



COMMISSION INTERNATIONALE DE L'ÉCLAIRAGE
INTERNATIONAL COMMISSION ON ILLUMINATION
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SPECTRAL LUMINOUS EFFICIENCY FUNCTIONS BASED UPON BRIGHTNESS MATCHING FOR MONOCHROMATIC POINT SOURCES 2° and 10° FIELDS

PUBLICATION CIE N° 75 (1988)
CENTRAL BUREAU OF THE CIE
A—1030 VIENNA, Kegelgasse 27 — AUSTRIA

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FOREWORD

The following members of TC1-02 Luminous Efficiency Functions took part in the preparation of this Technical Report. The Committee comes under CIE Division 1 Vision and Colour.

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SUMMARY

Spectral luminous efficiency functions based on heterochromatic brightness matching for point surfaces, 2° fields and 10° fields are presented. Their averaged functions are derived with the intention that they be used to evaluate the luminous efficiency for the brightness of monochromatic lights. These functions could be used as the basis for further work to evaluate light sources with compound spectra.

RESUME

On présente des fonctions d'efficacité lumineuse relative spectrale obtenues par égalisation hétérochrome de luminosité avec des sources ponctuelles, des champs de diamètre 2° et des champs de diamètre 10° . Les moyennes des fonctions ont été déterminées afin qu'elles soient utilisées à l'évaluation de l'efficacité lumineuse en termes de luminosité des rayonnements monochromatiques. Elles pourraient servir de base à des travaux ultérieurs concernant l'évaluation de la luminosité des rayonnements complexes.

ZUSAMMENFASSUNG

Es werden spektrale Hellempfindlichkeitsfunktionen auf der Grundlage eines heterochromen Helligkeitsabgleichs für punktartige Lichtquellen sowie für 2° und 10° Gesichtsfelder dargestellt. Diese aus mehreren Untersuchungen gemittelten Funktionen wurden aufgestellt mit dem Ziel, die Helligkeit monochromatischer Strahlung bewerten zu können. Sie sind auch die Grundlage für weitere Arbeiten mit dem Ziel, die Helligkeit von zusammengesetzten Strahlungen zu bewerten.

1 INTRODUCTION AND HISTORY

1978: CIE Publication No 41 entitled 'Light as a true visual quantity: principles of measurement' was published[1.1]. A difference was clearly shown between the luminous efficiency function of the CIE, $V(\lambda)$, and the function obtained by the direct heterochromatic brightness matching method, the efficiency of the latter being much higher than that of the former at both long and short wavelengths when both functions were normalized at 570 nm. The need to derive a standard luminous efficiency function for brightness was well recognized, but the data from direct matching experiments were rather limited, and the function was not derived at that time. Thus it was in 1978 that an appeal was made that more data be collected using the direct heterochromatic brightness matching method [1.2, 1.3].

1979: Experimental conditions for the data collection were set up as follows: Stimulus size of point sources, 2° and 10° arc of visual angle; Photopic illuminance level in the range of 50 to 500 td; Observers' age between 18 and 50 years old. Some tolerances were allowed so that as much data as possible could be utilized in the analysis. As a result of careful inspection of the data adopted in the 1978 report, that of 12 out of 31 observers were abandoned for various reasons, such as duplication of the same observers, insufficient data points with regard to the wavelength, etc. The data of 19 observers were finally adopted and the revised version of the 1978 report was prepared.

1981: As a result of this work a brightness luminous efficiency function for a 2° field based on 19 observers was achieved.

1983: The data for point sources, 2° and 10° fields were added to the previous report. The number of observers had increased from 19 to 37 for the 2° field. Correction factors to derive $V_{b,10}(\lambda)$ from $V_{b,2}(\lambda)$ were presented. However, it was

important to determine experimentally the difference between $V_{b,2}(\lambda)$ and $V_{b,10}(\lambda)$ rather than assume the macular pigment was the sole cause of this difference. To meet this point it was decided to collect more data, particularly for the 10° field. The $V_{b,\text{point}}(\lambda)$ was reported to be the same as CIE $V(\lambda)$ function with Judd's modification.

1985: Further newly obtained data for 2° and 10° fields was included in a final report based on 6 observers for point sources, 63 observers for the 2° field, and 76 observers for the 10° field.

2 PRINCIPLE OF THE HETEROCHROMATIC BRIGHTNESS MATCHING

Whether the field size is small or large, there must be two visual fields, one for a reference stimulus and the other for a test stimulus of defined wavelength. When the field size is large a bipartite field may be used, but when it is very small, such as a point source, two separated fields are usually employed. Normally the radiance of the test stimulus is varied and its brightness is made equal to that of the reference stimulus. The luminous efficiency of the stimulus is proportional to the reciprocal of the radiance at the match condition.

The use of a fixation point at the time of measurement is optional. An observer can easily view the stimulus foveally even when it appears without the fixation point. The luminous efficiency is not affected by the observer scanning over the field, or fixating at the central portion of the field, unless an intense fixation is made. Such an intense fixation induces a decaying of the field and the luminous efficiency may change, particularly in the case of point sources.

With using a 10° field and short wavelength light the observer normally sees a darker spot at the center of the visual field because of the macular pigment. The observer should be instructed to neglect the spot and evaluate the brightness in a parafoveal area.

3 EXPERIMENTAL CONDITIONS

Some of the experimental conditions are listed in Tables 3.1, 3.2, and 3.3 for point sources, 2° and 10° fields, respectively. Most of the researchers presented the stimuli to their observers continuously, but some used a flash, typically of one second duration.

4 TERMINOLOGY

The notation $V_b(\lambda)$ is used to represent the spectral luminous efficiency function based upon brightness matching for monochromatic light. Thus the function for point sources is denoted by $V_{b,\text{point}}(\lambda)$; for the 2° field by $V_{b,2}(\lambda)$; and for the 10° field by $V_{b,10}(\lambda)$.

It must be clearly recognized that the functions cannot be applied to light sources with compound spectra in order to obtain their luminous efficiencies for brightness, as is done by the CIE $V(\lambda)$ function, because of the failure of additivity for different spectra.

5 RESULTS

5.1 Point sources

It is difficult to define how small a stimulus should be to be called a point source: this needs to be defined quantitatively in the future. In this report it is defined as a source presenting almost no perceptual area to the observer. Only a small amount of data are available that satisfy this condition as is shown in Table 3.1 [5.1, 5.2]. The results are summarized in Table 5.1, values being given in logarithmic units. The data in the columns 2 and 3 are simply averaged, disregarding the number of observers, to give the average data in column 4. These average data are plotted in Fig. 5.1 as open circles, together with the Judd modified $V(\lambda)$ function as a solid line.

This figure shows that the spectral luminous efficiency