error)

Plate	Protan	Deutan	Tritan	Total
1	4	7	5	16
2	3	8	9	20
3	6	1	2	9
4	9	1	8	18
5	1	5	10	16
6	7	4	0	11
7	5	4	10	19
8	6	4	18	28
9	5	8	8	21
10	3	5	7	15
Total	49	47	77	173

Table 3
Frequency of types of colour vision errors for the Greek sample ($n = 101$; 17 subjects made at least one error)

Plate	Protan	Deutan	Tritan	Total
1	0	0	0	0
2	0	0	1	1
3	0	0	1	1
4	1	0	0	1
5	0	1	2	3
6	0	0	2	2
7	1	0	2	3
8	2	0	8	10
9	0	0	6	6
10	1	0	0	1
Total	5	1	24	30

49 (28.0%) protan errors and 47 (26.9%) deutan errors. As with the African data, there is a tendency for the last four plates to produce more errors, but unlike the African data, this tendency is more pronounced for the tritan errors than for deutan or protan errors.

In the Greek sample, one man made four deutan errors suggesting Daltonism, and there were 16 people who made at least one tritan error; of these 16, 12 people made just one error, and one person, aged 15 years made five tritan errors and 3 protan errors. Table 3 shows the distribution of errors across the ten plates; it can be seen that most of the errors occur on the last four plates, the ones with the smaller dots. There was some degree of association between age and the incidence of tritan errors: only one out of 23 people under 20 years of age made any errors, whereas the incidence of errors was more or less evenly spread across age for those over 20 years of age.

4. Discussion

About a fifth of the African sample and almost a fifth of the Greek sample made one or more colour vision errors; and the errors were predominantly tritan errors. None of the age-random British sample or the Spanish samples made any errors; and the Irish sample revealed just the expected level of Daltonism. The pattern of errors made by the African sample resembled the pattern exhibited by the old British sample. The old British sample made more errors on average, but in both cases tritan errors were the most common, and they were usually accompanied by deutan or protan errors. Such mixed patterns of errors were less common in the Greek sample: the modal pattern was a single tritan error. Further, the incidence of the condition significantly co-varied with age and place of residence within the African sample: older people were more likely to show the condition than the young; and those dwelling in rural locations were more likely to show the condition than those living in more developed regions. In the Greek sample tritan errors were rare in those under 20 years of age.

The results could be an artefact arising either from problems with the illuminants or misunderstanding of the instructions among the African samples, or both. We consider problems with the illuminant first. Ideally the test should be administered under light typical, of “a northern sky” — illuminant C — (Fletcher, 1980). Our field workers had made the best of the lighting conditions they found in the villages where the subjects lived, avoiding direct sunlight and deep shade, but it is possible that the reliability and validity of the test may be compromised under such conditions. However, there are several reasons to doubt whether inadequate lighting is sufficient to account for the data. First, most colour vision tests are robust under deviations of the illuminant from the ideal. For instance, Van Everdingen et al. (1991) report that there were very few errors made on a battery of tests for tritanopia even when the illuminance was reduced to 25 lux (like a badly lit room). Secondly, the lighting explanation does not account for the distribution of errors: the errors in our samples were primarily tritan errors and the simplest form of the lighting explanation would predict approximately equal frequencies of the three types of error. It remains possible however, that the distribution of errors results from the differential vulnerability of the three error choices to the deficiencies in the lighting: the lighting may make the tritan choice more similar to the target colour than either the protan or deutan choice (a point we return to below). Thirdly the lighting was not ideal for the European samples either, but except for the Greek sample and the old British sample there was little evidence of colour vision defects. Lastly, if the illuminant was responsible for the results, it might have been expected that the last four plates — the plates with the smallest dots — would produce the most errors. There have been some reports of the last four plates producing some false positive assessments (Birch, 1985). The last four plates did produce more errors on average than the first six plates in the African, the old British and the Greek samples, but in general the difference in error rates between the first six plates and the last four plates was small. On balance, it seems unlikely that the entire set of errors is due to the illuminant, but even so it is important to check the findings using the ideal illuminant.

Secondly, the high incidence of tritan errors could result from some of our African respondents not understanding the instructions fully. Again we believe that this is unlikely to account for all the difference between our African and European samples. We followed standard procedures in translating and back translating the instructions into Setswana, and our Setswana speaking colleagues were certain that the instructions and the task requirements were compatible with both the language and the culture. We have carried out other colour choice tasks on rural and urban adults and children in Botswana with conceptually similar task requirements and have always found the tasks have been understood and enjoyed. For instance, we have used a triads task in which the respondent is shown three colours and is either asked which pair of colours are most similar, or which colour is least like the other two. The task is readily understood by both adults and children as young as four years of age. Despite our confidence in our procedures, it may be that partial misunderstanding of the instructions in combination with problems with the illuminant may have contributed to the results. One draw back of the CUCVT (in common with the Farnsworth D15 on which it is based) is that the tritan choices are more similar to the target than either the deutan or protan choices, measured in Munsell steps. It could be then that some general visual defect presents as a tritan condition, because of this differential vulnerability to tritan errors, or that in combination with deviations from the ideal illuminant, and possibly with some misunderstanding of the instructions, some tritan errors were made. However, we restate that this is unlikely to account for the total incidence of tritan-like conditions found.

The pattern of errors is probably not consistent with Bornstein's short wavelength filter hypothesis. A filter that blocked most of the ultra-violet and blue light (300–500 nm) such as a Lee 101 yellow, tends to produce tritan errors on the City university colour vision test, but it produces no deutan or protan errors. In contrast, it was common in both our African and old British subjects for mixtures of tritan and other errors to occur. It is this mixed pattern of errors, and the increased incidence with ageing, which suggests we are probably observing an acquired defect.

It is probable that the main cause of the acquired defect is accelerated yellowing of the lens due to the high prevailing levels of ultra-violet radiation, augmented by reflected ultra-violet from the ground. The incidence of cataract — the end-point of such changes to the lens — increases with closeness to the equator (Young, 1991, ch. 8) and it is likely that the incidence of cataract can be used to estimate the incidence of less severe damage to the lens. In addition, the similarity between the data from the old British sample and the African sample is consistent with this premature ageing hypothesis. Our data do not allow us to estimate whether other factors such as diet are clearly implicated, because poor diet and an outdoor life style co-vary.

More detailed assessment of the apparent tritanopia is really required before speculating about its origin. Besides replicating the measures under a controlled illuminant the City university test should be followed up with a battery of other tests such as the Farnsworth–Munsell or the minimalist colour vision test, to describe the condition more precisely. In addition, wavelength discrimination tests and measures of increment thresholds across the spectra should be made. However, there are difficulties in following this course of action. First, there is the practical problem of control of the lighting in rural Africa; solving the problem of the illuminant may lead to the new problem that requiring subjects to come into a laboratory can be frightening and the acceptability of the procedure will be reduced. Secondly, we do not know whether the underlying principle of the Farnsworth Munsell — linear ordering of colours by similarity — or of the minimalist colour vision test (Mollon and Reffin, 1994) — choosing the most “colourful” stimulus — fits the conceptual structure of the colour domain in African languages or culture. We intend to try out such tests to assess their usefulness in the rural African context. We know that matching to sample, which is the basis of the City university test, is understood by our samples, and it should be possible to adapt the minimalist colour vision test to a matching to sample procedure (Mollon, personal communication).

If it is true that about a fifth of the people in rural southern and central Africa have a tritan-like condition, might this have contributed to the prevalence of terms for blue-and-green in the languages of the region? Tritan defects would make blues and greens less discriminable and there would be less “perceptual pressure” to encode the colour difference in the language. Perhaps Rivers (1901) original conjecture deserves further investigation after all.

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