Second Report for R1-44: Limits of Normal Colour Vision

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Terms of Reference: To review the literature to see what information is available to establish the limits of normal colour vision.

Introduction

As stated in last years report, the impetus for this Reportership was a paper presented by Barbur, Rodriguez-Carmona, and Harlow [1] at the ISCC/CIE Expert Symposium on 75 Years of the CIE Standard Colorimetric Observer. The paper documented their efforts to establish a better test for assessing colour deficiency based on the “the statistical limits of colour discrimination in ‘normal’ trichromats”. Thus, the goal of a TC arising out of this Reportership would not be to recommend the most suitable colour vision tests, but would be to link the assessment of colour deficiency to the measurement of normal colour vision. Hopefully this would lead to not only improved assessment of the severity of colour vision loss, but also better characterization of normal colour vision capabilities.

Last years report focused on the suitability of existing and proposed tests for assessing the limits of normal colour matching, colour discrimination and colour appearance. It concluded that the current tests and standards are inadequate for reliably and consistently describing the limits of normal colour vision because very little of the research to date appears to:

- systematically evaluate the colour matching, colour discrimination or colour naming performance of a wide range of colour deficient individuals;
- systematically measure the performance of a large number of colour normal individuals on tests of colour deficiency; or
- integrate the data from studies of colour discrimination etc. with the data from studies of colour deficiency.

Results of review

As a result of a more detailed review of the literature, it does appear that the colour matching and colour discrimination performance of a wide range of colour deficient individuals has been evaluated (e.g.[2-5]). The limitation with most of these studies is that the characterization of colour deficient versus colour normal is based on the results of clinical tests of colour vision capability. Since these tests can fail colour normals and pass the minimally colour deficient, a battery of colour vision tests are often used to ensure that all the people assessed can be characterized as colour deficient according to the categories outlined in the previous report. The unintended effect is that these studies probably fail to characterize the performance of people with minimal colour deficiencies. This possibility was pointed out by Wright [2] in his comprehensive review of the assessments of spectral sensitivity performance of people with a wide range of colour deficiencies. He noted that some people that perform normally on colour confusion tests will fail the lantern test because of reduced sensitivity to long wavelengths. These types of people would not have been included in the studies assessing the capabilities of people with abnormal colour vision that he reported. An additional problem is that many studies fail to report the criterion used on any given colour deficiency test or the conditions under which the test was performed. Consequently it is difficult to compare the populations used in different studies.

On the other hand, it does seem to be the case that there are relatively few studies that systematically measure the performance of a large number of colour normal individuals on tests of colour deficiency and then compare those results with their colour matching and colour discrimination performance. A recent study by Barbur, Rodriguez-Carmona, Harlow, Mancuso, Neitz, and Neitz [6] is somewhat of an exception. They compared the chromatic discrimination performance (using the CAD test) of 67 colour normals with their match point and range on the anomaloscope. They found no systematic relationship between the two measures. Unfortunately, there is no discussion of within subject
variability on either of the tests. Other studies that may provide some data on the limits of human colour vision are those carried out on female carriers of a defective colour gene [4, 5, 7, 8]. These studies find that such females often perform within the normal range on colour deficiency tests, although they do make some errors, but they can perform differently on tests of vision capability. For example, a recent study [5], using a subjective colour dissimilarity task with women heterozygous for colour deficiency, found that they tended to have a distorted colour space. Although such studies are not a substitute for the evaluation of people with normal colour vision, including them in large scale studies does ensure a more heterogeneous test population.

In parallel with studies assessing the colour matching, colour discrimination and colour appearance performance of colour deficient observers, there have been many studies assessing the variability in the performance of colour normals on these types of tasks (e.g. [2, 9-12]). This variability is attributed to such factors as variation in the peak spectral sensitivity of the M and L cones, density of the lens, density of the macular pigment, variation in the optical density of the cones, and rod intrusion [11, 13]. As well, performance has been shown to vary as a function of stimulus size, illumination level [14], and gender [15]. Finally, the methodology (e.g. method of adjustment, ‘n’ alternative forced choice) may also affect the range of performance on any given measure of colour vision capability [16]. While the individual effect of each of these factors has been reasonably well studied, the cumulative effect or interaction amongst variables is less clear. Moreover, there appears to be little data on the extent to which these factors may affect performance on colour vision tests. Are a small number of errors on a colour confusion test, for example, due to genetics, physiology, methodology, sloppy test procedures or even motivation? Since details about how the colour vision tests were administered or even what criterion was used are often not provided in studies of normal variability in colour vision as well as studies of colour deficiency, it is difficult to answer this question.

Overall, my review of the two sets of literature leads me to the conclusion that there is probably no absolute threshold for normal colour vision. This conclusion does not mean that it is not possible to define a threshold for any current or future test and to be able to reliably divide a given population into those that pass and those that fail. Moreover, to the extent that a subset of tests is assessing the same aspect of colour vision capability, they are likely to be correlated. The problem is in assessing whether a person, who is borderline on a particular test or passes some tests and fails others, is likely to perform poorly in colour vision sensitive tasks. It is this issue that seems to drive much of the continuing interest in colour vision testing and has led to the development of a wide range of occupational colour tests. The problem with that approach is that it leads to a proliferation of tests whose usefulness outside a specific industry is unknown. Moreover, the relevance of a test may change as the industry evolves. For example, does a colour vision test based on samples of cloth adequately assess the colour vision capability of people working on electronic displays? Some recent work by Webster et al. [10] suggests it may not. They found the variability in selection of unique hues both larger and different in form from what would be predicted for the subjects used by Stiles and Burch [17, 18]. They hypothesized that part of the difference could be due to the use of non-spectral lights in their study. Similarly, Oicherman, Luo, and Robertson [19] found that the impaired performance, in a metameric matching task, of two individuals with borderline colour deficiency, varied as a function of the type of display (CRT versus LCD) used.

An alternative to the development of industry specific tests is to define the limits of normal colour vision through a combination of systematic experimentation and modelling. The recent work by Barbur and his colleagues [6] is a good starting point. In that study, colour discrimination performance was collected on a wide range of individuals and compared with performance on the anomaloscope. In addition, they used modelling to predict the effect of optical density and separation of the L and M cones. However, discrimination is only one aspect of colour vision. As the study by Oicherman et al [19] showed, an individual who performs normally on colour confusion tests such as the
Ishihara colour plates and the Farnsworth 100 hue test, may fall outside the normal range on a colour matching task. In a related study [11], the same authors found that the variability in performance of their “colour normal” subjects was much larger than would be predicted by the Standard Deviate Observer. These findings suggest that there is a requirement to better define the limits of normal colour matching data. Similarly, research on the variability in perception of unique hues [10, 16] indicates that there is considerable variability in the perception of colour appearance by colour normals.

Defining the limits of normal colour vision would certainly seem to be within the mandate of CIE Division 1. It is related to the work in TC1-36 on the development of a fundamental chromaticity diagram with physiological axes, TC1-54 on age related changes of visual response, and TC1-61 on categorical colour identification among others. Moreover, it provides a different way of looking at the concept of a Standard Deviate Observer – a concept that has been heavily criticized as been unrepresentative of the real variation in colour matching. The extensive data available on the variability of colour normal and colour deficient vision suggests that the problem is not necessarily one of data collection, but of documenting the existing data and using it to develop models that would improving our understanding of the limits of colour vision and allow us to predict when performance on colour vision sensitive tasks are likely to be impacted. Such a task would seem to fall more within the expertise of colour scientists than ophthalmologists, but both disciplines should contribute to such an effort to ensure a useful outcome for all concerned.

Conclusion

At this point, I do not think there is any benefit in continuing R1-44. I believe that the review conducted to date clearly points to the need for a more systematic approach to assessing colour vision capability. Determining if this can be done using the current literature will require input from a broad range of experts conducting research in colour deficiency, colour discrimination, colour matching and colour appearance.

Recommendations

I would recommend that R1-44, be closed and Division 1 pursue the possibility of forming a Technical Committee.

If there is sufficient interest in setting up a Technical Committee to establish the limits of normal colour vision, I would propose the following Terms of Reference:

1) To document the correlation between performance on colour matching, colour discrimination, colour naming, and colour deficiency tests and factors such as variation in the peak spectral sensitivity of the M and L cones, density of the lens, density of macular pigment, variation in the optical density of the cones, L to M cone ratio, rod intrusion, illumination level, stimulus size, gender, stimulus duration and identify any substantive gaps in the existing literature.

2) Using the above database, develop a model or models that will allow the prediction of the effect of the above factors on colour discrimination, colour matching, and colour naming performance.

References


