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

TECHNICAL REPORT

CIE GUIDE TO INCREASING ACCESSIBILITY IN LIGHT AND LIGHTING

Vision Data and Design Considerations for Better Visibility
and Lighting for Older People and People with Disabilities

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Descriptor: Colour contrast. Luminance contrast
Contrast. sensitivity
Visual acuity
Defects of colour vision

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4. 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.
5. 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.

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1. 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.
2. Grundnormen und Verfahren der Messtechnik auf dem Gebiet der Lichttechnik zu entwickeln.
3. Richtlinien für die Anwendung von Prinzipien und Vorgängen in der Entwicklung internationaler und nationaler Normen auf dem Gebiet der Lichttechnik zu erstellen.
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5. 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 auf der ganzen Welt anerkannt.

Alle vier Jahre findet eine Session statt, in der die Arbeiten der Divisionen überprüft, 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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COMMISSION INTERNATIONALE DE L'ECLAIRAGE
CIE Central Bureau
Kegelgasse 27, A-1030 Vienna, AUSTRIA
Tel: +43(1)714 31 87 0, Fax: +43(1)714 31 87 18
e-mail: ciecb@cie.co.at
WWW: <http://www.cie.co.at/>

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This Technical Report has been prepared by a Working Group (Ad-hoc) in the CIE Board of Administration in cooperation with TC 1-54 "Age-related change of visual response" and TC 3-44 "Lighting for the elderly" and has been approved by the Board of Administration of the Commission Internationale de l'Eclairage for study and application. The document reports on current knowledge and experience within the specific field of light and lighting described, and is intended to be used by the CIE membership and other interested parties. It should be noted, however, that the status of this document is advisory and not mandatory.

Ce rapport technique a été élaboré par un groupe de travail (Ad-hoc) du Conseil d'Administration de la CIE en coopération avec TC 1-54 "Age-related change of visual response" et TC 3-44 "Lighting for the elderly" et a été approuvé par le Conseil d'Administration de la Commission Internationale de l'Eclairage, pour étude et emploi. Le document expose les connaissances et l'expérience actuelles dans le domaine particulier de la lumière et de l'éclairage décrit ici. Il est destiné à être utilisé par les membres de la CIE et par tous les intéressés. Il faut cependant noter que ce document est indicatif et non obligatoire.

Dieser Technische Bericht ist durch eine Ad-hoc-Arbeitsgruppe des CIE-Vorstands in Zusammenarbeit mit TC 1-54 "Age-related change of visual response" und TC 3-44 "Lighting for the elderly" ausgearbeitet und vom Vorstand der Commission Internationale de l'Eclairage gebilligt worden. Das Dokument berichtet über den derzeitigen Stand des Wissens und Erfahrung in dem behandelten Gebiet von Licht und Beleuchtung; es ist zur Verwendung durch CIE-Mitglieder und durch andere Interessierte bestimmt. Es sollte jedoch beachtet werden, dass das Dokument eine Empfehlung und keine Vorschrift ist.

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The following members of the Working Group took part in the preparation of this Technical Report.

Members:

Ad-hoc Group of CIE Board of Administration:

F. Hengstberger	South Africa
N. Pollard	United Kingdom
K. Sagawa	Japan (Chair)

TC 1-54:

H. Bouma	The Netherlands
L. Halonen	Finland
W. Iwai	Japan
J. Werner	United States

TC 3-44:

G. Cook	United Kingdom
Y. Akashi	Japan

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CIE GUIDE TO INCREASING ACCESSIBILITY IN LIGHT AND LIGHTING

Summary

This guide was written for lighting designers and engineers, as well as scientists of light, colour, and vision to assist them in taking account of the needs of older persons and persons with disabilities. The guide was developed in accordance with ISO/IEC Guide 71:2001 "Guidelines for standard developers to address the needs of older persons and persons with disabilities" and its technical guidelines ISO/TR 22411:2008 "Ergonomics data and guidelines for the application of ISO/IEC Guide 71 to products and services to address the needs of older persons and persons with disabilities" in order to implement accessible design in the field of light and lighting. Some content has been shared with those two documents. The guide was prepared by a Working Group (Ad-hoc) in the CIE Board of Administration in cooperation with TC 1-54 "Age-related change of visual response" and TC 3-44 "Lighting for the elderly".

GUIDE CIE POUR L'AMELIORATION DES LUMIERES ET DE L'ECLAIRAGE

Résumé

Ce guide a été rédigé à l'intention des concepteurs en éclairage, des ingénieurs, aussi bien que des scientifiques du domaine de la lumière, de la couleur et de la vision, dans le but de prendre en compte les besoins des personnes âgées et des personnes handicapées. Le guide a été mis au point en respectant le Guide 71:2001 ISO/IEC "Principes directeurs pour les normalisateurs afin de répondre aux besoins des personnes âgées et de celles ayant des incapacités" et ses directives techniques ISO/TR 22411:2008 "Données d'ergonomie et lignes directrices pour l'application du Guide ISO/CEI 71 aux produits et services afin de répondre aux besoins des personnes âgées et de celles ayant des incapacités" de manière à favoriser une conception satisfaisante des lumières et des éclairages. Certaines parties sont communes avec celles de ces deux documents. Ce guide a été préparé par un groupe de travail (ad-hoc) du Conseil d'Administration de la CIE en coopération avec le TC 1-54 "Modification des réponses visuelles avec l'âge" et le TC 3-44 "Eclairage pour les personnes âgées".

CIE LEITFADEN ZUR VERBESSERUNG DER ZUGÄNGLICHKEIT DURCH LICHT UND BELEUCHTUNG

Zusammenfassung

Dieser Leitfaden wurde für Lichtplaner, Ingenieure und Wissenschaftler im Bereich Licht, Farbe und Sehen geschrieben, um die Bedürfnisse älterer Menschen und von Menschen mit Behinderungen zu berücksichtigen. Der Leitfaden wurde in Übereinstimmung mit ISO/IEC Guide 71:2001 "Guidelines for standard developers to address the needs of older persons and persons with disabilities" und seinen technischen Richtlinien ISO/TR 22411:2008 "Ergonomics data and guidelines for the application of ISO/IEC Guide 71 to products and services to address the needs of older persons and persons with disabilities" geschrieben, um eine behindertengerechte Planung im Bereich von Licht und Beleuchtung einzuführen. Einige Teile des Inhalts wurden mit diesen Dokumenten abgeglichen. Der Leitfaden wurde von einer Adhoc-Arbeitsgruppe innerhalb des CIE-Vorstands in Zusammenarbeit mit TC 1-54 "Age-related change of visual response" und TC 3-44 "Lighting for the elderly" erstellt.

Introduction

With the global increase in the proportion of older people in the population, and awareness of the rights of persons with disabilities, care for older persons and persons with disabilities is becoming a worldwide concern in governmental, social, and industrial affairs. This global movement reflects on international standards organizations, such as ISO, IEC, ITU, and CIE, in their development of international standards. The design concept that is inclusive of older persons and persons with disabilities as users of products, services, or environments is called Accessible Design, Accessibility or Inclusive Design.

This document provides guidelines for implementing accessible design into the light and lighting field, furthering the concepts addressed in ISO/IEC Guide 71 [1] for Standards design. As pointed out in the Guide 71, there are many factors to be considered in providing better lighting and visible signs that meet the needs of older persons and persons with disabilities. CIE has developed considerable expertise in light and lighting since its establishment in the early 20th century and is ideally placed to deliver the technical information on human visual abilities of older persons and persons with disabilities that are indispensable in assessing (visual) accessibility. This CIE Guide therefore provides extensive data on visual abilities and design considerations that are useful for writers of CIE standards and technical reports as well as lighting designers who wish to take into account the needs of older persons and persons with disabilities.

The data presented here have been selected from the literature using the criterion that statistical features and variabilities, individual or conditional, were available and based on a large number of samples. Methods of applying this data to lighting design have been presented where possible as formulae or tables to inform good practice.

This Guide is based on a number of technical documents relevant to accessible design in light and lighting. CIE Publication 123 “Low vision – Lighting needs for the partially-sighted” [2] is an excellent report with useful information concerning physiology and lighting needs for low vision. The ISO Technical Report ISO/TR 22411 [3] also contains relevant information for implementing accessible design into the lighting field. Some parts of those documents are directly cited in this Guide. Inevitably, due to the wide range of issues involved in accessible design, information is still missing, particularly on persons with disabilities. The information contained in this document is not exhaustive, and the collection of data and design considerations is ongoing.

1 Scope

This CIE Guide provides fundamental knowledge and data on vision of older people and people with disabilities, as well as design considerations based on that data, in order to facilitate consideration of the needs of older people and people with disabilities.

While there is no clear definition for “older people”, this Guide presents data that include samples taken mainly from people over 60 years old. In addition, the visual disabilities addressed are low vision and colour vision defects. Care for totally blind people is not considered as light and lighting issues have no relevance for them, although non-visual issues such as tactile or auditory information for increasing accessibility are vitally important.

2 Terms and Definitions

For terms and definitions concerning vision and lighting used in this document the International Lighting Vocabulary [4] applies.

For terms and definitions concerning accessible design ISO/IEC Guide 71 [1] and ISO/TR 22411 [3] apply.

3 General Remarks on Vision of Older People and People with Disabilities

The pathway of the human visual system extends from the retina of the eye to the central brain, and is finely structured and coordinated to detect light and to recognize the information conveyed by the light. As with other sensory organs the abilities of the visual system change with age both physiologically and behaviourally, which makes the visual environment perceived by older people different from that perceived by younger people.

In addition to the ageing effects, various types of impairments, inherent or acquired, may occur in the visual pathway, which also makes the perceived visual world different from that of people with no impairment. A variety of forms of difficulty in visual perception are caused by different types of impairments, and depend on the site in the visual pathway where the impairment occurs.

The differences in perceived visual environment between younger people with normal vision on the one hand, and older people or people with visual disabilities on the other hand, should be taken into account in designing lighting and the visual environment. In the following sections the change of the visual system as a function of age and of impairments is described.

3.1 Age-related Change of the Visual System

At the very early stage of visual information processing, the light transmittance of the ocular media of the eye change with age, which is due to the absorption and scattering of light caused by opacification of crystalline lens of the eye [5]. This reduces the total amount of light reaching the retina, and consequently lowers visibility for older people.

The absorption and scattering in the ocular media also depend on the spectrum of the light [6]. The absorption and scattering of light in the shorter wavelength band (coloured violet to bluish) has much more effect than that in the longer wavelength band (reddish), which means that a violet or bluish light has lower efficiency or visibility for older people. This also causes a shift of appearance of colour to the more yellowish region. It has been reported, however, that the macular pigment, which covers the central part of the retina, has no change in its density with ageing [7].

There is also an ageing effect in the pupil reaction to light. The size of the pupil becomes smaller in general with age, and consequently the amount of light incident on the retina decreases with increasing age. This is particularly true for lower ambient lighting conditions where the pupil normally opens wider to collect light. Under conditions of dark adaptation, the pupil diameter of older people becomes smaller by 2,0 mm to 2,5 mm on average compared to that of younger people with normal vision, which reduces the light level approximately by one half to one fourth compared with younger people [8].

At the retinal level, the number of photoreceptors, in particular of rods, decreases with age [9]. In addition to this, the number of ganglion cells in the retina decreases with age. One of the effects caused by the decrease of the ganglion cells is the reduced visual field of older people. As the ganglion cells mainly convey the temporal changes of light signals, the reduction of the number of these cells makes visual information less sensitive to detecting flashing or flickering lights.

Similarly, the number of neurons responsible for visual information processing in the central part of the brain decreases with age. The effect of ageing at this central level has not been well documented. Some reports point out the existence of mechanisms for compensating for the decreases of visual sensitivity or reduced functions occurring in earlier stages of the visual pathway [10].

3.2 Low Vision

Low vision refers to the deterioration of visual function due to disease or injuries, which often last for the remaining life span and cannot be corrected with the best-corrective eye glasses. There is a large variety of visual impairments that result in reduced visual functions of different types. A number of diverse opinions exist in the literature on the terminology and classification of the reduced visual functions associated with low vision. CIE 123 addresses these issues [2].

According to medical classification of low vision there are five major types of impairment. These are macular degeneration, retinitis pigmentosa, cataract, glaucoma and diabetic retinopathy which between them account for about 70 % of low vision cases globally. A restricted visual field is one of the most typical problems caused by these impairments. Some patients have available vision only in the centrally limited visual field, some only in the peripheral field, and some others in a number of locally available small fields. Note that a low vision patient who has a visual field restricted to a small central area of the retina, will have associated reduced colour vision, or reduced spatial vision (e.g. reading task), even if in tests, which are usually carried out in the small central area, the results indicate a good visual acuity and colour vision.

3.3 Colour Vision Defects

Defective colour vision is an anomaly of vision in which there is a reduced ability to discriminate between some or all colours [4]. Congenital colour vision deficiency is brought about by the loss of one or two types of photoreceptors among the three normal classes of cone photoreceptors, the short-, middle-, and long-wave sensitive cones. According to the classification of the defects in terms of the photoreceptors, two major classes of colour vision defects exist, protan and deutan. There are two types of protan defect: protanopia in which there is a lack of the long-wave sensitive photoreceptors; and protanomaly in which there is a shift of the absorption spectrum toward either longer or shorter wavelength region relative to the normal position of the long-wave cones along with the wavelength axis. Similarly, the deutan defects are deuteranopia and deuteranomaly, the former with a lack of the middle-wave sensitive cones, and the latter with a shift of the absorption spectrum of the middle-wave cones [11].

Depending on the type of defect and also on race, approximately 5 % to 8 % of the population are affected by protan and deutan defects. There is a third type of colour vision defect called tritan, which includes tritanopia and tritanomaly and affects short-wave sensitive cones. The

incidence of this type of defect is so rare that it is estimated that only 0,002 % to 0,007 % of the population are affected.

Protan and deutan are called the red-green defects because the disorder of colour vision appears on the red-green axis in the chromaticity diagram, implying that some combinations of green and red lights can not be discriminated by the persons affected. Tritan is assigned as the yellow-blue defect with a disorder on the yellow-blue axis. None of these congenital defects of colour vision are associated with a loss in visual acuity or on rod receptors which operate at a very low illuminance level.

Acquired colour vision defects are the defects associated with diseases or injuries not only at the retinal level but also at the central level. A similar classification to that of congenital defects applies to the acquired defects, though it is rare that only one type of photoreceptor is impaired. Usually, two, or all three, types of photoreceptors are impaired. Various types of acquired colour vision defects are observed.

4 Design Considerations for Accessibility in Visual Signs and Lighting

This section contains basic design considerations for visual signs and lighting to increase accessibility. Contents were primarily taken from ISO/TR 22411 [3], together with additional information regarding light and lighting.

4.1 Luminance and Colour

4.1.1 Luminance Contrast

Contrast of luminance is one of the most critical factors for visibility. In general, higher contrast produces better visibility. Public signs or information displays should be of sufficiently high contrast for older people and for those with low vision to see them clearly. The visual sensitivity to contrast decreases with age, mainly due to the light scattering effect in the eye. For people with low vision, the sensitivity to contrast is much lower than that of older people due to various types of visual impairments, such as cataract, and the perceived contrast of those with low vision is, therefore, considerably reduced. For quantitative evaluation of contrast, the contrast sensitivity function (CSF), the fundamental property of human spatial vision, is used. The data on CSF for older people and for those with low vision are presented in 5.4 and 5.8 respectively.

Contrast is usually referred to achromatic patterns unless otherwise specified. Where coloured lights are concerned such as in electronic visual displays, for example, effective luminance of the coloured lights may change with age due to the spectral sensitivity change of the eye, and this should be taken into account in calculating contrast. Estimation of the effective luminance for any coloured light for a person at any age is described in 5.1.

It should be noted that extremely high contrast may cause glare for older people and for those with low vision, and care should be taken to avoid this.

4.1.2 Appearance of Colour

Colour is used as a way of marking or drawing attention to objects or light sources. Since appearance of colour differs with age and also with visual disabilities, such as colour deficiency or low vision, those differences should be taken into account in the choice of colour or colour combinations. Appearance of colour also changes with the luminance level, particularly in the mesopic range. Care should be taken in choosing colours for use in a low luminance condition. For example, due to the Purkinje effect, as the luminance level decreases a reddish colour looks relatively darker, while a bluish colour looks brighter. Thus visual signs in deep red should not be used at night as they may not be seen.

A typical example of a change in colour appearance for older people is the fact that a bluish colour looks relatively darker compared with its appearance to younger people, due to the absorption of the short-wavelength (bluish) component of light in the eye of older people. Consequently, letters coloured blue become difficult to see for older people when presented, for example, on a dark background. Another example is the effect of white colour looking yellowish to older people following yellowing of the lens due to the absorption of bluish light, which makes colour discrimination worse between white and yellow in particular. However, colour adaptation may occur under certain viewing conditions, and changes in the appearance of colour of objects may not be that obvious [45].

For people with colour vision defects, some colour combinations among reddish and greenish colours may be confusing depending on the chromaticity and luminance ratio as described in 3.3. Appearance of colour for a person with low vision is considerably different from that of a person with full vision the extent of which largely depends on the type of impairments.

The Purkinje effect is not limited to older people and people with visual impairments. It occurs generally at lower luminance levels, namely below a few $\text{cd}\cdot\text{m}^{-2}$ or about 10 lx, in which a bluish colour looks relatively brighter, and by comparison, reddish colours, darker. Furthermore, colours gradually become more desaturated as luminance decreases.

It should be noted that only giving information through the use of differences of colours should be avoided for those who have reduced colour vision mentioned previously. Other sensory information such as tactile information or other non-colour visual information such as symbols or letters should accompany the information.

The following can apply to the practical use and choice of colour to increase accessibility in visual signs and displays.

- It is advisable to avoid the use of too many colours.
- Blue should be used in higher luminance or higher illumination environments for older people than for younger people.
- The colour combination of green-red should be used with significant luminance contrast for people with colour vision defects.
- Care should be taken with respect to people with low vision who have reduced ability to discriminate and identify colours e.g. use of colour combinations with a fairly large colour difference, i.e. red-blue or green-purple (see 5.8.2).

4.1.3 Colour Combination

Colour combination is a useful tool for identifying and discriminating objects. As described in 4.1.2, appearance of colour changes with age, type of visual impairments, as well as luminance level. These changes should be taken into account in creating colour combinations for improved visibility.

A conventional method of colour combination is to use the opponent colours, such as red-green and yellow-blue. However, some combinations of red and green are difficult to discriminate for people with colour vision defects. Luminance difference improves conspicuity of the combination, when such defects exist.

The concept of colour category is a useful tool for making colour combination. Colours are perceived in a limited number of colour groups such as red, orange, yellow, green and so on. This is called categorical colour perception and has widely been accepted in the application of colour. This is described in 5.2 including an ageing effect.

4.1.4 Colour Coding of Information

Coding of information by colour is a simple and useful way of making objects, surfaces and luminaires easily perceivable, identifiable and distinguishable. Colours used for such purposes could be selected from categorical colours. Colours selected from different categories, such as red, orange, yellow, green, and so on, cannot be confused with each other. The span of each colour category, in terms of the membership of a colour to a category, is critical for the choice of colours, but depends on age and luminance level (see 5.2).

Most of the considerations given in the previous sections can apply for colour coding of information and objects. For example, identification of objects or information should be accompanied not only by colour but also by an alternative format of information, i.e. auditory or tactile information or other non-colour visual information using symbols and letters.

4.2 Size and Style of Font and Symbols

The legibility of font and symbols is associated with the reader's ability to visually discriminate one character from another, and is affected by the physical construction and properties of the font or symbol. Legibility is different from readability which addresses the meaningful grouping of characters to form words or sentences. Readability may be affected by contents, grammar, writing style, or even the spacing between characters or sentences. Font size and style will be recommended for various presentation mediums, such as printed information and display screens. Other standards provide additional guidelines for various situations [12].

With increasing age the lens in the eye loses elasticity and the ability to focus clearly. The opaque effect in the ocular media, which also increases with age, results in less contrast at the retinal image. These effects have a negative impact on visual acuity and consequently on the legibility of font for older people.

Persons with low vision have a significantly reduced visual acuity and a reduced visual field. Depending on the type of impairments, a much larger font size is required for persons with low vision in general than for older people. They tend to prefer light text on a darker background (the negative polarity) rather than darker text on a light background (the positive polarity) - see Figure 1.



Figure 1 – Examples of the negative and the positive polarity font, the former being preferred by people with low vision

4.2.1 Font Size

Visual acuity is the factor that most affects the legibility of letters or symbols. When the visual acuity is not good enough, the font size should be made larger for legibility; in contrast, the size can be smaller for people with better visual acuity. For older people, visual acuity at near viewing distances (less than about 1 m) becomes considerably worse. A larger font size is, therefore, required in this case.

Visual acuity is also affected by the luminance level. It becomes worse when the luminance decreases. A larger font size is required in this case. Luminance level here means the luminance of the background (brighter part) in case of a positive polarity, or the luminance of the letter (brighter part) when a negative polarity is used (see Figure 1). Sometimes luminance level is alternatively defined as the average luminance of background and text together to specify the adaptation level.

Data on how visual acuity changes with viewing distance and luminance level and its relation to legible font size are presented in 5.3.

4.2.2 Font Style

Font style also influences legibility. While significant research has attempted to identify whether serif fonts (those characters with small structural line ends) or sans-serif fonts (no serif) (see Figure 2) promote legibility or readability, the results are mixed. With high resolution displays or printed hardcopy, the standards developer needs to focus on overall font design, and ensure that serifs, if present, do not negatively affect legibility. However, when the output resolution (either on paper or screen) is low, a sans-serif font will likely be required because there will not be enough dots or pixels to render the serifs clearly. In recent studies, a sans-serif font is preferred and shows high legibility for all younger, older, and people with low vision [12] [13] [14].



Figure 2 – Example of fonts with serif and without serif (sans-serif)

The following font design should be considered for older people and those with low vision to increase accessibility in font style:

- consistent stroke widths (like a sans-serif font);
- open counter forms (the open space in letters like “e” and “a”);
- clearly visible ascenders and descenders (such as tails on the lower case letters “t” and “j”);
- wider horizontal proportions;
- extended horizontal strokes for certain letterforms (such as the arm of the lowercase “r” or the crossbar of the lowercase letter “t”);
- negative polarity font for people with low vision (see Figure 1).

4.2.3 Special Considerations for Fonts Used in Display Screens

Visual appearance of images in self-luminous screen displays is different from those reflected in printed medium (hard copy documents, books, etc.), and the difference should be taken into consideration for the display design. In particular, colour appearance of self-luminous displays differs from that of reflected images even if the physical characteristics of the light are the same. Some reference values for the display design have been reported. For example, contrast values between 6:1 and 10:1 are preferred for display screens in DIN TR124 [15], while 3:1 is recommended in ISO 9241-303 [12] for screens.

4.3 Provision of Lighting

Provision of lighting depends largely on visual tasks, environments, and visual capabilities of the person. For example, reading small characters requires a higher lighting level to increase visibility, while a lower lighting level is sufficient for relaxing in a living room. Visual tasks are categorized into the following groups: (a) detection of lights or objects, (b) recognition of

colour, (c) reading characters and symbols, (d) walking and other behaviours, and (e) relaxation and comfort. For each category the lighting level should be designed appropriately.

An appropriate lighting level in buildings should be defined for each part of the buildings by considering the purpose of the place, such as entrances, living rooms, dining rooms, or working rooms, as well as the extent of visual ability of the users. Standard lighting levels required for various indoor workplaces are defined in CIE S 008, but only for adults with normal vision [16].

A sufficient lighting level should be assured to maintain safety in transportation environments such as railway stations, subway stations, bus stops, roads, and pavements. Entrances of buildings, stairs, elevators, escalators should also be lit sufficiently to ensure safety.

4.3.1 Lighting for Older People and People with Visual Impairments

The design of an appropriate lighting level for older people and for people with visual impairments should take into account their visual sensitivity. For many of those people, an increased level of lighting may be required. People with low vision need a relatively higher level of illuminance when they view public signs or controls particularly at night.

It should be noted, however, that there is a large variation in the type and extent of impairments of people with low vision, and the appropriate level of lighting depends on the type of impairment. For example, a person who has opacification of the cornea or lens, or albinism, may find it difficult to see in bright light. Care should be taken not to cause glare when increasing the light level. Where possible the lighting should be controllable to accommodate the daily variation in lighting needs for users with visual impairments. This should also be applied to windows where curtains and blinds can provide effective control.

4.3.2 Spectral Composition of Light Sources

The spectral emission of a light source is a factor to be considered when better colour discrimination or colour identification is needed. The ability to discriminate colours decreases for older people as shown in 5.2. A light source with an appropriate spectral emission would therefore assist colour discrimination. This is also true for people with low vision who have difficulty in colour discrimination and colour identification [17].

4.3.3 Uniformity of Lighting

It is desirable that light is uniformly distributed on all relevant internal surfaces, and the production of strong shadows should be avoided. This can be achieved by ensuring that the Spacing to Mounting Height Ratio (SHR), as recommended by the manufacturers, is not exceeded. This is of particular importance in interiors which are heavily obstructed with objects and/or furniture. The use of surfaces with high diffuse reflectance will also assist in distributing light uniformly in a room [18] [19]. The distribution of light also affects the use of self-luminous displays with light being reflected from the screen and reducing the luminance contrast or creating specular reflections from the screen, thus obliterating the screen image and causing veiling reflections. The same holds true for glossy floors or glossy papers on which important information appears.

Within buildings producing a darkened area or areas with abrupt changes between light and dark should be avoided, because people with low vision may have difficulty seeing the details in the dark area due to their reduced ability to adapt to sudden changes of brightness. They have similar problems adapting to bright areas.

4.3.4 Consideration of Ambient Lighting

Lighting for tasks and surroundings should be appropriately designed so that there is no large brightness change between the task and the ambient lighting. The use of a well shaded task

lamp, which does not expose people who are visually impaired to high temperature surfaces and can adjust the amount and distribution of light over the task, provides a useful and effective lighting solution. To ensure safety, attention should also be paid to the ambient light level for walking areas. This is particularly important for older people and people with low vision, because their peripheral vision, which plays an important role in walking, is limited (see 5.5).

4.3.5 Avoidance of Glare

Due to the increase of light scattering in the ocular media of the eye, the effect of glare is exacerbated for older people and for people with visual impairments (e.g., cataracts, corneal edema, vitreous opacities, etc.). Glare can cause a feeling of discomfort (discomfort glare) and interfere with task performance by decreasing the perceived contrast in visual signs (disability glare).

Visual acuity decreases in the presence of glare particularly for older people [20]. Recovery from glare also requires more time for older people generally, with similarly extended times for light and dark adaptation. The age factor for disability glare is provided in CIE 146 [21] (see 5.7).

Disability glare is described by the decrease of detectability of a light or the decrease of spatial resolution of an image. With regard to discomfort glare, a Unified Glare Index (UGR) for illumination has been defined by the CIE, and recommended values for various workplaces are presented in CIE S 008 [16].

General solutions to the problem of glare include shielding of bright light sources, and the use of indirect lighting for illumination of tasks and workplaces. The following are examples of solutions taken from “Lighting the way: A key to independence”, LRC Guidelines, USA [22]:

- Avoid placing very bright lights against dark ceilings or walls. Choose light-coloured walls and ceilings to soften the effects of bright light.
- Shield bright objects from usual lines of sight. For example, if a light bulb is seen when seated at a dining table, it is better to hide the direct view of the bulb by adjusting its shade or repositioning the luminaire.
- Avoid clear lenses or shades on luminaires; they do not shield the light bulb from your view.
- Spread light over large areas by lighting ceilings and walls, or by using light sources which are shielded from direct view.
- Choose a deeply recessed luminaire to minimize direct view of the bulb when recessed downlights or “cans” mounted in the ceiling are needed.
- Place task lights to your side, not in front, to avoid reflected glare from shiny surfaces, like polished wood or glossy magazines.
- Use shades, blinds, or curtains to minimize glare from windows.

4.3.6 Lighting Design

There are several national lighting design guides available, although these have been produced for specific use in their country of origin (Lighting and the visual environment for Senior living, IESNA, USA [23]; Housing for people with sight loss, A Thomas Pocklington Design Guide, UK [24]). The following are lighting design considerations provided in the guidelines:

- Consider possible changes to the task to increase the luminance contrast and the visual size.
- Reduce the incidence of shadows on tasks and access routes through the use of wide distribution luminaires and high reflectance surfaces.

- Minimise disability glare and discomfort glare by reducing the risk of light sources being in the field of view and/or reducing the background luminance.
- In ambient conditions achieve a unified glare rating (UGR) of ≤ 19 .
- Light sources should have a general colour rendering index (R_a) of ≥ 80 .
- Provide lighting control for ambient and task lighting. Use blinds and curtains to control daylight.
- Provide a minimum of 300 lx for tasks undertaken by an older workforce.
- Provide for an increase of 50 % on the recommended ambient illuminance in design guidance for adults.
- Consider the provision of adjustable task lights.
- Comply with the recommended SHR for the luminaire (see 4.3.3).

5 Vision Data and Design Methods for Older People and People with Disabilities

This section provides vision data of older people and people with disabilities to be taken into account for better lighting and better visibility for those people. The data were selected from sufficient numbers of samples and conditions so that they can provide statistical features on variations, individual or conditional. In each section methods for applying the data are presented on how to use the data.

5.1 Luminous Efficiency Function and Age-related Luminance Contrast

The spectral luminous efficiency function, i.e. spectral sensitivity of the eye, is one of the fundamental characteristics of the visual system. This has been used in photometry widely since the establishment of the CIE standard luminous efficiency function, $V(\lambda)$, to estimate the visual efficiency of lights. The CIE $V(\lambda)$ function was based on the data taken from a hundred people approximately, but the ageing effect was not clearly addressed in these standard data.

Figures 3a and 3b are two major data sources showing the change of the spectral luminous efficiency function with age, reported by Kraft and Werner [25], and by Sagawa and Takahashi [26] respectively. Both data show the efficiency function measured by flicker photometry and by direct brightness matching as well. The data by flicker photometry clearly show the decrease of efficiency with age in the shorter wavelength region between about 400 nm to 500 nm. This means bluish lights look relatively darker to older people than they do to younger people. Care should be taken when using blue lights in visual signs, especially in traffic or emergency signs, so that they do not look too dark to older people.

This ageing effect is considered due to the yellowing of the lens in the eye. However, the decrease of efficiency is also observed in the longer wavelength region in the data measured by direct brightness matching (right side data in Figure 3a and 3b), which cannot be explained by the lens absorption only.

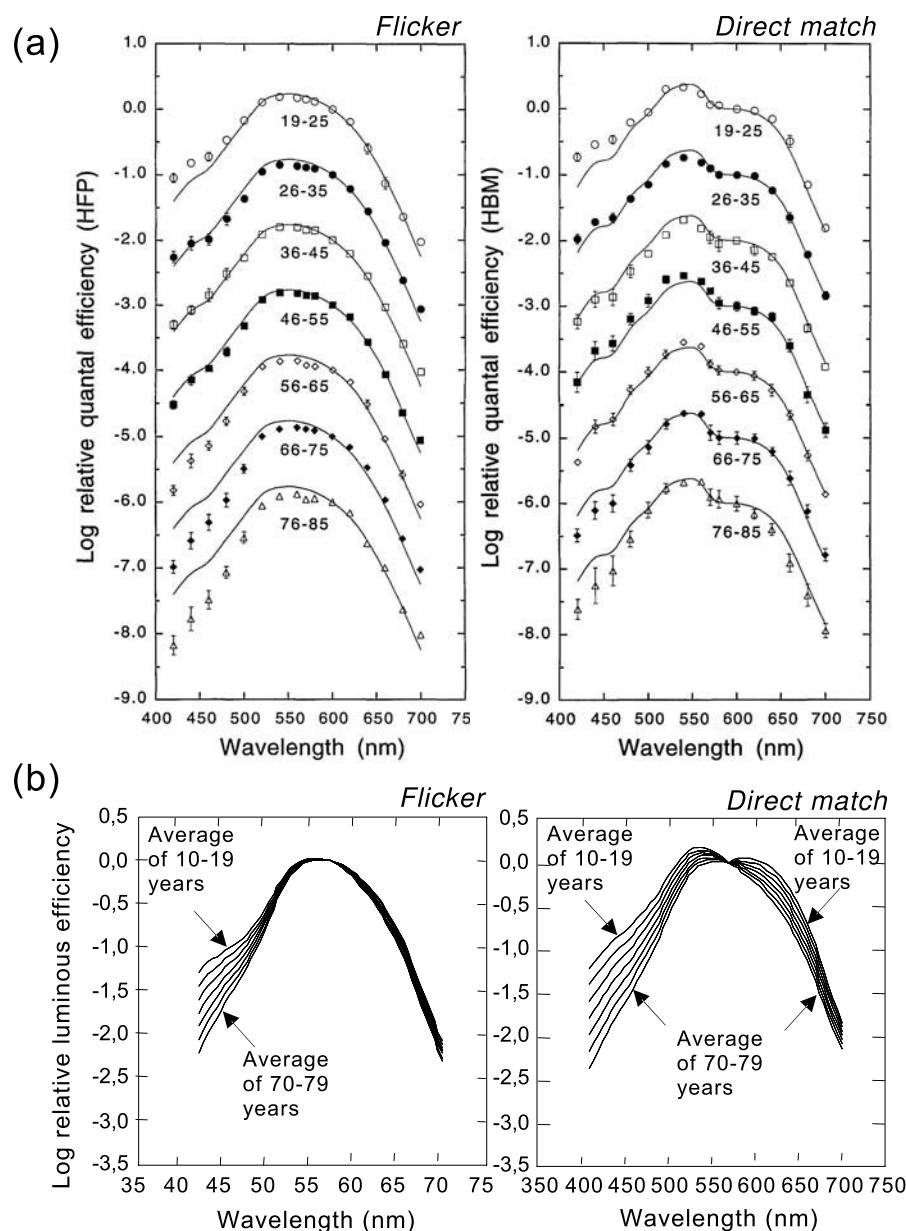


Figure 3 – Luminous efficiency functions measured by flicker photometry and direct brightness matching

(a) Kraft-Werner data
(HFP: heterochromatic flicker photometry,
HBM: heterochromatic brightness matching)

(b) Sagawa-Takahashi data

In the Kraft-Werner data (Figure 3a), the data of different age groups are shifted vertically to avoid overlap, and the solid lines in the left panel represent the $V(\lambda)$ function adjusted at 610 nm for each curve. In the right panel solid lines are averaged functions over the 7 curves throughout the age groups. In the Sagawa-Takahashi data each curve means averaged data for each of seven age groups, i.e. 10-19, 20-29, 30-39, 40-49, 50-59, 60-69, 70-79 from the top to the bottom, all being normalized at 570 nm for both the flicker and the direct match data.

Application

The major application field of the spectral luminous efficiency function is photometry in which light is evaluated in terms of visual efficiency. The age-related change of the luminous efficiency function as shown in Figures 3a and 3b can be used to estimate the efficiency of lights for people at any age. The method for this complies with the principle of photometry, but in order to avoid confusion with the existing CIE photometry, the age-related luminous efficiency functions can be safely used only for estimating visual contrast for a pair of lights [27].

For a given pair of any two lights, namely L_1 and L_2 , visual contrast is calculable by using Equation (1) taking L_1 as a test and L_2 as a reference (or a background), provided that the spectral radiance of the two lights are known. The contrast defined here should be called age-related luminance contrast, and denoted as C_a .

$$C_a = \frac{\sum_{380\text{ nm}}^{780\text{ nm}} L_{e,\lambda,1} V_a(\lambda) \Delta\lambda - \sum_{380\text{ nm}}^{780\text{ nm}} L_{e,\lambda,2} V_a(\lambda) \Delta\lambda}{\sum_{380\text{ nm}}^{780\text{ nm}} L_{e,\lambda,1} V_a(\lambda) \Delta\lambda} \quad (1)$$

$$\text{for } \sum_{380\text{ nm}}^{780\text{ nm}} L_{e,\lambda,1} V_a(\lambda) \Delta\lambda > \sum_{380\text{ nm}}^{780\text{ nm}} L_{e,\lambda,2} V_a(\lambda) \Delta\lambda$$

where

C_a is the age-related luminance contrast for age, a ;

$L_{e,\lambda,1}$ is the spectral radiance of light L_1 ($\text{W}\cdot\text{m}^{-2}\cdot\text{sr}^{-1}\cdot\text{nm}^{-1}$);

$L_{e,\lambda,2}$ is the spectral radiance of light L_2 ($\text{W}\cdot\text{m}^{-2}\cdot\text{sr}^{-1}\cdot\text{nm}^{-1}$);

$V_a(\lambda)$ is the age-related spectral luminous efficiency of age, a ;

$\Delta\lambda$ is the wavelength bandwidth (5 nm).

NOTE 1 Age a here is defined in decades such as 10-19 or 20-29 years, and the corresponding data on $V_a(\lambda)$ are given in Table B.1 (Annex B). For example, C_{20} and $V_{20}(\lambda)$ mean the age-related luminance contrast and the age-related spectral luminous efficiency function respectively, both for people in their twenties.

NOTE 2 The quantity $\sum_{380\text{ nm}}^{780\text{ nm}} L_{e,\lambda,i} V_a(\lambda) \Delta\lambda$ ($i = 1, 2$) corresponds to a relative value of luminance defined by CIE where the standard luminous efficiency function, $V(\lambda)$, and the maximum luminous efficacy, K_m (683 lm/W), apply. This quantity means the relative visual efficiency of the light.

NOTE 3 The wavelength bandwidth $\Delta\lambda$ was set to 5 nm for practical use, but the equation principally holds for other bandwidths less than 5 nm, such as 1 nm.

Figure 4 provides an example on how C_a is calculated for a given sign shown in the inset of the figure, which consists of a light L_1 (a blue symbol) and L_2 (a dark-brown background). The age-related luminance contrast was calculated for two age groups, the 20s and the 60s for example, by using their spectral luminous efficiency function (flicker photometry) shown in Figure 3b. The result of the calculation shows that the luminance contrast is 34 % for a younger subject and 15 % for an older subject. It turns out that the effective contrast of the sign is much lower for the older person than for the younger.