Article DOI: 10.26083/tuprints-00030832
DOI (proceedings): 10.26083/tuprints-00030825

Glare Contributors - A Metastudy on Scientific Research about Different Aspects of Glare

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1. Abstract

Glare was and is a relevant issue in vehicle lighting. Over the decades, several approaches had been taken to investigate glare in large variety. Many of these approaches have been published in separate scientific papers, PhD Thesis (mostly only available in German language), in research reports (e.g. BASt, Vedilis) or on conferences. This paper tries to integrate the individual scientific glare findings as an overview/Meta study in order to give substantial background to the actual and coming glare discussions.

Keywords: glare, discomfort, disability, contrast sensitivity, de Boer, Illuminance, Iluminance…

2. Contrast Sensitivity and Vehicle Situation

Without doubt, the performance of the human visual system is strongly depending on the adaptation luminance i.e. the perceived brightness of the scene. Thus, vehicle lighting with adaptation levels in the range of 0,05..2 cd/m² directly impacts the visual performance and contrast sensitivity or luminance difference for object detection. In a study with laboratory content and real driving content the effects by age, contrast, glare and driving conditions were investigated 2004 from the Darmstadt Laboratory of Lighting Technology for BASt. [Ref 1.].

The results (Fig.1, left) show: a factor 3 increase of ambient luminance to L_U = 0.1 cd/m² during the glare test (E_G=0,345lx) yields comparable results to the test without glare at an ambient luminance of L_U = 0.032 cd/m². In other words: The better the headlamp performance (i.e. higher ambient luminance), the better the visual performance. In a second part, a special head up display was installed on a test car. The task of the test subject was to name the orientation of a Landolt ring, to adhere to the specified speed, and to move the vehicle on the test track at about L_U = 1 cd/m^2. In addition, the visual acuity of the test subjects was measured. For this purpose, the size of the Landolt ring was presented logarithmically scaled for a constant logarithmically assessed contrast of K = 1.97. (Fig. 1 right)

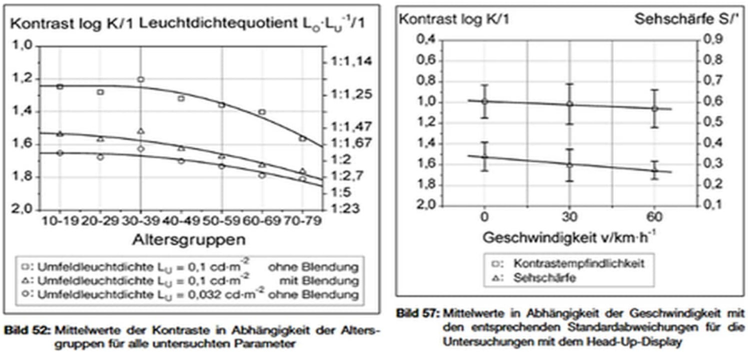


Figure 1: Contrast Sensitivity K /Visual Acuity S depending on Adaptation Luminance, Glare, Age and speed while driving a test /ehicle [Ref 1.]

For the investigated speed range up to v = 60 km/h, the average achievable contrast ΔK decreases appr. 15 % compared to the static test series. Visual acuity ΔS decreased by 21%. So results found under laboratory conditions further diminish in real driving situations and cannot be used as absolute values to describe contrast sensitivity under dynamic conditions.

Kosmas [Ref 2.] investigated 2019 disability glare/ luminance differences to detect objects under dry and wet road conditions. A test subject drove at 60 km/h in a test vehicle with LED low beams toward a stationary dazzling vehicle, also with LED low beams. The low beam illumination was be dimmed in three stages in the dazzling vehicle and in one stage in the test vehicle.

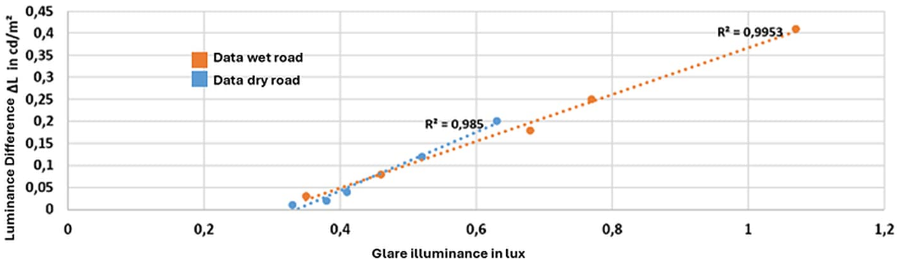


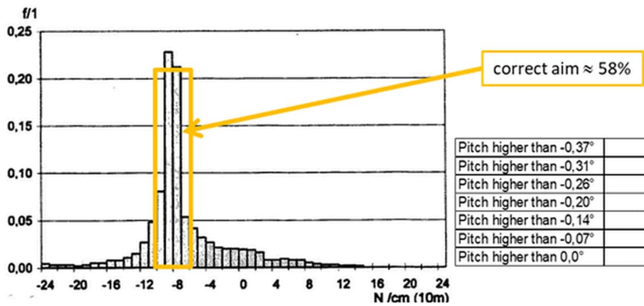
Figure 2: Luminance difference ∆L and glare illuminance for dry and wet road surfaces with varying headlamp illuminance [Ref 2.]

As seen in Fig.2, if glare illuminance increases, the luminance difference increases linear as well. That means the difference between object and ambient luminance must increase to detect the object with the same probability. Wet conditions just add glare illuminance to the eye.

3. Research on Dynamic Glare

In a research program for adaptive headlighting, Huhn [Ref 3.] was 1999 investigating the real time pitch change. A measurement device based on laser triangulation was installed in front and rear of the test cars. The driving with 8 cars was made during normal traffic. The maximum angular changes of the car inclination were recorded with +1,49° while accelerating and -1,81° while braking.

The analysis showed that there could be a significant time interval where the left cutoff is above the horizon i.e. 7,8% above N=0. (Fig. 3) Right cutoff/kink is thus even more often above horizon. This significant glare potential could not be directly linked to specific car parameters, but gear change and transmission, motor power, suspension and axle distance were found to contribute.
The total average glare potential was found to 4,78% in city, 2,86% on country road and 2,46% on motorways. These results are just from dynamic movement, no additional tolerances added like misaim etc.



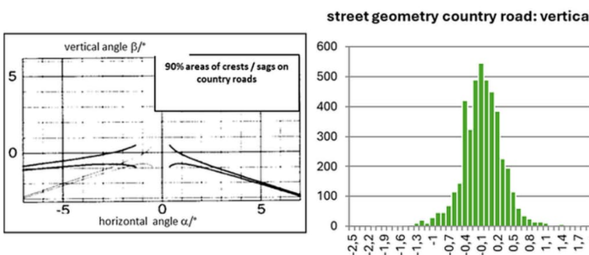
Pitch higher than -0,37°	25,4%
Pitch higher than -0,31°	21,4%
Pitch higher than -0,26°	17,9%
Pitch higher than -0,20°	15,4%
Pitch higher than -0,14°	12,9%
Pitch higher than -0,07°	10,4%
Pitch higher than 0,0°	7,8%

Figure 3: Investigation on real traffic dynamic pitch change for test car #6 driving in town. [Ref. 3.] The histogram was cumulated by the author.

"Correct" aim is assumed in a bar from aiming angle N= -12 ..-8 (=-1,2%..-0,8%) so the sum of investigated window is Δ = 0,4%= 0,23° This example in town driving with test car #6 gives an average "correct" aiming time of appr. 58%.

4. Environmental Influences: Street Geometry

The street geometry influences the area where the light hits the road. Under the assumption that not all streets are flat, descending and ascending slopes of the road surface have temporary but constant influence on the light. In a research program for headlight performance, Damasky [Ref 3.] was 1995 investigating the real street geometries on town, country and motorway roads. A video camera recorded the street scene of about 5500km of driving on German roads. A statistical evaluation gave classification how the coordinate system of the car relative to the street is positioned. As assumed, a large portion is above or below 0 (Fig.4).



Higher than -0,6	94,30%
Higher than -0,5	91,65%
Higher than -0,4	88,30%
Higher than -0,3	78,61%
Higher than -0,2	71,11%
Higher than -0,1	59,81%
Higher than 0	47,23%
Higher than 0,1	35,93%
Higher than 0,2	25,54%
Higher than 0,3	16,66%
Higher than 0,4	11,47%
Higher than 0,5	6,97%
Higher than 0,6	4,31%

Figure 4: Investigation on real traffic vertical angle change of country roads. Basic data is derived from [Ref. 4.] for video recording on 5500km on German roads. The histogram was cumulated by the author.

"Correct" street dynamics is assumed in from "aiming" angle α = -0,05°..+0,05° (plus Tolerance ± 0,10°), so the investigated window is Δ = 0,3° This example gives an average "correct" aiming time of appr. 34%. The real time where a car can be able to illuminate objects in some 70..100m is significantly limited by the dynamic effects of street and car.

Alternatively, the car produces glare. Multiplying the correct "aim" of a car in Fig. 3 with the correct street "aim" in Fig. 4 would result in a product of 34%*58%, giving a number of 19,7% as indeed "correct".

Kobbert [Ref 5.] analysed 2019 traffic 3D position and density in great detail. Using data from other PhD Thesis, a random stretch of 50 km length is randomly stitched together to form a statistically relevant road segment. Based on traffic density data by the German government, random vehicles with an average density of 444 vehicles per hour were placed on this stretch of road. Then the measurement vehicle was moved with a velocity of 100 km/h in steps of 1 m. Then all object locations were summed up and a traffic density was calculated over the complete segment. This is shown in Fig. 5 where the absolute number of vehicles under each angle is shown ±20° horizontally and from −0.6° to 5° vertically on a single lane country road. So there is a high probability that vehicles arrive over the horizon and potentially glare the driver.

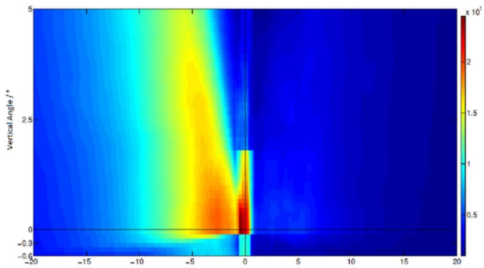


Figure 5: Simulated traffic density with 3D street simulation with absolute number of vehicles detected according to studies. [Ref 5.]

5. Pulsed glare investigations (Transient Glare)

Rosenhahn [Ref 6.] determined 1999 the re-adaptation times for rectangular stimuli. The geometry used corresponded to a situation of encountering during night-time traffic with a mutual distance of d = 50 m, a luminance of the road $L_p = 0.1$ cd/m^{-2} and a static basic glare with a glare illuminance of $E_s = 0.2$lx. The re-adaptation time is the period of time which has to elapse after the glare stimulus so that the observer is able to re-detect an object with a luminance that had been enhanced by p = 8% as compared to the recognition threshold.

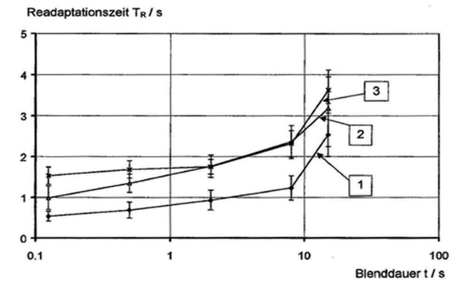


Bild 20: Readaptationszeit T_R für Rechteckimpulse unterschiedlicher Blendbeleuchtungsstärke E_B in Abhängigkeit der Blenddauer t
1: E_B = 1 lx; 2: E_B = 5 lx; 3: E_B = 10 lx

Figure 6: Readaptation time T_R for different pulse lengths t and illuminance levels E_B. [Ref 6.]

In Fig. 6 the measurement results of the re-adaptation time T_r for various glare illuminances are shown. The re-adaptation time is within the range between 2s and 4 s depending on the glare illuminance and glare exposure. These results confirm the existence of a critical glare time t_c = 7s where readaptation becomes even worse.

In 2019 Kobbert [Ref 5.] showed the general correlation between glare perception, photometric values and pupil metrics for rectangular glare pulses. Since the illuminance pulses recorded in real life showed to be not rectangular, a part of his investigations was dedicated to the influence of the pulse form on the glare rating. To approximate real life pulses, triangle pulses were shown, where the illuminance is linearly increased for half of the pulse duration and then linearly decreased for the rest of the duration. Rectangle and triangle pulses were presented at a random order. For this test setup 17 test subjects with an age between 20 and 29 years of age participated in the study.

Analysing the data, glare perception between pulses with different durations split up (Fig. 7). Pulses with a shorter duration were perceived as more glaring than pulses with the same exposure, but longer pulse durations. The data for each pulse duration then follows a strictly logarithmic behaviour and the fit data for each duration are nearly parallel.

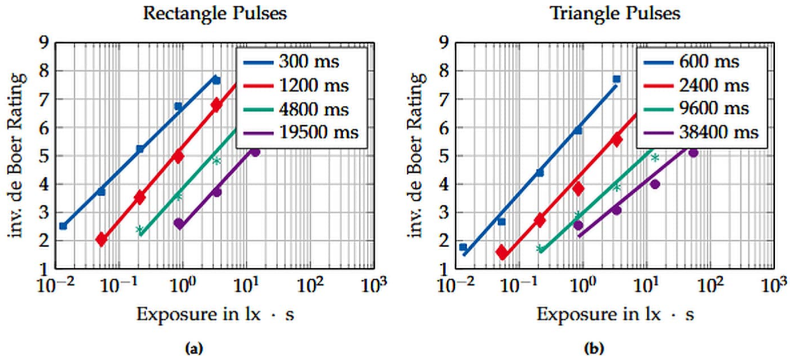


Figure 7: Inverted Glare Rating differences by rectangular or triangular pulses. Recorded was Exposure [lx*s] and presentation time. [Ref 5.].

Since for pulses with the same exposure, the intersection with the y-axis at x = 0 is always lower for the triangle pulses, the general glare perception of these pulses is lower than the perceived glare of rectangle pulses. When looking at rectangle pulses, this behaviour can not be seen and it was thereby deducted, that the slower rise of the illuminance gives the eye the chance to adapt to the to the illuminance level.

Lehnert [Ref 7.] investigated in 2001 the effects of transient glare. In a test setup he created a situation of oncoming traffic. The observers were in the driver's position behind the front part of a vehicle's body equipped with halogen headlamps with projection system. The headlamps produced a mean luminance in the area directly ahead of $Lu = 1$ cd/m^2, observer's eyes at $h = 1.13$ m. The glare source was located at the maximum available distance $d = 43$ m from the observer. The lateral displacement of the centre between both headlamps was $b = 2.58$ m. A glare angle $\alpha = 3.43$ ° was obtained. With the aid of an electronic activation of the stepper motor in the headlamp the inclination of the projection module could selectively be changed. Different glare stimuli were produced in the eye of the observer who has the impression that these glare stimuli were caused by pitching movements of a vehicle. The basic setting of the headlamps was N= - 1% , which resulted in a static basic glare of E_G = 0.2lx. A total number of 42 different glare stimuli was offered resulting from the combination of six different glare durations and seven different maxima of glare.

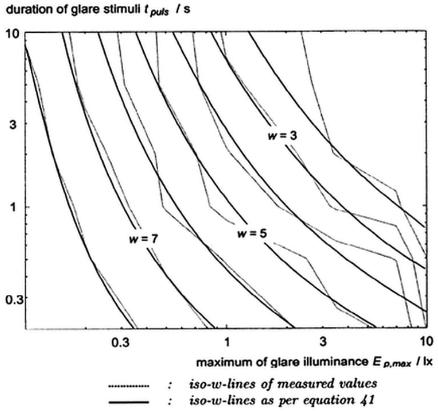


Figure 8: Lines of identical rates w = constant in the double logarithmic illustration of t_{puls} over $E_{p,max}$. [Ref 7.]
(A lower rating means a greater subjective discomfort feeling)

Fig. 8 shows the lines of identical rates w = constant. In the double logarithmic illustration of t_{puls} over $E_{p,max}$ these iso-w-lines are hyperbolae. The dotted comparative iso-w-lines are drawn in resulting from linear connection of adjacent measured points. The line $w = 5$ separating the parameter range that is felt to be uncomfortable from the one that is tolerable runs through the point $E_{p,max}$ = 1lx, t_{puls} = 1 s. Doubling the stimulus duration reduces the just acceptable maximum of glare stimulus to $E_{p,max}$ = 0,7lx. Halving the stimulus duration increases the just acceptable maximum of glare stimulus to $E_{p,max}$ = 1.9 lx.

6. Field Test: Headlamp Glare Evaluations

Zydek presented 2014 results of discomfort glare [Ref. 8].

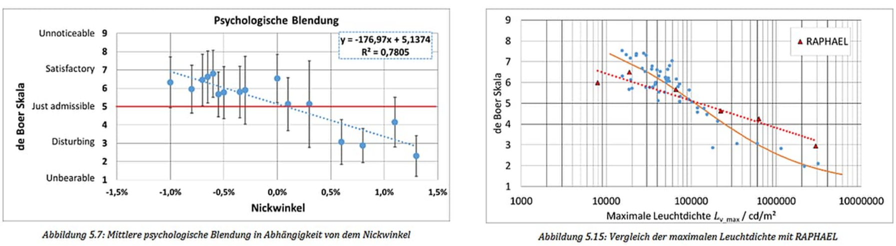


Figure 9: Average discomfort glare depending on pitch angle by load (left). De Boer rating of average luminance $L_{V\ max}$ of test vehicles (right) [Ref 8].

In a large scale outdoor test he investigated the influence of load, glare luminance and glare illuminance on discomfort. 25 different vehicles (HAL; XEN, LED), 3 different load levels (0%, 50%, 100%) were used in a dynamic test. Varying pitch angles were created depending on the chassis/suspension from -1% to +1.25% and thus delivering different glare situations (Fig.9). In his research, an average luminance of appr. 100.000 cd/m² delivered a de Boer rating “5”. A Δ±0,5 tolerance on the DeBoer scale (i.e. 4,5..5,5) gives span from about 80.000...150.000 cd/m².

The Laboratory of Lighting Technology (Schiller; Sprute; Haferkemper; Khanh) performed 2009 field tests [Ref 9.] on the subject’s feeling of discomfort glare. They analysed impact of optical concepts (reflexion; projection), spectrum of adaptation (HID, TH Halogen) and spectral power distribution of the glare source (HID, TH Halogen). Discomfort glare was tested for low beam using static conditions. The subject’s car as well as the glaring car was positioned in opposing traffic conditions in the middle of each lane. The distance between both cars was set to 50 m, which represents the worst case for glare. The mean values in Fig. 10 show that with TH and the HID projection system (TH Lens and HID Lens) glare ratings seem to be very similar for both spectra of adaptation.

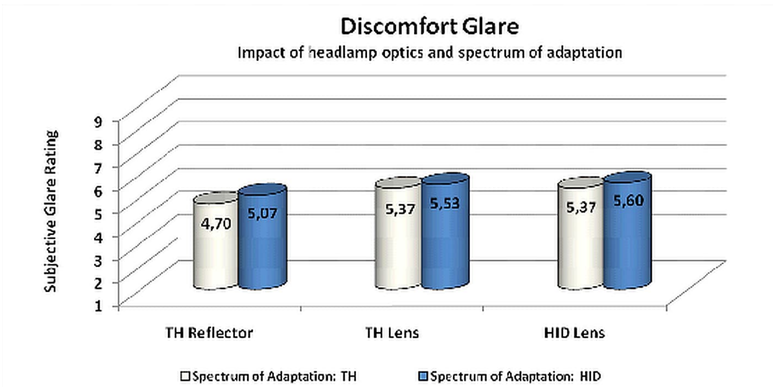


Figure 10: Impact of headlamp optics and spectrum of adaptation on discomfort glare rating [Ref 9.]

Johannsen [Ref 10.] presented 2025 similar real road investigations. The discomfort glare was investigated in a dynamic setting where test vehicles with different headlamp systems were oncoming on a straight dry country road. 17 participants were investigated. The test headlamps varied in luminance of the light emitting areas with Halogen or LED (see Fig. 11). The lab measured illuminance in B50L was comparable. Exception: one pair of headlamps was misaligned (maximum legal illuminance exceeded). After each pass glare had to be rated on the De Boer scale, each pair of headlamps was presented twice. All four correctly adjusted pairs of headlamps were rated as satisfactory (Range: 6.5-7.3), only the misaligned system was rated as disturbing (2.4). The LED Reference headlamp was rated as slightly more glaring (half a scale point). Some statistical verifications have been executed to proof the results.

So it can be concluded that under correct aim there is no significant difference from light source, aperture and spectrum.

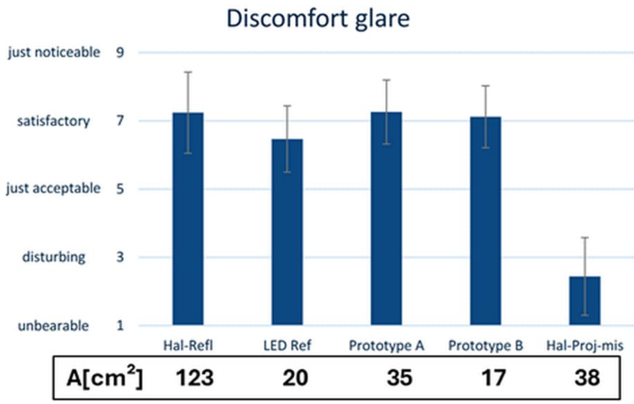


Figure 11: Discomfort glare rating impact of aperture and spectrum [Ref 10.] on real roads. Apertures added by the author from the article's text.

7. Special Investigations

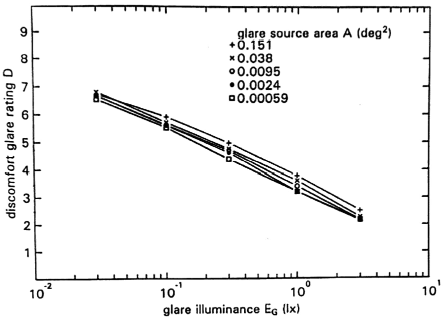


Figure 12: Measured discomfort glare rating as function of glare illuminance and glare source area [Ref 11.].

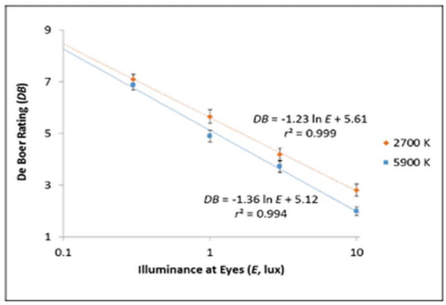


Figure 13: Mean / Standard Errors on discomfort glare rating as function of spectrum [Ref 12.]

Alferdinck [Ref 11.] investigated the effects of discomfort glare especially for Xenon headlamps in 1991. He displayed different apertures from 3x6..12x24cm in 25,50,100m, achieving a big variation in perceived angle (Fig. 12). The test persons had to perform a tracking task and made each time a de Boer Glare rating for discomfort. His results show a very small influence on de Boer ratings. His findings were that halving the size increases the glare about 0,1 de Boer points.

Bullough [Ref 12.] investigated 2019 effects of spectral influence on discomfort. He used LED of different colour temperature (2700K vs. 5900K) to check spectral influence with very high glare illumination (Fig. 13). With extreme glare illumination of 3 lux and more there is a spectral impact of about 1 de Boer Scale.

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