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PROCEDURE TO DETERMINE BACKGROUND LUMINANCE FOR USE IN ESI AND VISUAL PERFORMANCE METHODS

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SOMMAIRE

Les expressions "luminance du contour immédiat" ou "luminance de la tache visuelle" servent à décrire une tache dans le cadre de l'évaluation de la performance visuelle. L'imprécision et la mauvaise compréhension de ce paramètre limitent l'exactitude des méthode d'évaluation de la performance visuelle dans les études d'économie de l'énergie électrique et la conception des réseaux d'éclairage. On propose des méthodes expérimentales de mesure exacte de la luminance du contour immédiat pour des taches types retrouvées dans les bureaux et les écoles.

Procedure to determine background luminance for use in *ESI* and visual performance methods

A. W. Levy

Two major factors determine the visibility of common objects: the luminance contrast of the object detail with respect to its immediate background and the adaptation level of the visual system. *CIE Publication No. 19* chooses the term *task luminance* to characterize an observer's state of adaptation and then uses this factor to describe a task in connection with all operations carried out in the visual performance framework of methods. The imprecision and poor understanding of this parameter severely restrict the accuracy of the visual performance methodology in lighting energy conservation and design. Experimental procedures are proposed for accurate measurement of background luminance for typical office and school tasks.

Introduction

The human eye is capable of adapting to an enormous relative range of light levels, of the order of 10^{12} to 1, and to light of different colors. The adaptation process is complex, however, and incompletely understood.

The term *adaptation* is referred to when considering the effects of the luminance of surrounding areas on the apparent brightness of parts of the visual scene, and when discussing the phenomenon of glare that reduces visibility or causes discomfort. These effects result from complex interactions of optical, photochemical, neuromotor and neurological factors with the perceived sensations. Adaptation luminance is therefore extremely difficult to define concisely. In fact, the International Lighting Vocabulary[1] can only offer the following general definition:

"(1) The process by which the properties of the organ of vision are modified according to the luminances or the color stimuli presented to it.

"(2) The final state of the process. In particular, the terms light adaptation and dark adaptation are used, according as the luminance is of at least several candelas per meter squared or less than some hundredths of a candela per meter squared."

The present paper is concerned solely with light adaptation and the visibility of achromatic two-dimensional tasks where the luminance of the details of the visual tasks differs from their surroundings (*i.e.*, luminance contrast). Methods are proposed for measuring light adaptation luminance for tasks of nonuniform luminance, *e.g.*, a typewritten sheet of paper.

The term *background luminance* will be used in preference to the alternatives *adaptation luminance* or *task luminance* as a measure of the state of adaptation when viewing visual tasks of interest. It is nearest to the meaning of task luminance defined in *CIE* (Commission Internationale de l'Eclairage) *Publication No. 19*[2] but cannot be confused with the luminance of the task detail, as can the CIE definition. Similarly, the term *adaption luminance* will be avoided because its widespread use for visual phenomena such as glare can cause confusion.

The CIE visual performance system contains a framework of methods that enables the illuminating engineer to

(1) Evaluate the merits of different lighting systems in terms of the visibility they produce, and

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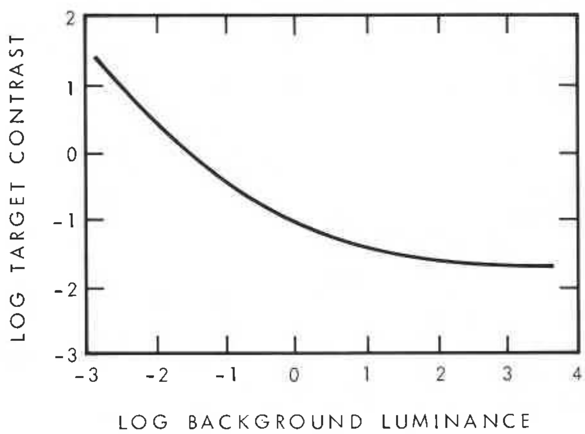


Figure 1. Typical threshold contrast–luminance curve.

(2) Determine the level of visual performance attained for different tasks at different illuminance levels.

Background luminance is an extremely important factor because it is the value of luminance used to describe a task in connection with all operations carried out in the unified framework of methods. For example, for a task involving a small detail of uniform luminance appearing in a background field of uniform luminance L_B, L_B is the task background luminance. For a task involving equal areas of two luminances such as a grating, L_B is the average of the two luminances. It is suggested that in other cases the appropriate value of L_B must be established empirically. The product of L_B and the reciprocal of the appropriate luminance factor yields a value of equivalent sphere illumination (*ESI*), which is the design parameter currently used by illuminating engineers.

Blackwell[3] has postulated that where a marked nonuniformity in the luminance of the task background exists, the value of L_B should be the luminance of that local portion of the background adjacent to the element of task detail with the greatest visibility. Little experimental or theoretical justification is given for this hypothesis, however, and the determination of L_B has remained unsatisfactory. In fact, very little consideration has been given to this most important factor. Although it has little influence compared to factors such as equivalent contrast (a measure of task difficulty) on visual performance, it still remains the most direct link to lighting power consumption.

A severe problem remains, therefore, in the application of the CIE system to most common office and school tasks. The background luminance of these tasks can be extremely nonuniform, and as the point of fixation changes, that which at one instant constitutes the task detail subsequently becomes part of the task surround. The important question is: What background luminance should be used in connection with all operations carried out in the CIE system? Is it simply the luminance of the paper on which details are printed (or handwritten), or should it be some weighted average of the luminance of print and paper? Typically, the luminance ratio of task detail to background is of the order of 1 to 20.

According to the CIE definition, background luminance will always be close to the luminance of the paper, that is, at one extreme of the luminance range, which can vary by a factor of 20. A priori, however, there is no reason why it cannot be close to the other extreme of this range for tasks where the printed material is closely spaced. Furthermore, since the recent addition[4] of ocular search and scanning (characteristic of the dynamic mode of vision) to the framework of the visual performance methodology, the CIE definition seems even less appropriate. For most common visual tasks the observer's eyes are in constant motion, with peripheral vision performing a major role in the process of seeing. Intuitively, it would appear more practical to assume that the eye is adapted to some weighted average luminance in the field of view rather than to a particular minute area of background luminance adjacent to a particular detail.

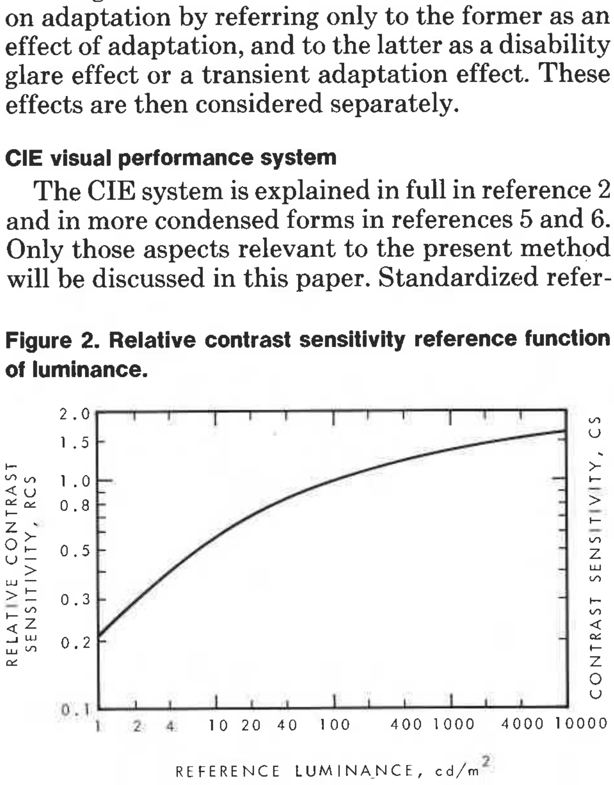
The experimental methods described here are designed to permit the determination of background luminance for any two-dimensional achromatic task, no matter how nonuniform the luminance surround. The present definition and use of background luminance can then be evaluated and modified as necessary.

The importance of accurately obtaining a value of background luminance will be realized when the CIE system is employed in lighting energy conservation programs and lighting design. These measures normally result in a reduction of light levels by a factor of two or three from current practice. Precision is important, therefore, in establishing the value of this crucial factor. The CIE system separates the effects of background luminance and surround luminance on adaptation by referring only to the former as an effect of adaptation, and to the latter as a disability glare effect or a transient adaptation effect. These effects are then considered separately.

CIE visual performance system

The CIE system is explained in full in reference 2 and in more condensed forms in references 5 and 6. Only those aspects relevant to the present method will be discussed in this paper. Standardized refer-

Figure 2. Relative contrast sensitivity reference function of luminance.



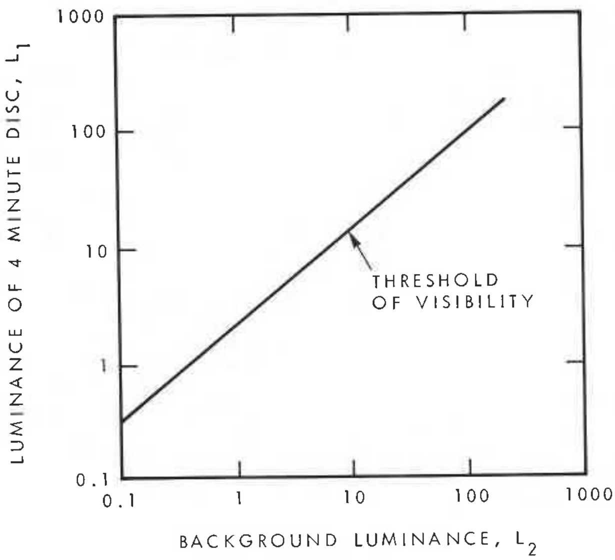


Figure 3. Luminance of the visibility reference task as a function of background reference luminance.

ence conditions are an essential feature of the CIE system, the philosophy being that if one starts with a set of reference conditions that can be described fully, then other conditions may be compared with that set.

Reference lighting that is easy to specify and reproduce was chosen—integrating sphere illumination where the illuminance is diffuse and unpolarized and the task surround is of uniform luminance. The visibility reference task is a four-minute luminous disc in a uniform background, presented for ⅕-second exposure under reference lighting conditions; the informational criterion is detection of presence of a contrast in a known position in the visual field. The reference population of observers used to collect the visual performance data comprised approximately one hundred 20 to 30 year old observers with normal vision.

If a psychophysical experiment is performed to find the minimum contrast (threshold contrast) of a given task that can be detected as a function of the uniform background luminance, the data will fall on a curve such as that presented in Fig. 1. The curve demonstrates that as background luminance is increased the ability to see tasks of low contrast is progressively improved. If the curve is inverted so that the reciprocal of threshold contrast, namely contrast sensitivity, is on the ordinate, then the curve demonstrates that as luminous power is increased the eye has a greater contrast sensitivity (Fig. 2). The relative contrast sensitivity reference function (*RCS* reference function) is the curve obtained using the reference population of observers viewing the visibility reference task under reference lighting conditions (Fig. 2). The curve is normalized to unity at 100 candelas per square meter.

The *RCS* reference function demonstrates a fundamental property of the visual mechanism. Contrast sensitivity increases with increasing luminance, but in a nonlinear fashion. This function is crucial to both the CIE system and the method of measuring background luminance described here.

Method

Central to the method proposed is the use of the curve illustrated in Fig. 3. Here the luminance, L_1, of the four-minute disc at threshold visibility is plotted versus the background or adaptation luminance, L_2, under reference lighting conditions. The curve is readily obtained from tabulated values of the *RCS* reference function.[4]

If C_1 is the threshold contrast of the four-minute disc, then

$$C_1 = \frac{L_1 - L_2}{L_2} \tag{1}$$

or

$$L_1 = L_2(C_1 + 1) \tag{2}$$

Now C_1 can be obtained from the *RCS* function, knowing the normalization factor,[5]

$$C_1 = \frac{0.0923}{RCS} \tag{3}$$

Therefore

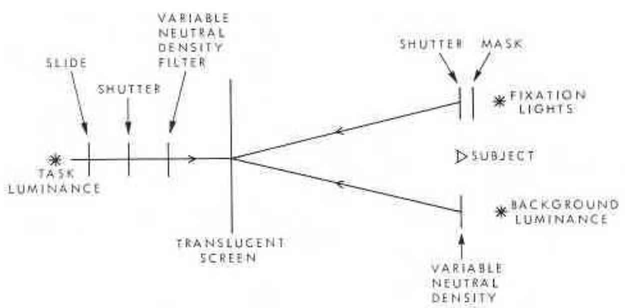
$$L_1 = L_2\left(\frac{0.0923}{RCS} + 1\right) \tag{4}$$

The curve in Fig. 3 shows the unique relation that exists between L_1 and L_2 for threshold visibility of a four-minute disc under reference lighting. To determine the background luminance when a subject views any two-dimensional achromatic task, the following experimental design and procedure can be adopted.

Two methods are proposed for performing the background luminance experiments (see Figs. 4 and 5). Method A provides the means for determining the value of the changes in background luminance when the nonuniformity of background field luminance surrounding the four-minute disc is systematically increased. Method B can be employed for actual tasks of interest. The principles of method A are illustrated in Fig. 4.

A transparency of the entire task (*e.g.*, a uniform pattern or a handwritten or typed sheet of paper) is projected on a translucent screen at a luminance level characterized by the luminance of the paper sheet itself (*i.e.*, with no ink on it). (This luminance in the present CIE system is taken as the background luminance; it is the purpose of the experiment to check the validity of this choice.) After the subject has been given sufficient time to adapt to the entire task of

Figure 4. Experimental method A.



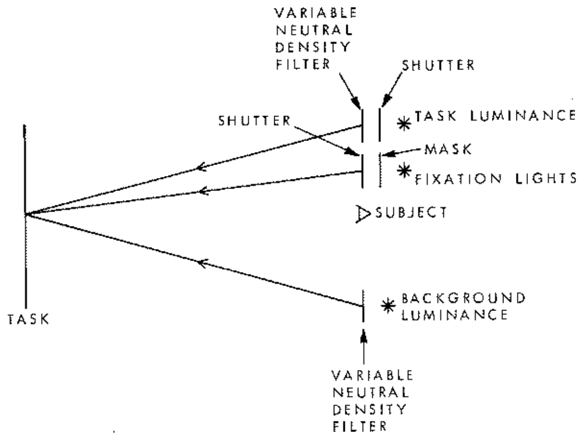


Figure 5. Experimental method B.

interest, a 1/5-second exposure of the four-minute disc is superimposed on the task itself (method B) or on its image on a screen (method A) and the threshold luminance of the disc determined by adjusting its luminance. The threshold luminance L_1 [defined in Equation (4)] will be the luminance value that is obtained when the four-minute disc is identified correctly in 50 percent of the trials. Either the "fixed-choice" or "staircase" psychophysical technique can be applied.

Fixation lights are presented before the onset of and during the presentation of the four-minute disc to act as a fixation and accommodation cue. The fixation lights will have a higher visibility than any other detail in the field of view. L_1 can be entered on the ordinate of Fig. 4, and L_2, the effective background luminance, read off from the abscissa. It is suggested that L_2 or some modified value of it, depending on the actual task in question, be used as the background luminance in all operations carried out in the CIE system. For method B the task of interest itself is used as the screen. The four-minute disc is presented periodically in the apparatus illustrated in Fig. 5.

In both methods the background luminance is determined by reference to threshold contrast of the four-minute disc (the visibility reference task) under reference lighting conditions. The effective background luminance is the luminance of the background of the visibility reference task (four-minute disc) under reference lighting that would give the same level of background luminance as occurs with the actual task under actual lighting conditions.

Any factors that affect contrast sensitivity will alter the value of effective background luminance. In a properly designed experiment the disability glare factor and transient adaptation factor can be eliminated. With transillumination (back-projection) and use of a suitable material for the screen, the contrast rendering factor (*CRF*) should be close to unity in method A. As method B, however, employs the actual task as the screen and reflected light, it could be expected that there will be some veiling reflection present and the *CRF* could differ from unity. This may be minimized by deploying the light source illuminating the screen in such a geometry so as to keep the *CRF* close to unity.

The importance of luminance nonuniformities in relation to background luminance can be examined in a systematic fashion. For each separate trial the position at which the disc appears can be altered. In a controlled fashion, the disc will appear in an area relatively free of print and then in areas with a greater density of print.

Discussion

Other methods of determining adaptation luminance (which has been called background luminance) that also use the technique of comparison with a set of reference or standard conditions have been described.[7,8] The state of adaptation is characterized by the time required to reach dark adaptation in one instance, and in the other by determining the luminance that is just distinguishable from subjective black. For the generally short viewing time involved in looking at typical written and printed tasks it would be rather impracticable to measure adaptation luminance by these methods, and in any case there is no reason to assume that they correctly measure the most relevant background luminance. The method described in this paper ought to be more appropriate for use with the CIE system. It uses the very concepts and ideas embodied in that same system.

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