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TECHNICAL REPORT

Discomfort Glare in Road Lighting and Vehicle Lighting

CIE 243:2021

UDC: 628.931
628.987
612.84

Descriptor: Electrical lighting design
Evaluation of lighting installations
Vision

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COMMISSION INTERNATIONALE DE L'ECLAIRAGE
CIE Central Bureau
Babenbergerstrasse 9, A-1010 Vienna, AUSTRIA
Tel: +43(1)714 31 87
e-mail: ciecb@cie.co.at
www.cie.co.at

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This Technical Report has been prepared by CIE Technical Committee (TC) 4-33 of Division 4 "Transportation and Exterior Applications" and has been approved by the Board of Administration and by Division 4 of the Commission Internationale de l'Eclairage. The document reports on current knowledge and experience within the specific field of light and lighting described, and is intended to be used by all with an interest in excellence in light and lighting. The information provided here is advisory, and not mandatory.

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The following members of TC 4-33 “Discomfort glare in roadway and vehicle lighting” took part in the preparation of this Technical Report. The committee comes under Division 4 “Transportation and Exterior Applications”.

Authors:

Voelker, S. (Chair)

Fotios, S.

Gibbons, R. (Chair till 2015)

Villa, C.

Wood, J.

Niedling, M.

Germany

United Kingdom

USA

France

Australia

Germany

Advisors:

Donners, M.

Stockmar, A.

Van Heur, R.

Netherlands

Germany

Belgium

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DISCOMFORT GLARE IN ROAD LIGHTING AND VEHICLE LIGHTING

Summary

The topic of this report is discomfort glare in the context of road and vehicle lighting. It provides an overview of the research methods, mathematical models and the variables which are considered to influence discomfort glare. The report describes the difficulties associated with the evaluation and measurement of discomfort glare and the variance in the models.

One aim of the report is to encourage further research on discomfort glare using methods informed by the proposals raised in this report. Such research will generate a greater body of credible data, thus enabling the development of a more robust model. It is intended to update this report in due course with these additional data and a revised discomfort glare model.

EBLOUISSEMENT INCONFORTABLE DU A L'ECLAIRAGE ROUTIER ET AUTOMOBILE

Résumé

Le présent rapport traite du phénomène appelé éblouissement inconfortable que ressentent les conducteurs de véhicules motorisés lorsqu'ils sont éblouis par l'éclairage routier et automobile. Il fournit un aperçu des méthodes de recherche, des modèles mathématiques et des facteurs qui influencent l'éblouissement inconfortable. Le rapport décrit les difficultés associées à la mesure de l'éblouissement inconfortable et les différences entre les modèles existants.

Un objectif de ce rapport est d'encourager de nouvelles recherches sur l'éblouissement inconfortable en utilisant des méthodes fondées sur les propositions formulées dans ce rapport. Cela permettra de constituer un corpus plus important de données crédibles en vue de développer un modèle plus robuste. Il est prévu de mettre à jour ce rapport en temps utile avec des données supplémentaires et un modèle d'éblouissement inconfortable révisé.

PSYCHOLOGISCHE BLENDUNG IN DER STRASSEN- UND KFZ-BELEUCHTUNG

Zusammenfassung

Der vorliegende Bericht beschäftigt sich mit dem Thema *Psychologische Blendung*, verursacht durch Straßen- und Kfz-Beleuchtung. Er liefert eine Übersicht der weltweit verwendeten Forschungsmethoden, der mathematischen Modelle und der photometrischen und geometrischen Größen, welche die psychologische Blendung beeinflussen. Der Bericht beschreibt sowohl die Herausforderungen bei der Messung als auch die Varianz in den Modellen.

Ein Ziel dieses Berichts ist es, weitere Forschungen zur psychologischen Blendung anzuregen, die sich auf die in diesem Bericht dargelegten Methoden und Vorschläge stützen. Dies wird zu einem größeren Bestand an glaubwürdigen Daten führen, die die Entwicklung eines robusteren Modells ermöglichen. Es ist beabsichtigt, diesen Bericht zu gegebener Zeit mit zusätzlichen Daten und einem überarbeiteten Blendbewertungsmodell zu aktualisieren.

1 Introduction

1.1 General

A glare source is one that is excessively bright compared with its surroundings and leads to visual impairment (disability glare) and visual discomfort (commonly known, and referred to here, as discomfort glare) while driving at night. Both disability and discomfort glare have been the focus of numerous research projects: such work is important given that glare may influence both the comfort and safety of drivers and other road users.

The physical basis of disability glare is well defined, resulting from the physiology of the human eye and behaviour of light as it enters the ocular media (CIE, 1999b). Discomfort glare causes a psychological response, although there is no widely accepted theory regarding the response. The different response mechanisms mean that the two forms of glare (disability and discomfort) are fundamentally different.

This report concerns the discomfort from glare experienced by drivers of motorized vehicles. Literature on discomfort glare regarding pedestrian or cyclist applications is not discussed in this report. There is as yet no fully satisfactory index for quantifying this discomfort. The formerly used Glare Control Mark (GCM), symbol G , (CIE, 1976), was the first CIE-recommended scale for the description of discomfort glare. It contributed to some of the differences found between the discomfort glare predicted by the GCM and real-world experiences of discomfort glare. While the application of limits determined using threshold increments (CIE, 2020, 17-31-145) to control for disability glare seems to lead to acceptable lighting solutions, a standard metric for discomfort glare is, however, missing. Furthermore, the recent widespread adoption of LEDs for road lighting has initiated the need for new research because these sources exhibit different characteristics (source dimensions, source luminance, source uniformity and spectral power distribution) compared to conventional lamps such as low-pressure sodium and metal halide.

The present report provides background information on discomfort glare in road and vehicle lighting and presents calculation methods that may be applied to determine the degree of discomfort glare in a given situation. The report includes the results of studies investigating discomfort due to both vehicle headlamps and road lighting.

The development of a robust model for predicting discomfort from glare in the context of driving requires a robust set of data. One aim of this report is to promote further research, specifically research conducted giving consideration to the methodology recommendations discussed in this report.

1.2 Limitations to the scope

This report describes models for predicting discomfort from glare, focusing on discomfort glare for drivers in the context of road and vehicle lighting, but does not present recommendations for thresholds that would restrict or reduce discomfort completely. The report focuses on dry road surfaces; while wet road surfaces present additional problems, there are insufficient data available to draw conclusions.

This report is based on CIE 031:1976 (CIE, 1976), CIE 055:1983 (CIE, 1983); CIE 112:1994 (CIE, 1994), CIE 115:2010 (CIE, 2010), CIE 136:2000 (CIE, 2000a) and CIE 146:2002 (CIE, 2002). In CIE 115:2010 (CIE, 2010a), CIE 132:1999 (CIE, 1999), CIE 140:2019 (CIE, 2019a) and CIE x023:2002 (CIE, 2002), discomfort glare is not considered as a quality criterion in the context of road lighting for drivers. In CIE publications on other areas of lighting, e.g. CIE 129:1998 (CIE, 1998) for outdoor workplaces or CIE S 021:2011 (CIE, 2011) and CIE 188:2010 (CIE, 2010b) for vehicle lighting, no differentiation is made between discomfort and disability glare. Because the effects of disability and discomfort glare are differently influenced by contextual factors they are considered as separate items in this report.

The current report also considers models developed for calculating glare in the context of sports lighting (CIE 112:1994) because these are based on discomfort.

2 Definition of glare

According to the International Lighting Vocabulary, glare is defined as a "condition of vision in which there is discomfort or a reduction in the ability to see details or objects, caused by an unsuitable distribution or range of luminance, or by extreme contrasts" (CIE, 2020, 17-22-099).

Two separate forms are identified:

- 1) discomfort glare: glare that causes discomfort without necessarily impairing the visibility of objects;
- 2) disability glare: glare that impairs the visibility of objects without necessarily causing discomfort.

Although both discomfort and disability can be experienced in the same situation, the two forms of glare are different phenomena.

It is generally accepted that both discomfort and disability effects of glare should be minimized in road lighting installations. A functional connection between the two kinds of glare has, however, not yet been determined; therefore the two are generally treated separately.

2.1 Disability glare

Disability glare results from the scattering of light within the eye which reduces the contrast of retinal images. The effect may be explained by the superimposition of a uniform luminance veil over the scene, which is quantified as the equivalent veiling luminance. The magnitude of this veiling luminance depends on the illuminance at the driver's eye resulting from the luminaires, the angles at which they are seen and the age of the observer. Although the degree of disability increases with the equivalent veiling luminance, it decreases as a function of the average road luminance (CIE, 2010).

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 perceived objects is low. The reduction of contrast caused by the veiling luminance might cause the perceived contrast of an object to fall below contrast sensitivity thresholds so that the object cannot be detected. Disability glare is most often of importance at night when contrast sensitivity is low and there may be one or more bright light sources near the line of sight, such as vehicle headlamps, road luminaires or floodlights.

In road lighting, the threshold increment (TI) is used to quantify the effects of disability glare on visibility of objects. TI is expressed as the percentage increase in luminance contrast threshold required between an object and its background for it to be seen equally well with a source of glare (CIE, 2020, 17-31-145).

Figure 1 shows an example of the visual disability caused by glare from vehicle headlamps. This is a road with a row of small visibility targets located alongside a parked vehicle. When the headlamps of this vehicle are turned on to low beam fewer of the targets are detected. In particular, all of the targets beyond the parked vehicle are not visible. The effect would be more significant if instead the high-beam headlamps were used.



NOTE When the headlamps of this vehicle are switched off it is possible to detect the array of objects running alongside the vehicle (left). However, when the headlamps are switched on, they lead to a reduced detection ability (right).

Figure 1 – View of a road with a parked vehicle illustrating disability glare by vehicle headlamps
(Photo credit: Ron Gibbons)

2.2 Discomfort glare

Discomfort glare is defined by CIE as “glare that causes discomfort without necessarily impairing the perception of objects” (CIE, 2020, 17-22-103).

The CIE definition assumes that glare causes discomfort but without necessarily impairing the perception of objects or necessarily impairing effects of bright sources in the peripheral visual field.

3 Methods for discomfort glare assessment

The likely presence of discomfort glare can be predicted using a discomfort glare model. There are three steps to establish such a model:

- 1) Subjective evaluation of the degree of discomfort experienced by a representative sample of the population.
- 2) Measurement of the photometric characteristics of the visual field.
- 3) Development of an equation that can predict the subjective perception of discomfort glare as a function of the photometric characteristics.

The degree of discomfort is commonly evaluated using psychophysical methods, most commonly adjustment and category rating. While other methods such as behavioural observation or the measurement of involuntary physiological responses are possible (measured through electrophysiological methods), they have been less commonly used in discomfort glare research. Figure 2 illustrates some of the methods which have been used to evaluate discomfort glare.

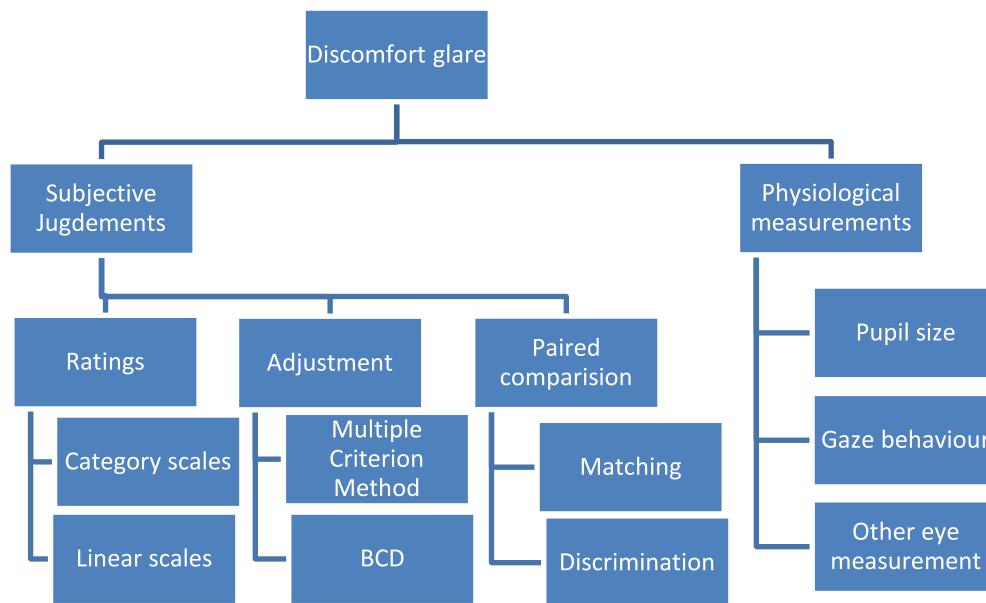


Figure 2 – Methods for assessing discomfort glare

3.1 Subjective judgements

3.1.1 General remarks

Discomfort evaluation methods are based on standard psychometric methods, each of which has both advantages and disadvantages (Theeuwes and Alferdinck, 1996; Voelker, 2017; Fotios, 2015; Liu and Konz, 1991). Whichever method is used, the data are affected by stimulus range effects (the set of lighting installations or headlamps being compared) and by the large variability in individual perceptions of discomfort glare.

Subjective judgements are context-dependant, which means the degree of discomfort is associated with a specific visual scene. A subjective judgement does not give an absolute assessment of discomfort but rather is a relative evaluation. One significant issue is the effect of stimulus range bias (Poulton, 1977) whereby respondents tend to make the range of observed stimuli fit the range of available response options. Experiments presenting different ranges of glare source luminance will lead to different responses.

An absolute assessment of discomfort is not possible: what we can do is compare luminaires (or other characteristics of lighting) under the same conditions. The result is a relative ranking of the glare assessment. This approach is useful, if we want to compare different low-beam headlamps or different road luminaires in a given study.

3.1.2 Ratings

The test participant is required to decide which point on a rating scale best describes the discomfort experienced from the visual scene presented by the experimenter. Ratings usually vary from none or almost negligible discomfort to intolerable discomfort. The response scales are either categorical or linear scales.

3.1.2.1 Category scales

In category ratings, the observer allocates the visual scene to one of several categories identifying the degree of visual discomfort experienced.

In previous CIE reports and elsewhere there have been some variations in the category scales employed for evaluating and specifying discomfort in different contexts. Table 1 shows scales that have been used in previous work associated with road lighting, vehicle lighting, sports lighting and exterior work areas.

Table 1 – Examples of discomfort glare scales used in previous work¹

Report	CIE 031-1976	CIE 112-1994, CIE 129-1998		Schmidt-Clausen and Bindels, 1974
Application	Road lighting	Sports and area lighting; exterior work areas		Vehicle headlamps
Glare metric	Glare Control Mark (GCM, symbol <i>G</i>) ^a	Glare Control Mark (symbol used in CIE 112: <i>GF</i>)	Glare Rating (symbol used in CIE 112 and CIE 129: <i>GR</i>) Note: $GR=10(10-GF)$	Glare Rating ^b (symbol <i>W</i>)
High degree of discomfort	1 Unbearable	1 Unbearable	90	1 Unbearable
	3 Disturbing	3 Disturbing	70	3 Disturbing
	5 Just Admissible	5 Just Admissible	50	5 Just Admissible
	7 Satisfactory	7 Noticeable	30	7 Acceptable
Low degree of discomfort	9 Unnoticeable	9 Unnoticeable	10	9 Noticeable
^a The scale based on GCM is often called 'de Boer scale' because this scale was published also in a text book of de Boer. In this document the term "nine-point scale" is used. ^b Schmidt-Clausen and Bindels used the term "glare rating", which according to CIE publications is termed "glare control mark".				

In all three examples shown in Table 1 a nine-point scale was used, with the odd-numbered categories defined using a description of discomfort magnitude. While discomfort descriptors for the three higher degrees of discomfort are consistent (i.e. just admissible, disturbing and unbearable), there is variation in those for the lower two degrees of discomfort. For sports and area lighting, the 1 to 9 evaluation scale for the Glare Control Mark is transposed to a 90 to 10 scale of the Glare Rating for specifying discomfort limits.

There are many aspects regarding Table 1 that should be questioned.

- **The number of response points:** Two common variations are a four-point scale (Yamin Garreton et al., 2015) (adapted from Hopkinson's multiple criterion scale as used in the adjustment procedure) and a seven-point scale (Ngai and Boyce, 2000; Tyukhova and Waters, 2018), but other scales can and have been used, too. Further work is needed to determine whether the number of response options matters and if so, the optimum number of response points. According to (Chan, 2018) the scale number could influence decisions. Further work is needed to determine whether the apparent magnitude of the response scale impacts on discomfort responses.
- **The direction of scale:** In Table 1 the lowest magnitude response label (1) is attributed to unbearable discomfort while the highest magnitude response label (9) is attributed to unnoticeable (in Columns 2 and 3) or noticeable discomfort (in Column 5). It is suggested that this order is counterintuitive and that more extreme discomfort should be associated with a higher response label, but this proposal has yet to be substantiated.
- **The comprehensibility of the response scale labels:** It should not be assumed that respondents correctly understand the meaning of the response scale labels. A particular issue is the use of the term 'satisfactory' (in Column 2). It has been demonstrated that naïve

¹ Symbols in this table are given as introduced in the respective publications, regardless of their non-compliance to the rules for the diction of quantity symbols.