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Individual Observer Data for the Stiles-Burch 2° Pilot Investigation

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Foreword

This is to express our thanks to Dr. Trezona for undertaking considerable work in recovering and processing these individual 2° field data. We are very glad that she has been successful.

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NATIONAL PHYSICAL LABORATORY

Individual Observer Data for the 1955 Stiles-Burch 2° Pilot Investigation

by
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Abstract

Although the results of the 2° Stiles-Burch investigation were published in 1955 in the form of mean data, individual results have not been available. It is only very recently that they have been in wide demand. Since in 1955 this demand was not anticipated, individual results were left in an unprocessed form; the processing has now been completed. Tables follow for each of 10 observers and their mean for colour matching functions, unit (WDW) co-ordinates and the relative luminous efficiency function.

Background

In the early 1950s, Dr W.S. Stiles set out to build a new instrument, the NPL Trichromator, and then to use it to measure the colour vision characteristics of a large number of observers having normal colour vision, for fields subtending both 2° and 10° at the eye's pupil. Originally he was assisted by Mr Robert Donaldson who died tragically before the completion of the instrument. Dr J .M. Burch joined the project at the stage where calibrations and measurements commenced. The investigation fell into two parts. First there was the Pilot Investigation which used 10 observers for derivation of mean colour matching functions, unit co-ordinates and relative luminous efficiency functions for both 2° and 10° field sizes (1,2). At the C.I.E. meeting of 1955 (3, p333) two decisions were made.

1. The 2° data, although significantly different (2) from those of the Wright-Guild investigation on which the 1931 Standard Observer was based, were judged not sufficiently different to warrant changes being made.
2. The 10° data, however, differed sufficiently from the 20 to require a new investigation to be undertaken. Such a difference is only to be expected on physiological grounds.

A massive project for collecting 10° data for 49 observers and under various observing conditions then formed the second part of the investigation (4,5), the results of which, together with similar data from work by Mme N.I. Speranskaya (3, p.140), led to the CIE 1964 colorimetric standards for large fields. This overshadowed the Pilot Investigation which became largely forgotten, but the fact remains that, with 10 observers, it was a comprehensive and painstaking undertaking in its own right, yielding valuable colorimetric data.

In 1931 the CIE Standard Observer was based on 2° investigations by Wright (6) at Imperial College and Guild (1) on different equipment at NPL. No spectro-radiometric measurements were made. Unit co-ordinates do not require them, but colour matching functions do. As far as the latter were concerned the system incorporated the $V(\lambda)$ function and so indirectly used the spectro-radiometric measurements of its derivation. These were made prior to 1924, when $V(\lambda)$ was adopted, and this function applies to a different set of observers: implicit in the procedure is the assumption of the Law of Additivity of Luminances (Abney's Law). The Law of Additivity of Colour Equations is of course presupposed for complete colour matches (Grassman's Law). Thus, although unit co-ordinates are fully colorimetrically-based, colour matching functions are reached in part through photometry. The 2° Stiles-Burch investigation, on the other hand, is fully colorimetrically-based. It had its own spectro-radiometric measurements and is independent of $V(\lambda)$ or any other function. An associated photometric curve can be derived from it, by taking a linear combination of the colour matching functions weighted by the relative luminous efficiencies of the reference stimuli, but this time it is photometry which must be reached by assuming Abney's Law: the resulting function differs from $V(\lambda)$. As the 2° Stiles-Burch system is fully colorimetrically-based, Estevez (8,p115) and others consider that it is the only existing 2° system which should be used when colour matching

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functions are required. As far as unit co-ordinates (which are independent of spectroradiometric measurements) are concerned, Estevez (8, p44) compared the Stiles-Burch data with those of Wright and Guild separately and considered discrepancies to be no greater than those between Wright and Guild.

In the last few years there has been increased interest in individual observer data (8, p114), (9; p94), (3, PP344-346). Without this, even where the standard deviation for each matching stimulus at each test wavelength is given, the information is incomplete: no account is taken of the fact that, for a given observer, the deviations from the mean at different test wavelengths may be correlated. Data for individual observers would allow the standard deviation to be derived for any spectral power distribution, not just for spectral colours. Colour matching functions have been used in assessments of the spectral properties of the eye's lens and macular screening pigments by a variety of methods: with individual data observer variations in density of these pigments can be studied.

Results of the 2° Stiles-Burch individual observers have not, so far, been available. Following some unfruitful searches amongst Stiles' and Burch's papers, they were widely believed to be lost. However some computer print-outs for 2° and 10° individual and mean data were eventually found, and were believed to be those in question since both mean sets of data were linear versions of the published tables (2, Appendix). The computer paper was fragile and faded, but it was just possible to decipher all characters. Initially it was disappointing to discover that the mean tables could not be reproduced by averaging the individual data. However, written on each page of mean data was "Pilot group corrected mean results". It was possible to track down, from notebooks of that period, a correction which allowed for small changes in measurement of spectral responsivity of a photocell and spectral transmission characteristics of neutral filters during the course of the experiment. Another minor adjustment concerns the intractable violet region: in order to avoid providing misleading results, for two wavelengths only results for observer No. 2 had been omitted and replaced by default values which were the mean of the other 9 observers: these and derived values are marked with an asterisk. After applying the corrections to the arithmetic mean of the individual data, followed by the necessary normalisation procedure (see below), agreement was reached with the mean values published by Stiles and Burch. Thus the way ahead was clear for applying correction and normalisation procedures to the individual data and processing them in a suitable form for publication.

In spite of this there is still a small, inevitable discrepancy between the mean colour matching functions, shown below in Table 11, and a corresponding table already published (3, p334). It arises because of the order in which the operations were carried out. For Table 11 to be directly related to the individual tables (1 to 10), the mean must be taken after corrections and renormalisation have been applied to the individual results, whereas in 1955 the mean had been found first. This would have made no difference if the original normalisation had been perfect: then the renormalising matrices which follow the corrections would have been truly diagonal ones. However, small non-zero non-diagonal values cause each of the 3 colour matching functions to be slightly influenced by the other 2, this influence being different in the individual cases from the mean case. The discrepancy is greatest (3%) for low values of the green reference stimulus with a violet test stimulus. It is an easy matter with the computer facilities available in 1984 to assess such discrepancies, but it must be remembered that computing 30 years ago was quite different. The discrepancy is unimportant and is only mentioned in case the two slightly different versions of the mean may be questioned by the reader.

Both mean and individual data needed a further small spectral correction, followed by renormalisation. This was for chromatic aberration and absorption of an auxiliary lens (5, p9) and has already been applied to the mean of the 2 data (3, PP 334, 335).

The Tables

The data in these tables are the results themselves, not smoothed, interpolated or extrapolated. The presentation closely follows that of Stiles and Burch for the mean values of the 2° figures (2, Appendix). The data are stated for reference stimuli of wave-numbers (wavelength) 15500 cm^{-1} (645 nm), 19000 (526) and 22500 (444) which are very close to the instrumental stimuli of 15418 (649), 18997 (526) and 22456 (445). The required linear transformation, referred to above as "normalisation", ensures that for test stimuli of 15500, 19000 and 22500 cm^{-1} each reference stimulus is either 1 or 0. In making this linear transformation the Law of Additivity of Colour Equations (Grassman's Law) is assumed.

The individual colour matching functions (Tables 1 to 10) and their arithmetic mean (Table 11) are the powers of the 3 reference stimuli required to match unit power of the test stimulus, taken at intervals

throughout the visible spectrum. The tables follow a technique of Wyszecki and Stiles (3, p334), giving a linear presentation rather than the less convenient logarithmic, but without losing meaningful figures for low absolute values. In each case the value must be multiplied by the power of 10, shown bracketed. The number of figures given also closely follows that of Wyszecki and Stiles.

The unit co-ordinates are stated in the WDW System, that is the units of the "red" and "green" functions are equal at wave-number (wavelength) 17250 (580) and the "green" and "blue" functions are equal at 20500(488). Tables 12 to 21 show individual values, directly obtained from the corresponding colour matching functions, and Table 22 gives their arithmetic mean.

Tables 12 to 21 also show individual values of the relative luminous efficiency function and Table 22 gives their arithmetic mean. Tables 12 to 21 were derived from the corresponding colour matching functions, together with additional data; each observer had determined the relative luminous efficiency of the reference stimuli by direct heterochromatic matching with a white stimulus. The validity of Abney's Law was assumed for this purpose. Each function was normalised to unity at 18000 cm^{-1} (566 nm).

Table 23 gives some appropriate information about the observers.

Although some of them have their 10° data of the Main Investigation published (3, p817), comparison is not recommended as the latter experiment used a much higher luminance level; consequently, it was not necessary to identify the Pilot Investigation observers. Details of luminance levels, field configuration and other experimental information can be found fully covered in the Stiles-Burch publications.

Acknowledgements

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