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Glare by Light Emitting Diode (LED) vehicle traffic signals

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Abstract

Background: In this paper we analyze devices for traffic signals (traffic lights) with light-emitting diode (LED) technology.

Methods: The traditional measurements of luminous intensity were complemented with the luminance analysis of the devices, evaluated for diverse angular fields. Besides, a subjective glare evaluation is presented. In the experience, signals with LEDs directly visible and signals with refractors are compared. Both signals were introduced in the visual field of 30 observers within a perceptive scene that simulated night vision conditions for a driver. The observers were later inquired about the experienced perturbation or discomfort sensation.

Results: The obtained results show a significant increase in the punctual luminance as well as an evident perturbation and discomfort for the observers.

Conclusions: This effect together with the relatively high degree of coherence of the color lights could result in new kinds of glares not considered in the current standards.

Background

The present study has its origin in the claims of road users about the presumed visual perturbation that the signaling devices using LED as lighting source produced. Specifically, the luminous signals referred as "annoying" had the characteristic of having LEDs individually visible. The sign that represented the signal (a circumference, an arrow, letter, etc.) was formed by the sum of luminous dots and was seen as homogeneous only at a considerable distance. The glare effect was also observed by the laboratory technicians in charge of photometry, who normally observe the signal when centering and adjusting the measurement system. The effect was verified in devices whose emitted luminous intensities were not so different from those of "conventional" devices, considering the latter as uniformly illuminated (whether they use LEDs or another luminous source).

Figure 1 shows the LEDs individually visible studied devices. The diameters of the used LEDs ranged between 2 and 5 mm, while the separation between the observed adjacent elements was 12 mm.

The effect under study appears when the signal begins to be perceived as discrete (formed by dots). The observer visual acuity, defined as the reciprocal of the minimum perceptible visual angle expressed in arc minutes (1/δ), determine when the separation between dots is perceived.

Considering a rectangular signal formed by luminous points, shown in a schematic representation in Figure 2, the visual acuity of the observer (1/δ) will define, for an observation distance D, the maximum separation between LEDs (d) from which the signal is perceived as homogeneous.

The maximum visual acuity depends, among other factors, on the kind of object used for the experience, its contrast and adapting luminance. According to the authors, the minimum angular values δ observed are between 0.5 and 1 minute (Moon 1936). Figure 3 shows the relationship between the observation distance D and the separation of luminous dots d, for both limit angles of the visual acuity. Signals with separations d of 5 mm could be distinguished as formed by "separated points" from distances D shorter than around 17 m (for a maximum visual acuity of 1/0.5 min) or 8 m (visual acuity of

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Figure 1 **GLeds (left) and Mleds (right).Studied traffic lights with directly visible LEDs.**

1/min) -shadowed area in the figure-. Following the same line of thought, the signal Mled, with 12 mm of LEDs separation, will be perceived as a "non homogeneous light" from distances shorter than 20/ 25 m (see Figure 3).

Additionally, if the subtending angle by the signal is such that its image occupies a part of the fovea or the central fovea, the emission of each led will affect a small number of photoreceptor cells and therefore the glare effect will be more severe. This solid angle of maximum visual acuity varies between 54' and 1.2° (Bardier 2001). The image of a 300 mm diameter traffic light (the biggest standardized traffic signal) observed from the front, subtend a 1° angle from 17 m, so the image occupies all the central fovea. That is why glare could be severe for observation distances shorter than this.

Considering an urban signposting, a crossroad between 6 and 8 m wide will produce observation geometries with distances shorter than 15 m, and therefore, the traffic lights under study will be clearly seen as formed by luminous dots.

Revision glare

The term "glare" makes reference to a particular vision condition where there is discomfort, reduction in the visual capacity or both phenomena, simultaneously (CIE Commission Internationale de l'Éclairage Publication 017/E ILV 2011). The causes of glare could be:

- Inappropriate spatial distribution of luminance.
- Extreme luminance range in the visual field.
- Excessive contrast in space or time.

Usually two kinds of glare are differentiated:

a) Discomfort glare (also called psychological)
b) Disability glare (or physiological).

The first definition refers to perceptive situations where there is certain discomfort, not necessarily accompanied by an alteration in the vision of objects. Instead, in the second one there is loss of visual capacity, which can or cannot be linked to discomfort feelings or lack of comfort. In some situations, both types of glare occur simultaneously (CIE Commission Internationale de l'Éclairage Publication 55 1983).

Research carried out so far indicates that the luminance of the source is the main factor responsible for the discomfort glare. Instead, the disability glare is linked to the amount of light that enters the visual system. Here, again, we have the possibility of finding combined effects: glare sources with great luminance, which in turn produce high levels of intraocular luminance.

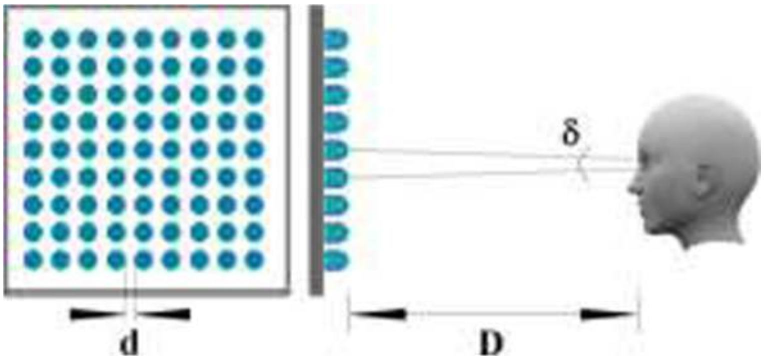

Figure 2 **Light signal perceived as formed by luminous dots.**

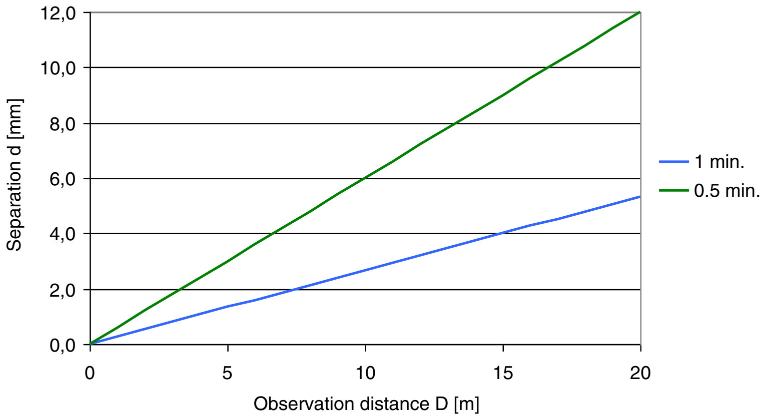

Figure 3 Distances to distinguish "dots" for different LEDs separations and visual acuities.

Glare is caused by a complex combination of diverse factors: a glare source in a determined position, an observation direction, a background luminance, etc. The values or indexes used as control parameters depend on the model used for describing the glare situation to be assessed. These experimental models have been oriented to "static" indoor lighting on one hand and to "dynamic" road lighting on the other. The glare produced by traffic signals involves a new perception model to be studied.

Methods

The basic situation for describing the annoying glare is shown in Figure 4, where a glaring source of luminance L_s is placed in the peripheral visual field of an observer whose line of vision goes to an object O. The object is visible thanks to the contrast that offers against a luminance background L_f. The line of vision is displaced an angle θ in relation to the position of the glare source.

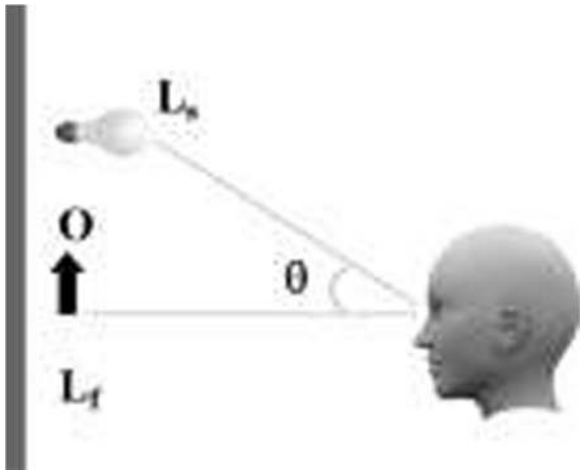

Figure 4 Basic diagram for describing the discomfort glare.

For this situation, the carried out studies (Hopkinson 1940; Holladay 1926) conclude that glare is greater as the displacement angle θ is reduced between the line of vision and the glare source. It is also increased with the image size that the glaring source forms in the eye retina of the observer and its luminance. Besides, glare is reduced when the background luminance increases (Lf), considering that the observer has his vision adapted to this value.

The index adopted as marker of glare degree (G, Glare Constant, according to CIE) assumes the form indicated in the equation (1).

$$G = \frac{L_s^a W^b}{L_f^C F(\theta)} \tag{1}$$

In equation (1), W is the solid angle of the glare source and F(θ) is a complex function that relates the vertical and horizontal displacement of the source, weighting its influence. The exponents a, b and c depend on the situation. In the case of small glare sources with high luminance a = 1.3, F(θ) ≈ 1 and b = c = 1 are chosen.

G values lower than 10 indicate imperceptible glare levels. On the other hand, 150 is the limit adopted for the maximum acceptable discomfort. Higher values (600) would be in the limit of becoming unbearable.

When the situation is not "static" any longer, that is, the observer moves, the characterization is more complex. The road and highway lighting is the typical case where there is relative movement between the observer and the source. The index used, also called G (Glare Control Mark for this case), is indicated in the expression (2).

$$G = SLI + 0.97 \cdot \log(L_{av}) + 4.41 \cdot \log(h) - 1.46 \cdot \log(p) \tag{2}$$

G depends on the parameters typical of the luminaire, grouped in SLI (Specific Luminaire Index), on the road average luminance (Lav), vertical distance between the observer and the height of luminary assembly (h), and the number of luminaires per kilometer (p).

The scale used is inverse to the previous case: low values (≈1) indicate unacceptable glare (van Bommel & de Boer 1982; Publication CIE N° 30–2 (TC-4.6) 1982).

Disability glare

The method used to assess the disability glare is based on Holladay, Adrian and Schreuder's studies, among others (Holladay 1926; Adrian & Schreuder 1970). Taking as starting point a diagram similar to that of Figure 1, the veil over the observed objects produced by the light of the glare source entering the eye was estimated. The effect was quantified with the equivalent veiling luminance Lv.

$$L_v = 10\frac{E_{eye}}{\theta^2} \tag{3}$$

The equivalent veiling luminance depends directly on the iluminance produced by the glare source over the eye, in a perpendicular plane to the vision line (Eeye) and inversely with the square of the angle between the vision line and the glare source (in degrees). The expression (3) has as application limit θ values lower than 60° and there are also corrections according to the observer's age (Adrian & Schreuder 1970; Fisher & Christie 1965).

The veiling luminance is added to both background luminance and object luminance, what determines an effective loss of contrast. Thus, in order that the object remains with the same degree of visibility, the contrast in scene with glare source should be increased in the so-called "perception threshold" TI, obtained with the empiric expression (4).

$$TI = 65\frac{L_v}{L_{av}^{0.8}} \tag{4}$$

TI is a measurement to calculate how much the vision of the object is disturbed. Values between 10 and 20 are the limits admitted in road lighting (see CIE Recommendation (Publication CIE N° 30–2 (TC-4.6) 1982) or Argentinean Standard (Instituto Argentino de Racionalización de Materiales 2008)).

Glare can be limited in a simplified way indoors or in working places; for instance, establishing maximum relations between the background luminance and object, for different angles of vision (República Argentina, ley 19.587/72 1972). Another alternative is to establish relations between the veiling luminance and the background luminance (ANSI/IESNA Illuminating Engineering Society of North America 2000).

The study

The regulations that reach vehicle traffic signs (European Committee for Standardization, European Standard EN 12368 2006; Performance Specification of the Institute of Transportation Engineers 2005) specify (as regards photometric parameters) minimum and maximum values of luminous intensity. In the case of uniformly illuminated signals, the average luminance is easy to calculate from the standardized diameters (200 mm and 300 mm). No luminance limits are established except for a weak regulation as regards uniformity obtained over areas of 25 mm in diameter. It is evident that for the case of signals consisting on the addition of luminous dots, a given intensity value can be reached from the sum of 'bright' dots with more luminance than the others; and after this stimulus; measuring 'punctual' luminance might affect directly the observer's perception.

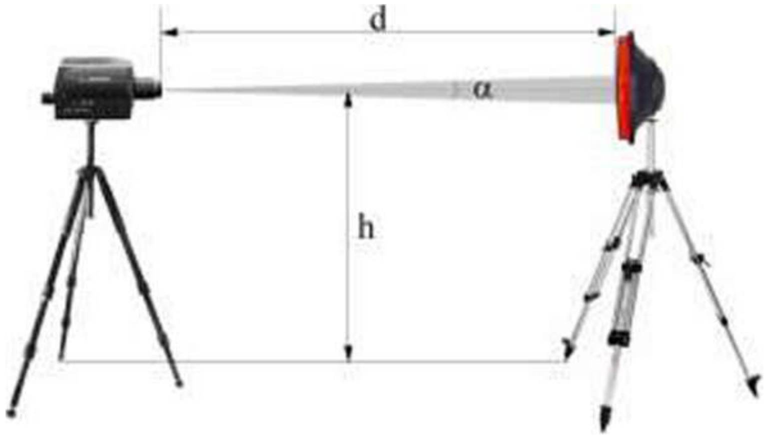

Figure 5 Experimental diagram.

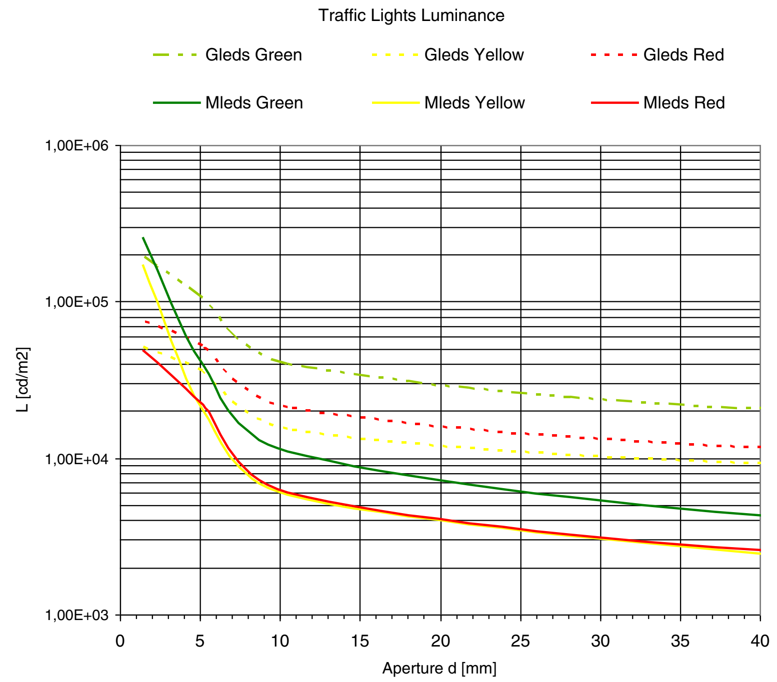

Figure 6 Measurements of luminance in traffic lights heads.

Measurements

Figure 5 shows the experimental diagram used for luminance measurements.

The luminance of the device under study was measured with a luminance meter according to Pritchard (Photo Research Inc 2012), using such angular fields and measurement distances that they allowed exploring areas of the luminous surface from about 40 mm in diameter to areas smaller than a single Led (<1 mm in diameter). In parallel, the emitted luminous intensities were measured, using a traditional goniophotometer.

Figure 6 shows the results obtained for traffic lights for vehicular traffic. The measured luminance is increased as the surface detected by the instrument decreases, up to values higher than 1.0E + 05 cd/m^2 when a single led is covered. The model called “Gleds” has an average separation between Leds of 9 mm with a Led size of 5 mm. The respective dimensions are 12 mm and 2 mm for those indicated as “Mleds” (see Figure 1).

In Table 1 the measured values are compared with those normalized according the standards (see reference (European Committee for Standardization, European Standard EN 12368 2006)), for a signal of 300 mm in diameter, type 3/1, typical in important avenues in our country. The considered luminous area was of 0.071 m^2 and the average luminance was obtained as L = I/A.

It can be observed that the luminance perceived by the observer when the luminous dots are distinguished is 25 times higher than the average luminance of the signal and almost 15 times greater than the maximum allowed by the standard.

Subjetive experiment

The aim of this study was to evaluate subjectively the glare effect of the traffic lights. A traffic light with visible dots (Gleds) and a conventional-type traffic light with colored refractor and no directly visible leds were compared. The experience took place in a room prepared for sinulating a night vehicle drive on a route or road. Thirty people participated in the experience, all with normal vision aged between 23 and 50 years old. The signals were presented alternatively and randomly during a fixed time and after a period of adaptation to a background luminance. Then, the level of subjective

Table 1 Measured values and standardized values

Values	Results
Normalized values EN12368:06	
I_{min} principal axis (cd)	400
I_{max} principal axis (cd)	1,000
L average minimum (cd/m^2)	5.6 E + 03
L average maximum (cd/m^2)	14.0 E + 03
Measured values	
I principal axis (cd)	570
L average (cd/m^2)	8.0 E + 03
L punctual maximum (cd/m^2)	2.0 E + 05

Figure 7 Type I traffic light (conventional - left) and type II traffic light (Gleds - right).

disturbance experienced by the observer was assessed. He had to answer a questionnaire consisting of De Boer scale (nine steps, 1 unbearable, 9 imperceptible) to describe the experienced discomfort.

Experimental outline

The studied devices were of two types (Figure 7):

- LED traffic lights with colored refractors which are presented as a uniformly illuminated disc, similar to traditional traffic lights (type 1). Red and green colors were tested.
- Traffic lights with leds directly visible, Gleds, red and green colors (type II)

Both traffic lights were photometrically equivalent, with similar emission diagram, both according to the mentioned standard (European Committee for Standardization, European Standard EN 12368 2006).

The room lighting of the scene where the experience took place (background light) was produced with a reflector equipped with an incandecent halogen lamp, dimmerized in order to control the background luminance.

Figure 8 Experimental aspects.

The experience was carried out in a dark room, without windows, producing a uniform lighting, taken as base for the observers' adaptation. They were individually placed, sitting on a chair faced to a white plane used as background, at a distance of 5 m (Figure 8). This distance was about 30% longer than the average width of a lane and could be considered within the minimal distances of observation that occur in a real situation (urban street). The light source used for producing values of room lighting and background luminance was placed, hidden, at the end of the room, thus avoiding a direct projection on the observer and unwanted reflections on the observer's vision.

The luminance on the background (adaptation luminance) was adjusted to 1.5 cd/m2, value controlled with a luminance meter placed near the observer. The adopted luminance value is representative of road average luminances according to CIE and Argentinean standards.

The experience procedure was as follows:

1. The experiment procedure is explained during the period of the observer's vision adaptation to the room lighting (around 10 minutes), being his sight towards the background.
2. One of the traffic lights is turned on (the order of the traffic lights type I and II was at random) indicating the observer to stare at it for 15 seconds.
3. The traffic light was turned off.
4. The experience was repeated with the other traffic light following the same steps.

In all the experience no technical feature was mentioned to the observer about the difference between the studied signals.

Finally, he is inquired about the discomfort sensation caused by each traffic light, providing him with de Boer scale for classifying it.

Subjectivelly, the individuals found traffic light type II more "glaring" than type I. The results expressed graphically (Figure 10) show a marked "peak" classifying traffic

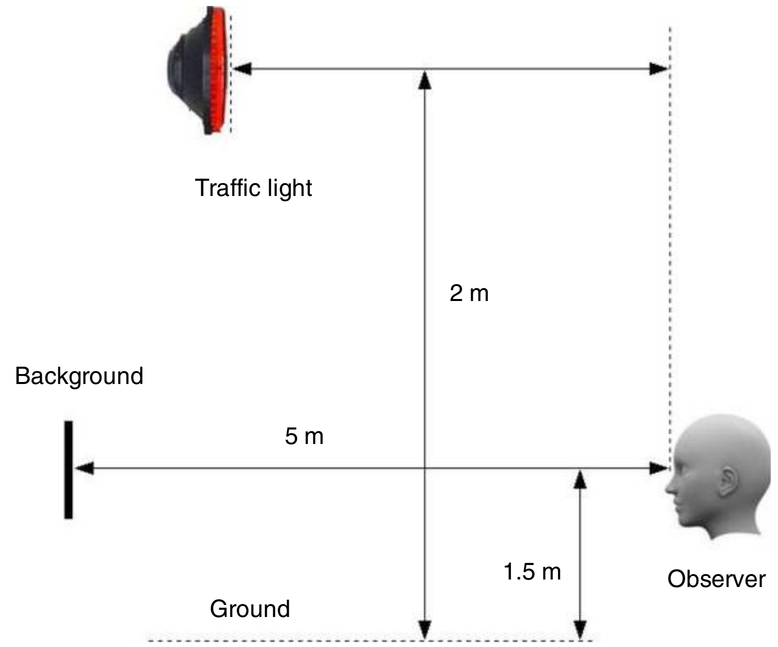

Figure 9 Diagram of the experimental set up.

light type II as "Disturbing". Moreover, great number of observers classified type II signal as "disturbing – unbearable" and even "unbearable". The Wilcoxon Signed Rank Test applied to the experimental sample, with 28 pairs of answers (two answer gave no differences), resulted in a Z-score equal to 3.65. Assuming a normal distribution for the Wilcoxon rank W, this Z value results in a very low probability (less than 0.05), that is way we concluded that the found differences are statistically significant.

The average De Boer index obtained for traffic light type I was 4.8 observers while the average for traffic light type II was 3.1. From this part of the experience it can be concluded that the design with luminous "dots" causes a subjective feeling more disturbing on vision than the homogeneous traffic lights. This assessment came together with the general comment that the "image" (disturbing veiling image) of this traffic light remained as an after image for longer time in their vision than the image of traffic light type I.

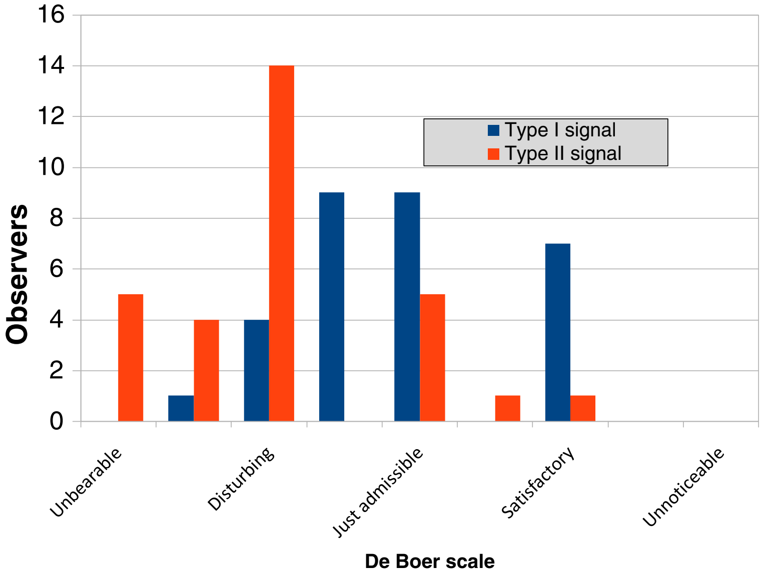

Figure 10 Graph of indexes of De Boer scale attributed by the observers to the disturbing feeling.

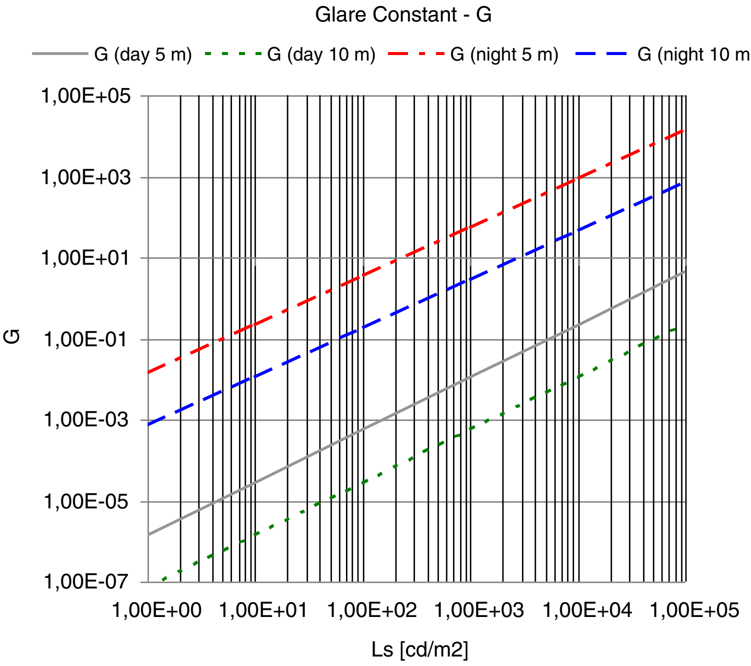

Figure 11 **Calculated Glare Constant G for measured luminances.**

Analysis of results

A first issue to be considered is which degree of discomfort can be attributed to the high punctual luminance values found in the type II LEDs studied signals. At first, it cannot be catalogued as disability glare, since neither L_v nor TI (equations 3 and 4, 2.2) has detrimental values, not existing differences between a traditional (type I) device and those here studied.

However, the situation changes when considering the G index (equation 1). Figure 11 shows the values calculated for a typical background luminance in daylight condition ($L_f = 1000$ cd/m^2) and night condition ($L_f = 1$ cd/m^2) and different observation distances. These distances define a range of solid angles W for signals of the order of 300 mm in diameter.

As it is logical to predict, values of L_s slightly higher than 1.0E + 05 cd/m^2 are not disturbing during the day ($G < 10$), but they exceed by far the tolerable limits during night, with extreme values ($G \approx 1.0E+04$) for short distances of observation.

In situations of night traffic and especially where road lighting is poor, maximum admitted values should be reconsidered. In this sense, the publication CIE 48 (CIE Commission Internationale de l'Éclairage Publication 48 1980) limits the luminous intensity to no more than 200 cd or around 3000 cd/m2, values by far exceeded nowadays.

These greater punctual luminances present in the devices with directly visible leds (Gled, Mled, type II devices) compared to the “homogeneous” Type I lights seem to be responsible for the discomfort feeling obtained from the subjective experience.

Conclusions

Like every new technology, the use of LEDs brings about advantages (increase of device efficiency, color stability, better design possibilities) and undesired effects. This is the case of the detected high luminance, which can cause disturbances or discomfort for certain situations of use. In the case of devices designed under standards (traffic lights), the glare effect goes beyond the limits or controls established for the right functioning, since the recommendations are oriented to uniform signals and not to those formed by luminous dots. It is essential then to progress in their up-dating in order to limit the phenomenon.

Similarly, the results shown point out the need for creating regulations for other road luminous devices applying Led technology installed in public areas such as signals and billboards, luminous poles in special vehicles (police cars, ambulances). The tendency indicates that Led emission will continue increasing, while the size of emitting surfaces will be reduced. It should be then strongly legislated to limit the present luminaries in the visual environment of drivers and pedestrians using the public space.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

IP, PM , RN. carried out the LED research experience mentioned in this paper; MGH. participated in the sequence alignment and drafted the manuscript.

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References

Adrian, W, & Schreuder, D. (1970). "A simple method for the appraisal of glare in street lighting". *Lighting Research and Technology, 2*, 61.

ANSI/IESNA Illuminating Engineering Society of North America. (2000). *"American National Standard Practice for Roadway Lighting"*. NY: RP-8-2000.

Bardier, D. (2001). "de la Visión al Conocimiento". In SA Tradinco (Ed.), Montevideo.

CIE Commission Internationale de l'Éclairage Publication 017/E ILV. (2011). *International Lighting Vocabulary*. UK: http://cie.co.at/index.php?i_ca_id=827.

CIE Commission Internationale de l'Éclairage Publication 48. (1980). *"Light signals for road traffic control"* (pp. 14–7). Paris.

CIE Commission Internationale de l'Éclairage Publication 55. (1983). *Discomfort Glare in the Interior Working Environment*. France.

Commission Internationale de l'Éclairage CIE. (1982). *"Calculation and measurement of luminance and illuminance in road lighting". Computer program for luminance, illuminance and glare. CIE N° 30–2* (pp. 4–6). Paris, France: CIE Editorial.

Crawford, B. (1936). "The integration of the effects from a number of glare sources". *Proc. Phys. Soc. of London, 48*, 35.

European Committee for Standardization, European Standard EN 12368. (2006). *"Traffic control equipment. Signal heads" Brussels* (pp. 25–30). Brussels.

Fisher, A, & Christie, A. (1965). "A note on disability glare". *Vision Research, 5*, 565.

Holladay, L. (1926). "The fundamentals of glare and visibility". *Journal of the Optical Society of America, 41*, 235–244.

Hopkinson, RG. (1940). *"Discomfort glare in lighted streets"*. London: Transactions of the IES, 5 (1).

Instituto Argentino de Racionalización de Materiales. (2008). *IRAM AADL J 2022–2, "Alumbrado Público, Vías de Tránsito – Clasificación y niveles de iluminación"*. Buenos Aires.

Moon, P. (1936). *"The Scientific Basis of Illuminating Engineering"*. London: McGraw Hill Book Company.

Performance Specification of the Institute of Transportation Engineers. (2005). *Vehicle Traffic Control Signal Heads*. Washington, D.C: Light Emitting Diode (LED) Circular Signal Supplement.

Photo Research Inc. (2012). *PR880 Photometer specification*. http://www.photoresearch.com/current/pr880.asp.

República Argentina, ley 19.587/72. (1972). *"Ley de Seguridad e Higiene e el trabajo", Anexo IV, cap. XII*. Buenos Aires: Iluminación y Color.

van Bommel, W, & de Boer, J. (1982). *"Road Lighting"*. The Netherlands: Philips Technical Library.