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COMMISSION INTERNATIONALE DE L'ECLAIRAGE
INTERNATIONAL COMMISSION ON ILLUMINATION
INTERNATIONALE BELEUCHTUNGSKOMMISSION

CIE COLLECTION on GLARE

2002

Contents:

146 CIE TC 1-50 report: CIE equations for disability glare

147 CIE TC 3-01 report: Glare from small, large and complex sources

Abstracts of CIE Publications related to glare

CIE 146:2002

CIE 147:2002

UDC: 612.84

Descriptor: Vision

THE INTERNATIONAL COMMISSION ON ILLUMINATION

The International Commission on Illumination (CIE) is an organisation devoted to international co-operation and exchange of information among its member countries on all matters relating to the art and science of lighting. Its membership consists of the National Committees in 37 countries and one geographical area and of 9 associate members.

The objectives of the CIE are :

1. To provide an international forum for the discussion of all matters relating to the science, technology and art in the fields of light and lighting and for the interchange of information in these fields between countries.
2. To develop basic standards and procedures of metrology in the fields of light and lighting.
3. To provide guidance in the application of principles and procedures in the development of international and national standards in the fields of light and lighting.
4. To prepare and publish standards, reports and other publications concerned with all matters relating to the science, technology and art in the fields of light and lighting.
5. To maintain liaison and technical interaction with other international organisations concerned with matters related to the science, technology, standardisation and art in the fields of light and lighting.

The work of the CIE is carried on by seven Divisions each with about 20 Technical Committees. This work covers subjects ranging from fundamental matters to all types of lighting applications. The standards and technical reports developed by these international Divisions of the CIE are accepted throughout the world.

A plenary session is held every four years at which the work of the Divisions and Technical Committees is reviewed, reported and plans are made for the future. The CIE is recognised as the authority on all aspects of light and lighting. As such it occupies an important position among international organisations.

LA COMMISSION INTERNATIONALE DE L'ECLAIRAGE

La Commission Internationale de l'Eclairage (CIE) est une organisation qui se donne pour but la coopération internationale et l'échange d'informations entre les Pays membres sur toutes les questions relatives à l'art et à la science de l'éclairage. Elle est composée de Comités Nationaux représentant 37 pays plus un territoire géographique, et de 9 membres associés.

Les objectifs de la CIE sont :

6. De constituer un centre d'étude international pour toute matière relevant de la science, de la technologie et de l'art de la lumière et de l'éclairage et pour l'échange entre pays d'informations dans ces domaines.
7. D'élaborer des normes et des méthodes de base pour la métrologie dans les domaines de la lumière et de l'éclairage.
8. De donner des directives pour l'application des principes et des méthodes d'élaboration de normes internationales et nationales dans les domaines de la lumière et de l'éclairage.
9. De préparer et publier des normes, rapports et autres textes, concernant toutes matières relatives à la science, la technologie et l'art dans les domaines de la lumière et de l'éclairage.
10. De maintenir une liaison et une collaboration technique avec les autres organisations internationales concernées par des sujets relatifs à la science, la technologie, la normalisation et l'art dans les domaines de la lumière et de l'éclairage.

Les travaux de la CIE sont effectués par 7 Divisions, ayant chacune environ 20 Comités Techniques. Les sujets d'études s'étendent des questions fondamentales, à tous les types d'applications de l'éclairage. Les normes et les rapports techniques élaborés par ces Divisions Internationales de la CIE sont reconnus dans le monde entier.

Tous les quatre ans, une Session plénière passe en revue le travail des Divisions et des Comités Techniques, en fait rapport et établit les projets de travaux pour l'avenir. La CIE est reconnue comme la plus haute autorité en ce qui concerne tous les aspects de la lumière et de l'éclairage. Elle occupe comme telle une position importante parmi les organisations internationales.

DIE INTERNATIONALE BELEUCHTUNGSKOMMISSION

Die Internationale Beleuchtungskommission (CIE) ist eine Organisation, die sich der internationalen Zusammenarbeit und dem Austausch von Informationen zwischen ihren Mitgliedsländern bezüglich der Kunst und Wissenschaft der Lichttechnik widmet. Die Mitgliedschaft besteht aus den Nationalen Komitees in 37 Ländern und einem geographischen Gebiet und aus 9 assoziierten Mitgliedern.

Die Ziele der CIE sind :

11. Ein internationaler Mittelpunkt für Diskussionen aller Fragen auf dem Gebiet der Wissenschaft, Technik und Kunst der Lichttechnik und für den Informationsaustausch auf diesen Gebieten zwischen den einzelnen Ländern zu sein.
12. Grundnormen und Verfahren der Meßtechnik auf dem Gebiet der Lichttechnik zu entwickeln.
13. Richtlinien für die Anwendung von Prinzipien und Vorgängen in der Entwicklung internationaler und nationaler Normen auf dem Gebiet der Lichttechnik zu erstellen.
14. Normen, Berichte und andere Publikationen zu erstellen und zu veröffentlichen, die alle Fragen auf dem Gebiet der Wissenschaft, Technik und Kunst der Lichttechnik betreffen.
15. Liaison und technische Zusammenarbeit mit anderen internationalen Organisationen zu unterhalten, die mit Fragen der Wissenschaft, Technik, Normung und Kunst auf dem Gebiet der Lichttechnik zu tun haben.

Die Arbeit der CIE wird in 7 Divisionen, jede mit etwa 20 Technischen Komitees, geleistet. Diese Arbeit betrifft Gebiete mit grundlegendem Inhalt bis zu allen Arten der Lichtanwendung. Die Normen und Technischen Berichte, die von diesen international zusammengesetzten Divisionen ausgearbeitet werden, sind von der ganzen Welt anerkannt.

Tagungen werden alle vier Jahre abgehalten, in der die Arbeiten der Divisionen überprüft und berichtet und neue Pläne für die Zukunft ausgearbeitet werden. Die CIE wird als höchste Autorität für alle Aspekte des Lichtes und der Beleuchtung angesehen. Auf diese Weise unterhält sie eine bedeutende Stellung unter den internationalen Organisationen.

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The Reports in this publication have been prepared by CIE Technical Committees within Division 1 "Vision and Colour" and Division 3 "Interior Environment and Lighting Design". The reports draw on current knowledge and experience within the specific field of light and lighting described, and are intended to be used by the CIE membership and other interested parties. It should be noted, however, that the status of the reports is advisory and not mandatory. The latest CIE proceedings, CIE NEWS, future issues in the "CIE Collection" Series or publication listing should be consulted regarding possible subsequent amendments.

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CIE TC 1-50 REPORT**CIE EQUATIONS FOR DISABILITY GLARE**

The following members of CIE TC 1-50 “Disability glare formula” took part in the preparation of this report. The committee comes under CIE Division 1, “Vision and Colour”.

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CIE EQUATIONS FOR DISABILITY GLARE

SUMMARY

Three disability glare equations have been defined to extend the classic Stiles-Holladay equation to take account of the effect of age, the effect of ocular pigmentation and to extend the angular domain over which the equations are valid. They all describe the veiling luminance L_{veil} (in cd/m^2) due to a point glare source at an angle θ (in degrees) to the line of sight that gives rise to an illuminance E_{glare} (in lx) in the plane of the observer's eye, and they do so with adequate accuracy within their respective validity domains.

The CIE Age-adjusted Stiles-Holladay Disability Glare equation has a restricted validity domain of $1^\circ < \theta < 30^\circ$ that is extended in the low angular region by the CIE Small Angle Disability Glare equation to the domain of $0,1^\circ < \theta < 30^\circ$. The CIE General Disability Glare equation further increases the validity domain to the range of $0,1^\circ < \theta < 100^\circ$ and also includes an eye pigmentation factor p which plays a role at glare angles greater than 30° . They all include age A (in years) as a factor.

FORMULES CIE POUR L'EBLOUISSEMENT D'INCAPACITE

RESUME

Trois formules pour l'éblouissement d'incapacité ont été définies pour étendre le domaine de la formule classique de Stiles-Holladay en prenant en compte l'effet de l'âge, l'effet de la pigmentation oculaire et pour accroître le domaine angulaire dans lequel la formule est valide. Elles donnent toutes la luminance de voile L_{veil} (en cd/m^2) due à une source ponctuelle, éblouissante, située à une distance angulaire θ (en degrés) de la ligne de vision, en produisant un éclairement E_{glare} (en lx) dans le plan de l'œil de l'observateur. Ce résultat est obtenu avec une précision convenable pour leurs domaines respectifs de validité.

La formule CIE d'éblouissement d'incapacité de Stiles-Holladay avec une correction d'âge possède un domaine de validité limité de $1^\circ < \theta < 30^\circ$, lequel est accru dans le domaine des faibles valeurs angulaires de $0,1^\circ < \theta < 30^\circ$ par la formule CIE d'éblouissement d'incapacité aux petits angles. La formule générale CIE d'éblouissement d'incapacité augmente encore le domaine angulaire de validité de $0,1^\circ < \theta < 100^\circ$ et comprend un facteur p de pigmentation oculaire qui joue un rôle aux angles d'éblouissement supérieurs à 30° . Toutes les formules comprennent l'âge A (en années) comme facteur.

CIE GLEICHUNGEN ZUR PHYSIOLOGISCHEN BLENDUNG

ZUSAMMENFASSUNG

In Erweiterung der "klassischen" Stiles-Holladay Gleichung zur Beschreibung der physiologischen Blendung werden drei Beziehungen formuliert, die den Einfluß des Alters, den Einfluß der okularen Pigmentierung und die Erweiterung des Blendwinkel-Bereiches beinhalten.

Diese Gleichungen spezifizieren die sog. Schleierleuchtdichte L_{veil} (in cd/m^2), die durch eine punktförmige Lichtquelle im Winkelabstand θ (in Grad) zur Blickrichtung bei einer Beleuchtungsstärke E_{glare} (in lx) in der Ebene des Beobachterauges verursacht wird. Sie gelten innerhalb ihrer jeweiligen Definitionsbereiche mit adäquater Genauigkeit.

Die "altersangepaßte" Stiles-Holladay Formel der CIE gilt im Winkelbereich $1^\circ < \theta < 30^\circ$. Dieser Bereich wird durch die "Kleinwinkel-Formel" der CIE auf $0,1^\circ < \theta < 30^\circ$ ausgedehnt. Die "Allgemeine CIE Gleichung zur physiologischen Blendung" erweitert den Blendwinkelbereich nochmals auf $0,1^\circ < \theta < 100^\circ$ und enthält darüber hinaus einen okularen Pigmentierungsfaktor p , der für $\theta > 30^\circ$ relevant wird. In jeder dieser drei Gleichungen tritt das Alter A (in Jahren) als Faktor auf.

INTRODUCTION

Disability glare is glare that impairs vision (CIE, 1987). It is caused by scattering of light inside the eye because of the imperfect transparency of the optical components of the eye, and to a lesser extent by diffuse light passing through the scleral wall or the iris (Van den Berg et al., 1991). The scattered light overlays the retinal image of objects reducing the contrast of the retinal image. This overlying scattered light is usually described as a veiling luminance (L_{veil}) because the effect is not dissimilar to viewing through a net curtain.

The veiling luminance of scattered light will have a significant effect on visibility when intense light sources are present in the peripheral visual field and the contrast of the objects to be seen is low. The reduction of contrast caused by the veiling luminance may cause the contrast of an object to fall below threshold so that the object is not seen, or the contrast to be reduced to near threshold so that the target object is difficult to see. Disability glare is most often of importance at night when contrast sensitivity is low and there may well be one or more bright light sources near to the line of sight, such as car headlights, streetlights or floodlights. But even in daylight conditions disability glare may be of practical significance: think of traffic lights when the sun is close to them, or the difficulty viewing paintings hanging next to windows.

Disability glare must be distinguished from discomfort glare, which refers to the irritating and distracting, but not necessarily impairing effects of bright sources in the peripheral visual field. This report deals with disability glare only. It should further be noted that, in addition to the intraocular light veil, there might be an extraocular light veil due to scattering in the atmosphere, by condensation, rain, dirt or scratches on the windscreens of cars or on spectacle lenses. The veiling luminance due to this extraocular straylight adds to the intraocular veiling luminance (Vos and Padmos, 1983), but this additional source of disability glare is not considered in this report.

The magnitude of the veiling luminance depends on the intensity and distance of the glare source which together determine the relevant parameter E_{glare} , the illuminance at the eye caused by the glare source, and the angle between the glare source and the line of sight θ (Fig. 1.).

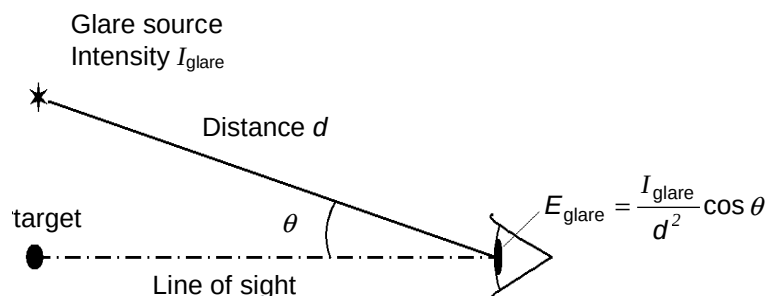


Fig. 1. Geometry in glare situations with a point glare source and a point target to be viewed.

Holladay (1926, 1927), Stiles (1929, 1930) and Stiles and Crawford (1937) provided the foundation for a well-defined knowledge of disability glare. Their results were brought to the meeting of the CIE in 1939 at Scheveningen, and an empirical description of disability glare was launched (CIE, 1942) which, although never formally adopted by the CIE, was destined to become widely accepted and used to quantify disability glare. The formula, generally described as the Stiles-Holladay disability glare formula (for point sources), reads

$$\frac{L_{\text{veil}}}{E_{\text{glare}}} = \frac{10}{\theta^2} \quad (1)$$

with L_{veil} the veiling luminance in cd/m^2 , E_{glare} the illuminance at the eye due to the glare light in lux^1 , and θ the angle between the direction of the glare source and the direction of the

¹ Consequently, the unit of $L_{\text{veil}} / E_{\text{glare}}$ is $(\text{cd/m}^2) / \text{lx} = [\text{lm} / (\text{sr} \cdot \text{m}^2)] / (\text{lm} / \text{m}^2) = 1/\text{sr}$.

target in degrees. The illuminance on the eye depends on the luminous intensity of the source (I_{glare}) in cd, the distance of the source to the eye (d) in m and the angle of incidence of the glare light on the plane of the pupil (φ), such that²

$$E_{\text{glare}} = \frac{I_{\text{glare}} \cos \varphi}{d^2} \approx \frac{I_{\text{glare}} \cos \theta}{d^2} \quad (2)$$

The Stiles-Holladay equation has served the lighting community well for more than 60 years, even though limitations on its validity were well known. These limitations include its divergence at $\theta = 0$, which limits its validity to glare angles that are not too small, and its failure to account for evident age effects.

In view of these known limitations and the lack of formal status of the Stiles-Holladay relation, the CIE set out to further develop the Stiles-Holladay relation to define a CIE Disability Glare Equation with wider validity. The result is given in this report.

This report will be concise, concentrating on main arguments and results. It has a long genesis, though, which can be found in four subsequent reports to the CIE community. The first report (Vos, 1984) sets out the starting point for the revision of the glare equations and the second (CIE, 1997) provides the scientific foundation. The third (Vos, 1999) is a review of the history of understanding glare and the fourth (CIE, 1999) develops the new equations that are set out in this report.

SCIENTIFIC BASIS FOR UNDERSTANDING DISABILITY GLARE

Many investigators (see Vos, 1984 for an extensive bibliography) have determined $L_{\text{veil}}/E_{\text{glare}}$ as a function of θ in various parts of the angular domain, using photometric techniques. Fig. 2. summarises these empirical results.

The straight heavy line in Fig. 2. is the Stiles-Holladay relation, which serves as a reference. The figure shows that the Stiles-Holladay relation describes the empirical results (the thin lines) quite well in the main angular glare domain, between 1° and 30° , but that marked deviations occur outside these angular limits. The curved heavy line corresponds to the full range disability glare equation derived by Vos and Van den Berg (CIE, 1997). It is based on the average course of the thin lines, but in addition on three other considerations:

1. the course at very small angles – i.e. outside any practical glare angle domain – is taken from Campbell and Green's (1965) modulation transfer data. These show, of course, that the point spread function, by which name the glare function is better known in the minutes of arc range, bends to a maximum at 0° .
2. from measurements by Van den Berg et al. (1991) we know that diffuse light passing through the ocular wall sets a bottom-line, as indicated here by a horizontal dotted line.
3. in particular in the large angle domain, where experimental data are scarce, theoretical considerations based on the mechanisms of intraocular scatter, have helped in extrapolating.

² For all practical purposes φ may be equated to θ . Only for values of φ over 45° significant deviations from $\cos \varphi = \cos \theta$ occur, due to the refractive properties of the cornea (Vos and Van den Berg, 1997). So, for $\cos \varphi$ one should use then instead the more accurate but more complicated version $\cos [0,92 (\theta - 5)]$.

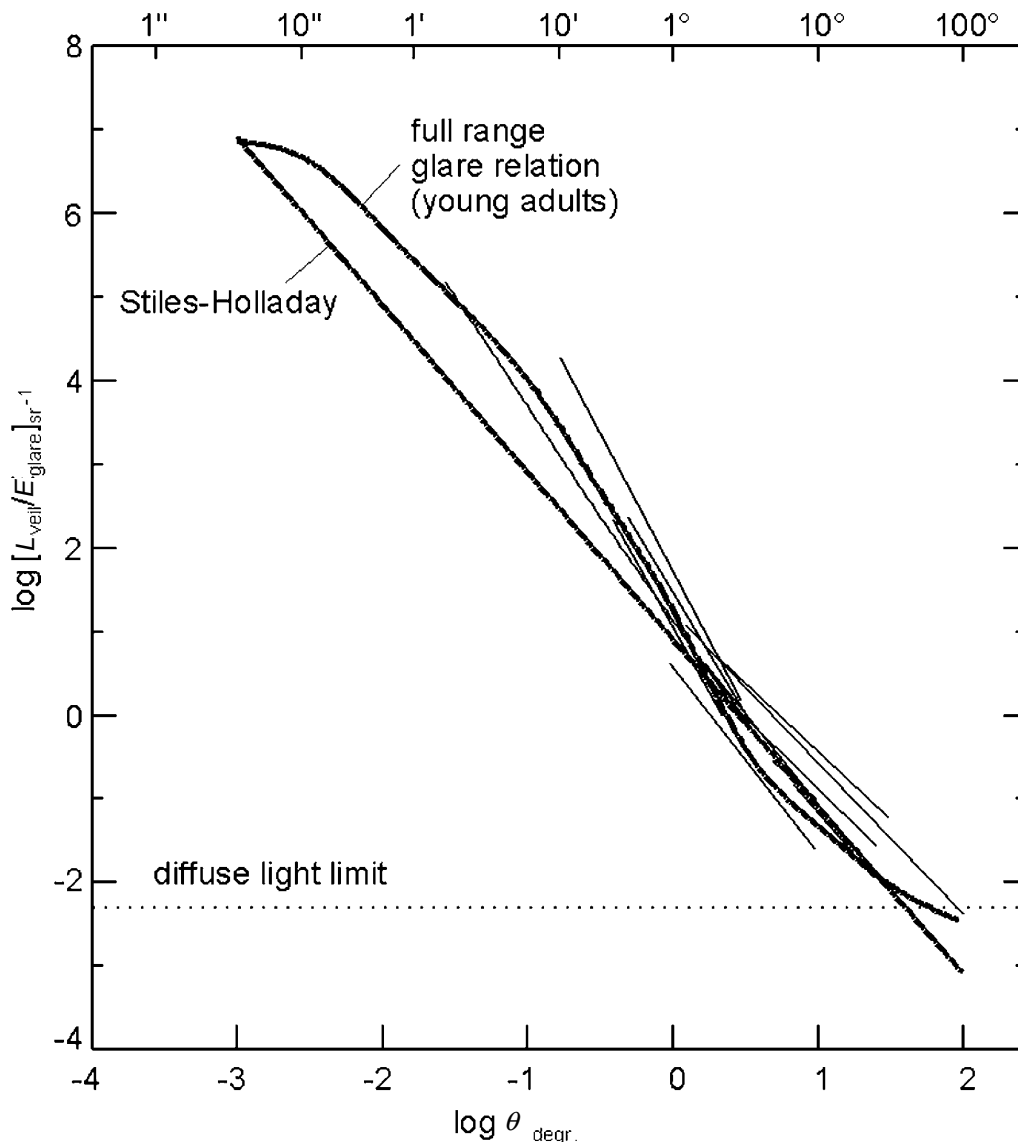


Fig. 2. Disability glare relations for point sources for mainly young adult caucasian subjects. Thin lines: experimental data from literature (Vos, 1984 and CIE, 1997). Heavy straight line: the Stiles-Holladay relation $L_{\text{veil}} / E_{\text{glare}} = 10 / \theta^2$, here drawn over the full angular range. Curved heavy line: full range glare relation for young adults (CIE, 1997). Dotted line: diffuse light limit, set by diffuse light through the ocular wall. (For the unit sr^{-1} see footnote 1. p. 3.)

Though information on the characteristics of the experimental subjects used in these glare investigations is seldom given, it can be safely assumed that most experimental data were obtained with young caucasian adults. Reliable data on the dependence of disability glare on age and on ocular pigmentation have come available only recently, and only in a rather restricted glare angle domain (Van den Berg et al., 1991; Van den Berg, 1995). Extrapolation to other glare angles therefore necessarily rests on theoretical arguments (CIE, 1997). The committee feels justified, though, to endorse the generalised course of the full range glare equation, as illustrated in Fig. 3. for a few age-pigmentation combinations. The plot shows a fanning out at large glare angles due to differences in eye pigmentation, and an upward shift in the 1° to 30° range due to age. We do not give here the describing formula as derived in CIE, 1997 as it is rather complicated and not useful as such in practical lighting calculations. However, the observation that the effects of pigmentation remain restricted to the large angle domain and the effects of age to the middle angle domain, mainly, together with the indicated spread due to individual differences, allows for a definition of simplified formulae in restricted glare domains. This is developed further in the next section.

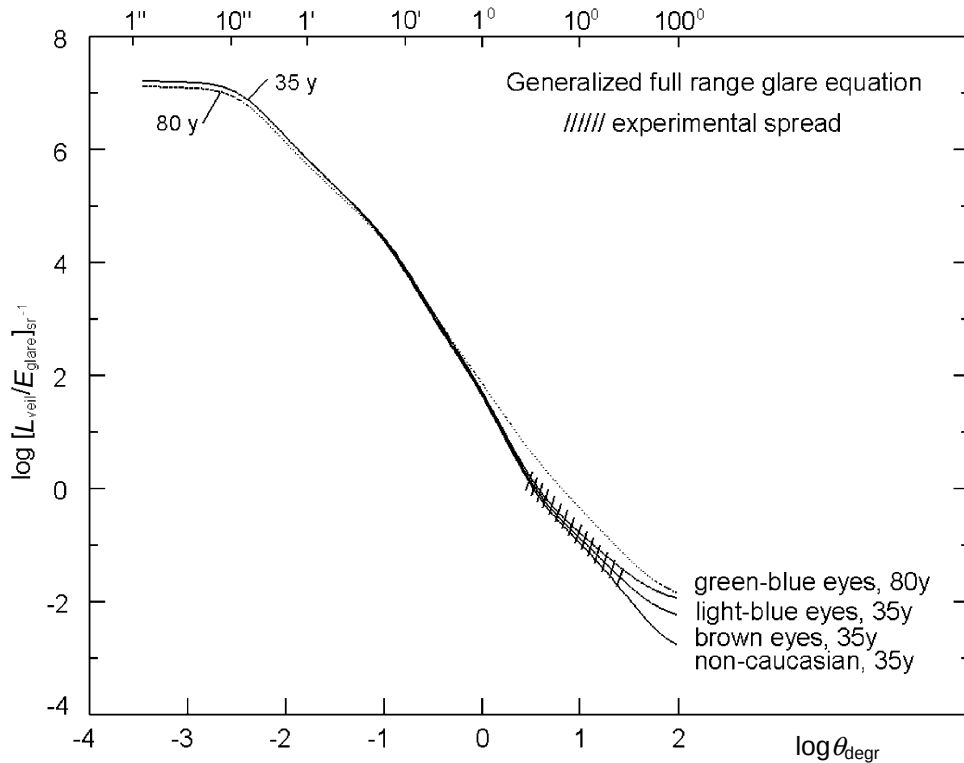


Fig. 3. Generalisation of the full range disability glare relation, here specified for two age groups and for different degrees of ocular pigmentation. The hatched zone indicates the extent of individual differences for IJspeert et al.'s (1990) 129 subjects. (For the unit sr^{-1} see footnote 1. p. 3.)

In the treatment thus far, wavelength of light has not been considered because it plays a very minor role in glare problems (see, e.g. Wooten and Geri, 1987). The following proposed CIE equations can therefore be taken to hold regardless of the spectral composition of the glare source light.

PRACTICAL DISABILITY GLARE EQUATIONS

Three versions of the disability equation will be presented. The first one is the most simple one, and therefore valid – i.e. with an accuracy compatible with the individual variability – in a restricted angular domain, $1^\circ < \theta < 30^\circ$. The second one is a bit more complicated, but has a more extended validity domain, $0,1^\circ < \theta < 30^\circ$. The last one, finally, covers the most complete angular domain, $0,1^\circ < \theta < 100^\circ$. It should be noted that the last equation, the CIE General Disability Glare Equation, is the obvious choice in computer calculations. The other formulae are just handy approximate versions in restricted angular ranges.

CIE Age-Adjusted Stiles-Holladay Disability Glare Equation

In the angular domain between 1° and 30° the angular dependence follows the Stiles-Holladay relation. The fanning out due to differences in ocular pigmentation is not important in this angular domain. Consequently the only addition to the Stiles-Holladay equation we need to apply is the introduction of an age factor. This is derived from IJspeert et al.'s (1990) data as summarised in Fig. 4. It shows a virtual absence of the influence of age below 40 y, but a steep ascent beyond 70 y, and can reasonably be described by

$$\text{Age factor} = 1 + \left[\frac{A}{70} \right]^4 \quad (3)$$

where A is the age in years.