Lux junior 2005
23. bis 25.9.05 Dörnfeld

Night-time driving – new light sources in car headlamps – visibility and glare

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1. Introduction

Night-time driving on the road is under mesopic conditions. Car headlamps illuminate a small part of the visual field, street lighting produces a background luminance, and the headlamps of oncoming vehicles influence the visibility of the driver and his or her general state of adaptation in a very unpredictable way causing glare for the driver.

The task that a driver has to perform includes the observation of an obstacle, do rapid correcting manoeuvre and the identification of a person and his or her intention, i.e. to distinguish brightness contrasts and at the same time fine details.

In recent years many new headlamp constructions came onto the market: the traditional and later the halogen incandescent lamp become replaced by high pressure gas discharge lamps, first called Xenon and at present known as the High Intensity Discharge (HID) lamp.

Moreover, nowadays manufacturers already equip their concept cars (see e.g. [1]) with LED headlamp. Presently, most high efficiency white LEDs have relatively high correlated colour temperature of 5000K or above, although efforts are made to decrease this value. In a recent paper Sivak and co-workers [2] postulated – based on incandescent and HID car headlamp glare evaluation – that headlamps with LEDs will be more glaring then headlamps with the other two types of sources. They established their statement on the fact that presently available LEDs have a chromaticity, which is bluer than the chromaticity of the other two lamp types. Neither the spectral visibility, nor the spectral glare sensitivity of the human observer has been determined in the nighttime driving situation unambiguously.

Utilization of more efficient light sources can be more energy saving, they could ensure better illumination resulting in better vision under nighttime circumstances. This is an essential question, since the nighttime accident probability is much larger, than the daytime probability and it has been proved that lower visual acuity and longer reaction times – due to lower illumination – have a non-negligible part in this. With better illumination accidents can be avoid [3].

2. Car headlamp light sources

Incandescent lamps

The classical incandescent lamp is used only in very old types of cars. Presently, we can mainly meet with halogen incandescent lamps. Their colour temperature is between 3000 K and 3200 K and their chromaticity co-ordinates are about x=0.416, y=0.410.

Lately coloured bulb halogen incandescent lamps have been produced too, with bluish or yellowish tint, to imitate HID lamps.

HID headlamps

HID-lamps are more efficient, they can ensure larger illumination on the road, even with less power consumption. Their advantage is also longer lifetime and smaller source size, so that their light can be addressed better then that of the traditional incandescent lamp.

However, the HID headlamp is far more expensive and for its operation supplementary ignition and current stabilizer power supply units are needed. Their colour temperature is between 4000 K and 5000 K. The light of the aging lamp gets even more bluish.

Light emitting diodes – LEDs

LEDs (Light Emitting Diodes) are solid-state semiconductor light sources and offer an alternative technology to conventional halogen or HID headlamps. LEDs are now available in a number of colours. White emission colour can be achieved either by mixing the light of red, green and blue

LEDs or by transforming part of the blue emission of a LED into a yellow light using a photo-luminescent material and mixing the blue and yellow emission[4]. Modern high intensity LEDs are more efficient than incandescent lamps, and the forecast is that their efficacy will surpass that of HID lamps as well. They have also long life – depending on the current density on the p-n junction and some technological constraints – it can be between 50 000 and 100 000 hours.

The big advantage compared with halogen lamps is also that LEDs work efficiently over a wide voltage range, whereas halogen lamps have a narrow operating range – if the voltage is too low, the efficacy drops rapidly and over-voltage drastically reduces the lifetime.

The colour temperature of white LEDs is usually higher then that of HID lamps, thus their light is more bluish and their correlated colour temperature is between 6000 K and 8000 K.

A further advantage of LEDs is that their light can be modulated at high frequencies by modulating the LED current, thus they will respond quickly on a human action (important for break lights) and can be used at the same time also as communication emitters.

3. Spectra of different light sources, their impact on visibility.

Figure 1 shows characteristic spectra [5] of three different kinds of light sources (in case of HID and LED we show two-two samples). The spectra show large differences.

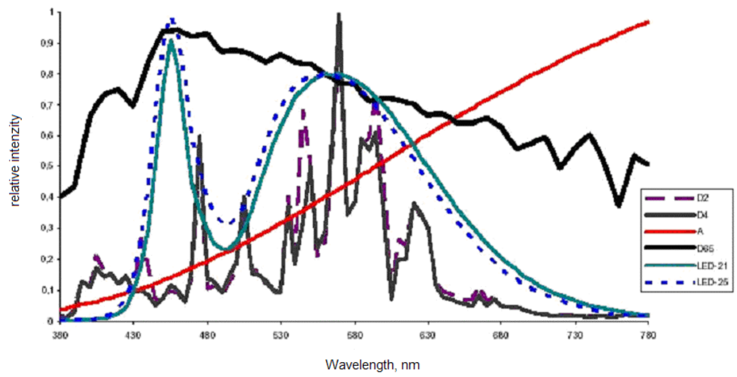

Figure 1: Spectra of an incandescent lamp (A), two types of HID-lamps (D2 and D4), two types of LEDs (LED 21 and LED 25), as well as the spectrum of standard daylight (D65).

Current practise uses the photopic photometric system for the evaluation of road-lighting installations and of car headlamps' performance. But under nighttime driving conditions the photopic photometric system should be used only for foveal vision and the recognition of fine detail. For parafoveal vision (for instance recognition of road traffic signs) a 10° photometric system would be more suitable [6]. At mesopic light levels the contribution of the rods cannot be neglected either. Figure 2 shows foveal and parafoveal spectral sensitivity curves in case of 0.1 cd/m^2, as determined by Bodrogi and co-workers [7].

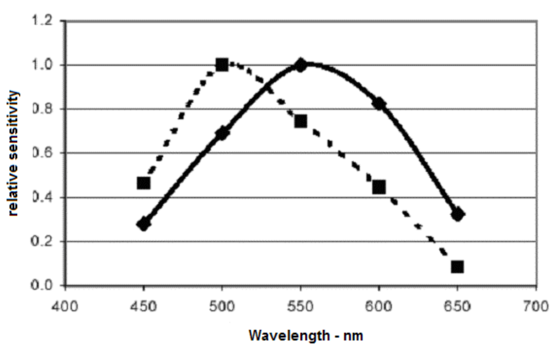

Figure 2: On-axis (continuous line) and off-axis spectral sensitivity (dash line) in case of 0.1 cd/m^2 background luminance:

We can see clearly the displacement of the maximum of the spectral sensitivity. Hence when we see objects parafoveally we might anticipate seeing fine details better in case of HID or LED headlamps than with incandescent lamps producing the same illuminance on the road.

However, to see red traffic signs well, a given amount of long-wave radiation has to be in the light of the headlamp. A revision of the minimum required red content of the car headlamp is under investigation [8].

4. Visibility and glare

Investigations have shown that both the recognition of fine details increases [9] and the reaction time in nighttime car driving situations decreases[10] if more blue light is in the light to be perceived. But there are many complaints that HID headlamps are more glaring than incandescent lamps.

The International Lighting Vocabulary[11] distinguishes between two types of glare as:

> ***"Disability Glare:*** *Glare that impairs the vision of objects without necessarily causing discomfort."*

> ***"Discomfort Glare:*** *Glare that causes discomfort without necessarily impairing the vision of objects."*

Experiments conducted by Flannagan [12] have shown that well-adjusted car headlamps produce no disability glare, but the reported discomfort depends on the spectrum of the lamp. Some people are of the opinion that the novelty of the HID headlamps contributes to the number of complaints. Experiments have shown, however, that the human spectral responsivity to glare peaks in the bluish part of the spectrum, leading to speculations that discomfort glare might be mediated by the blue cone response or the rod response [13, 14]. As seen from Figure 3 the spectral data available up-to-now are not conclusive enough to be able to identify the physiological basis of discomfort glare.

Akashi and Rea [16] conducted their experiments under simulated driving conditions and reported differences between on-axis and off-axis glare.

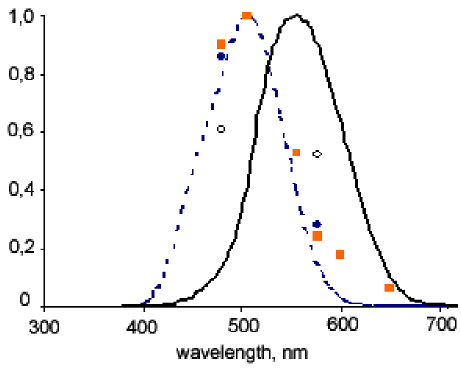

Figure 3: Estimates of human spectral glare perception [15], V(λ):——; V'(λ): ------;
■: earlier measurement data; ●: dim surround; ○: bright surround.

5. Discomfort glare experiment

We conducted experiments under laboratory conditions to define the spectral dependence of discomfort glare. Our glare source was illuminated by an extra high pressure Xe lamp, the light of which was focused via a relay lens and interference filters to monochromatize the radiation onto a holographic diffuser that served as the glare source, see Figure 4. A set of neutral density filters served to set different glaring intensities.

The glare source was adjusted so that the observer could see it under two degrees from an appropriate distance. Other parts of the screen were black.

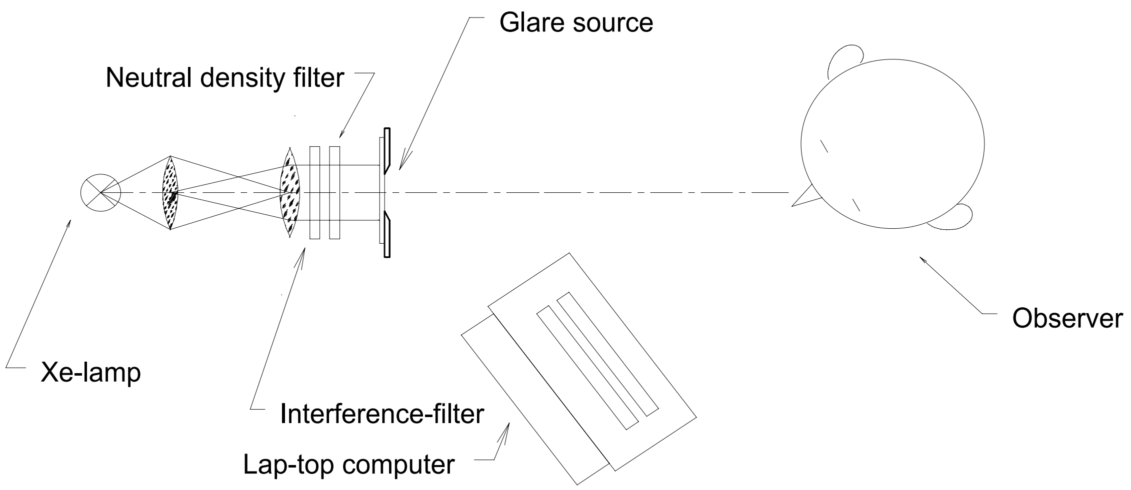

Figure 4: Set up of the visual experiment to investigate the spectral dependence of discomfort glare (not to scale).

Before the experiment the test person was seated in the test chair and the room lighting was set to a dim level (approximately 10 lux horizontal illuminance on the computer keyboard), and the subject was instructed to work on the computer.

The task was to carry out a visual task on the computer, while he or she was asked about the disturbing level of the given monochromatic luminance of the glare source. In two experimental series the glare

source was once seen a few degrees above the computer screen, in the second one at approximately 30° off-axis

After the test person was familiarized with the set-up by making a few trials with the computer task, five minutes of dark adaptation followed. The experiment was started with each interference filter set at the lowest glaring luminance level. After a few minutes of work on the computer the test person was asked to rate on a five-value scale how annoying he or she felt the coloured glaring light. Then selecting another neutral density filter a higher luminance was set. This was continued until the highest glare level was reached.

The experiment was repeated several times with each interference filter in the light path of the glare source. For every person at every wavelength, the neutral filter combination with the lowest transmission that produced a given glare rating value was recorded. Subsequently, the spectral radiance was measured with a PR 705 spectro-radiance-luminance meter.

In the present investigation five naïve observers took part, four males and one female, aged between 20 and 45 years). The subjects' eyesight and colour vision was tested: they had (corrected) 20/20 visual acuity, and made not more than two errors on the Munsell-Farnsworth 100 hue test.

6. Results

Figure 5 shows the necessary minimum radiance needed at each wavelength to produce the level of “disturbing” glare, both for a source positioned 0° horizontally (the source was offset 5° vertically from the main viewing axis) and for a source positioned 30° horizontally to the main viewing direction. We fitted fifth order polynomials to the measurement points, shown as trend lines. Correlation coefficients were for the on-axis view R^2= 0.92, and for the 30° off-axis view R^2= 0.84.

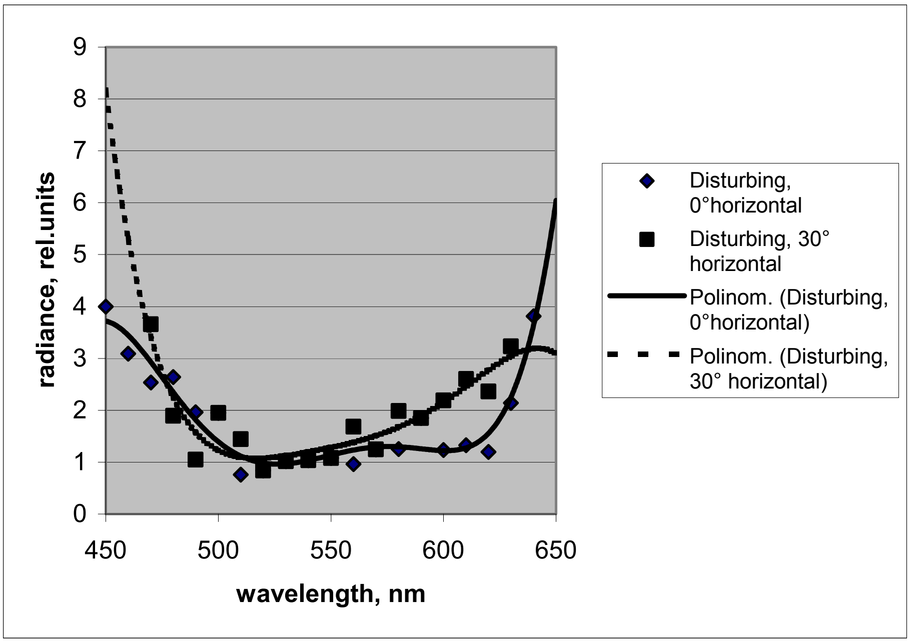

Figure 5: Spectral radiance needed for subjects to report the glare source as "disturbing", and fifth order polynomial fits to the data.

For further evaluation we transformed these minimal spectral radiance values to glare sensitivity, and normalized the curves to the area under the curve. Fifth order polynomials were again fitted to the measured points. Figure 6 shows these results together with the $V(\lambda)$ and $V'(\lambda)$ curves.

Despite of the relatively high scatter of the individual plots it can be seen quite clearly that neither the $V(\lambda)$ nor the $V'(\lambda)$ function fits the results of the measurements.

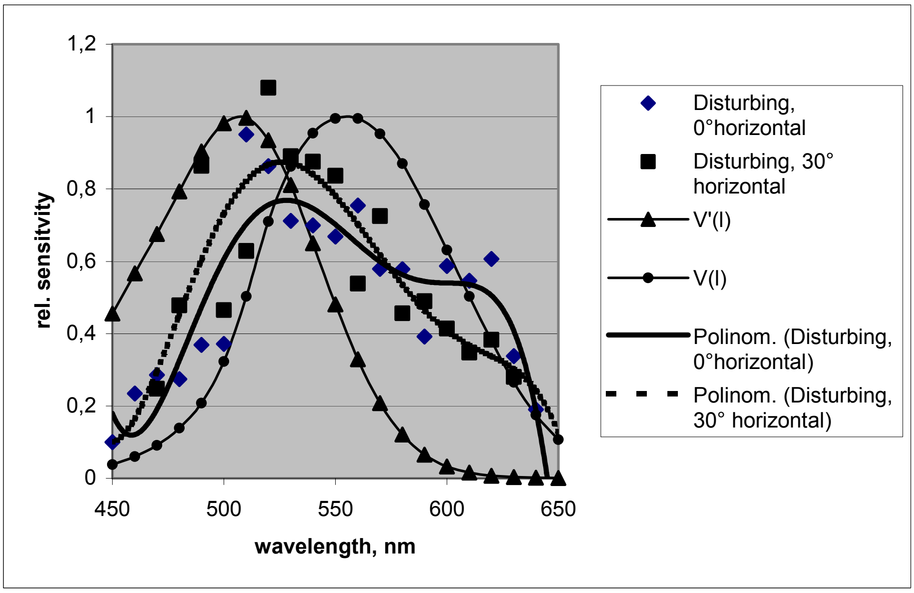

Figure 6: Averaged "disturbing" spectral glare sensitivity for 0° and 30° horizontal off-axis viewing along with fifth order polynomial fits to the data, plus the $V(\lambda)$ and $V'(\lambda)$ curves.

7. Discussion and conclusions

Up to now only five test persons have participated in the glare experiment; but further test persons are involved in the test. Comparing our results with those in the literature [15] one can state, however, that glare spectral sensitivity can be described neither with the $V(\lambda)$ nor the $V'(\lambda)$ function. Our results show a broad spectral responsivity curve that peaks in the blue-green region of the spectrum; thus the short wavelength cone response function alone is not adequate to describe the effect either.

The experiments were conducted in dim surround. No main lights were on, the observer adapted to the dim (approximately 10 cd/m^2) computer screen and the glare source. Peak luminance values of the glare source were well in the photopic luminance range, i.e., ten to a hundred cd/m^2, but these were seen non-foveal (at 0^o horizontally, 5^o vertically, and at 30^o horizontally, 0^o vertically), thus one can only speculate what the adaptation luminance really was that could have influenced the state of adaptation of the observer. In the direction of the glaring source the eye sensitivity could partly be described by the $V_{10}(\lambda)$ [18] function and partly by the influence of perception mediated by the rods ($V'(\lambda)$).The glare sensitivity curves we have measured show some similarity to the mesopic spectral sensitivity curves shown in Figure 7.

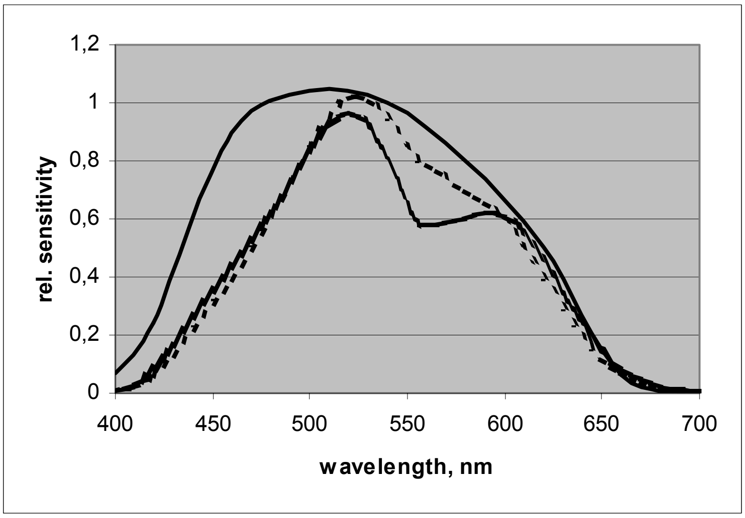

Figure 7: Spectral sensitivity of the human eye under mesopic conditions (0.1 cd/m^2) according to the Rea et al model[19] (——) and the measurements of Várady and co-workers[20] for para-foval vision: detection (– – – –) and identification (Landolt-C: - - - -) tasks.

The resemblance of the glare sensitivity curves with the mesopic spectral luminosity curves might have major practical consequences, because it would permit the conclusion that for best mesopic visibility on the road one can optimise the car headlamp spectral power distribution to increase visibility, but one would have to use other means to decrease glare (e.g. the long debated use of polarized light for vehicle headlamps, see e.g. [21].

We intend to continue our spectral glare investigations, partly by increasing the number of subjects, and partly by introducing objective psycho-physical measures of the discomfort (measures that are important in car driving, such as distraction by glare).

Acknowledgment

Authors would like to acknowledge the help of Mr. K Borsi and P Mórocz in performing some of the measurements and calculations, as well as the support of the European Union within its “Integrated communicating Solid-State Light Engine (ISLE) for use in Automotive Forward Lighting and information exchange between vehicles and infrastructure” project.

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