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Glare Causes in Nighttime Traffic - How can we minimize the risk of glaring headlights to increase traffic safety?

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1. Abstract

Glare is generally described as a visual condition in which one feels uncomfortable or visual performance is reduced due to unsuitable lighting conditions. Drivers especially encounter the issue of glare in nighttime traffic. Besides the uncomfortable feeling for the driver the reduction of visual performance due to glare can affect safety. Therefore, regulations regarding photometric limits and the continuous development of adaptive front lighting systems aim to minimize the risk of glare in nighttime traffic. However, since glare events still occur, it is necessary to continue the investigation of glare issues. Here the question arises whether the basic conditions, such as photometric limits and headlight system design, are decisive, or whether circumstances that can change during the operational life of a vehicle (headlight adjustment, soil contamination, etc.) are mainly responsible for increasing the glare risk.

Therefore, the aim of this paper is to identify glare causes that occur during the product life cycle of a vehicle. These causes should then be assigned to the different phases in the product life cycle (production, operation) and evaluated according to their relevance. The findings of the research should be used to address contributors (OEMs, suppliers, legislation, society) to the respective causes of glare, who can play a decisive role in remedying or at least improving the current situation. It is crucial to draw the attention of all parties involved to the glare issue in order to have the chance to reduce glare for all road users and improve safety in nighttime traffic.

Keywords: Glare, Adaptive lighting

2. Glare Causes

According to the Commission International de l'Éclairage (CIE) 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 luminance contrasts" [1]. Glare can be classified into two different effect types. While disability glare describes the objective glare effect ('glare that impairs the vision of objects without necessarily causing discomfort' [1]), the subjectively perceived glare effect is called discomfort glare ('glare that causes discomfort without necessarily impairing the vision of objects' [1]). To address the question of actions for glare reduction, it is essential to understand which photometric factor serves as the main contributor to these glare effects. For this purpose, several studies will be considered that have examined the causes of glare and their effects.

Locher et al. conducted studies to determine the influence of glare illuminance and the luminance of the light source on disability and discomfort glare [2]. For this purpose, a light source was positioned at the angular position of measurement point B50L [3]. In the execution of the experiment, on one hand, the glare illuminance at the observer's eye was set to values of 0.4 lx (value within UNECE regulations [3]), 0.8 lx, and 1.6 lx (values outside UNECE regulations [3]) with a constant luminance of the light source of 100,000 cd m^{-2}; on the other hand, the luminance of the light source was varied in the range of 50,000 cd m^{-2} to 250,000 cd m^{-2} at a constant glare illuminance of 0.4 lx. During the experiment, the participants had the task to recognize the orientation of a Landolt ring at various contrast levels. This serves to determine the threshold contrast and thus the visual performance of the subjects depending on the glare situation (disability glare). Additionally, the subjects rated their subjective glare perception on the de Boer scale, ranging from 1 – unbearable glare to 5 – just acceptable glare and up to 9 – just noticeable glare (discomfort glare). [2]

Figures 1 and 2 show the results of the investigation. It can be seen that for the disability and discomfort glare the glare illuminance at the observer's eye plays a significant role. The results for disability glare indicate that as the glare illuminance increases, the threshold contrast which is necessary for the recognition of the Landolt ring orientation also increases (see Figure 1 above). The analysis of the results for discomfort glare (Figure 1 below) also shows the significant impact of glare illuminance on subjective glare perception. While at the value of 0.4 lx the glare, with a de Boer value of 5.32, is perceived within the "not glaring" range, it falls below the critical threshold of 5 at the other two glare illuminance levels. Thus, it becomes clear that the legally required maximum values for glare assessment are appropriate for this purpose. [2]

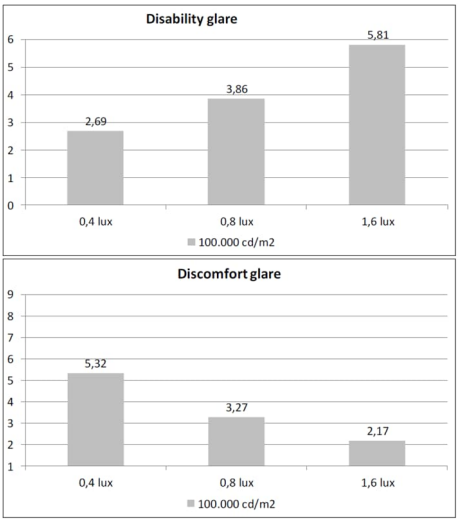

Figure 1: Impact of illuminance on disability and discomfort glare [2].

In contrast, when the luminance level of the light source is varied, there is no significant effect on either disability or discomfort glare (see Figure 2). Furthermore, the discomfort glare is rated as just acceptable due to the legally permissible glare illuminance of 0.4 lx, regardless of the luminance level (glare rating on the de Boer scale ≥ 5). [2]

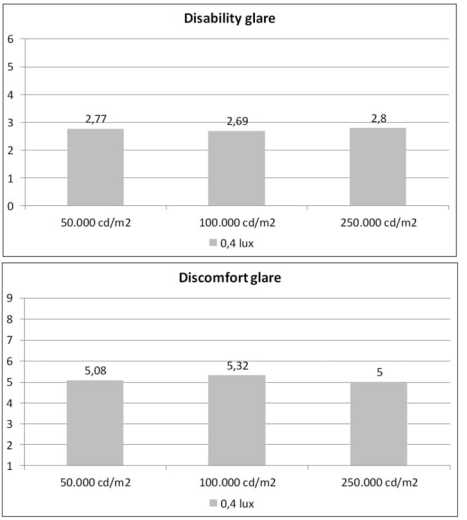

Figure 2: Impact of luminance on disability and discomfort glare [2].

Furthermore, Locher and Kley [4] show that the light source (halogen tungsten bulb, HID, LED) does not have a significant impact on the disability glare for the headlights (see Table 1). The discomfort glare is also not significantly affected by the choice of the light source (halogen tungsten bulb, HID). Even if the two LED prototype headlights shift the de Boer rating one level towards glare, they are still rated higher than 5 and thus considered as not glaring. [4]

Table 1: Glare impact of different light sources [4].

Glare type	Halogen reflection	Halogen projection	HID	LED Prototype 1	LED Prototype 2
Disability (Threshold contrast)	3.78	4.00	4.24	4.50	4.16
Discomfort (de Boer rating)	6.80	6.80	6.70	5.70	5.90

The situation is different with incorrectly adjusted headlights or "tuning" retrofitting solutions. By raising the glare illuminance level above the legal limit, these significantly affect both disability and discomfort glare. Similar findings are shown by studies from Erkan et al. with retrofit LED light sources for halogen headlights. Many retrofit LED solutions are commercially available, which can be installed in halogen headlights but are not photometrically calibrated to them. This leads to an alteration of the headlight beam pattern, which can result in an increased glare potential. [4, 5]

Another aspect of the increase in glare illuminance is addressed in studies by Kosmas et al.. They show that dynamic pitch movements of the vehicle and additional loading lead to a significant increase in glare illuminance, regardless of the light source, if this is not compensated by a headlight leveling system. [6]

Furthermore, Kosmas shows that soiled headlights not only reduce the visibility range for the driver but also increases the glare risk for other road users due to stray light [7].

In general, it can be concluded that the glare illuminance is the main cause of disability and discomfort glare.

3. Basic actions to prevent glare

The last section shows that the illuminance at the driver's eye is crucial for glare. This section presents fundamental actions that can reduce glare for other road users, not only during the construction of a vehicle but also by every individual vehicle user.

3.1 Headlight adjustment

The low beam represents a compromise between maximizing the visibility range for the driver and minimizing glare for oncoming traffic. To realize this compromise in the light distribution of headlights, a clear separation of illuminated and non-illuminated areas is essential. This is achieved by creating a cutoff line. The area below the cutoff line is brightly illuminated, while the area above the cutoff line is not illuminated. Due to this high intensity difference, it is particularly important that the initial headlight adjustment is carried out very precisely and correctly. The consequences of incorrect headlight adjustment are either a reduced visibility range for the driver or an increased glare risk for other road users. The extent to which headlight aiming is influenced by various environmental conditions was examined by Hinterwälder et al. [8]. A comparison was also made between the initial headlight aiming at the end of the production line by the OEM and the headlight aiming of vehicles evaluated by the IIHS. It was found that the initial headlight adjustment at the OEM is performed within a narrow tolerance band of ± 0.2% (see Figure 3 left). At the same time, it can also be seen in Figure 3 (right) that the headlight aiming of vehicles change over time, resulting in significant variability that can also exceed the tolerance band. [8]

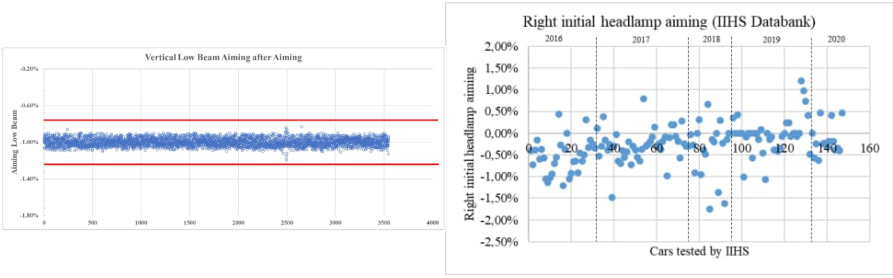

Figure 3: Vertical headlamp aiming at OEM & from IIHS databank [8].

To correct this shift in headlight aiming, it is necessary to regularly check and adjust the headlight aiming. This should be done by properly trained professionals with the appropriate equipment (digital light collection box, evened adjustment area). Furthermore, the awareness of vehicle users of the importance of headlight adjustment must be increased so that they will have the headlight aiming checked regularly.

3.2 Headlamp cleaning

The necessity of a headlight cleaning system is legally linked to the light source used and its luminous flux (≥ 2000 lm). This means that with modern LED headlight systems, where the light sources have a lower luminous flux than 2000 lm, the headlight cleaning system is no longer installed by most OEMs. Thus, the cleaning of the headlight cover also becomes the responsibility of the individual vehicle user and must be actively carried out in order to reduce stray light and thus the glare risk for other road users.

3.3 Leveling

Similar to the headlight cleaning system, the requirement for automatic headlight leveling was also linked to the light output of the light sources (≥ 2000 lm). With a change in the regulation the automatic headlight leveling will become mandatory for newly registered vehicles starting in 2027 [9]. This is an important step to compensate for load-dependent pitch movements of the vehicle and thereby reduce the resulting glare risk. In the case of particularly high-performance headlights, it would also be helpful to use a dynamic leveling system to reduce glare, as it can compensate for the dynamic inclinations that occur during driving in addition to the static load condition.

4. Adaptive light functions

The actions mentioned in the previous section are fundamental actions that are essential for glare reduction. Nevertheless, especially due to road topology effects, there may still be increases in the illuminance level at the driver's eye and thus glare events. A general adjustment of the regulatory light intensities is not adequate, as the previously described studies have shown that the currently applicable maximum values are appropriate, and only an increase in glare illuminance at the driver's eye beyond these maximum values leads to glare events. Additionally, a general reduction of the regulatory limits would lead to weaker illumination of the roadway for the driver, resulting in impaired visibility conditions. Therefore, it is necessary to find a solution that reduces the glare risk for other road users without impairing the safety-related aspect of roadway illumination in the currently experienced situation. To be able to react in such situations and reduce the glare risk, adaptive lighting functions are a promising option. For more than 10 years, adaptive driving beam (ADB) systems have been developed and used, which allow for high beam driving on rural roads without blinding other road users (see Figure 4).

Figure 4: Adaptive Driving Beam in the Audi A8 [10].

The results of the studies by Zydek presented in Table 2 show that ADB systems achieve detection ranges comparable to high beams, while they lie within the range of low beams for both disability glare and discomfort glare. [11]

Table 2: Comparison of detection distances and glare impact between different light functions [11].

Light function	Mean detection distance in m	Disability glare (threshold contrast)	Discomfort glare (de Boer rating)
Halogen Low Beam	58.20	6.40	7.60
HID Low Beam	88.40	7.44	7.20
Halogen High Beam	131.50	27.38	2.10
HID High Beam	141.30	46.51	1.70
HID ADB	120.40	7.77	7.10

The realization of an Adaptive Driving Beam is currently only possible in high beam mode, as there is no legal basis in low beam mode. The implementation of an Adaptive Low Beam could further reduce the glare risk in addition to the Adaptive Driving Beam through fully adaptive adjustment of the low beam distribution. This is because the Adaptive Driving Beam prevents glare through the high beam distribution but cannot fully compensate for topology effects, as the conventional low beam distribution is still fully present. Extended compensation of topology effects in oncoming situations would be possible with an Adaptive Low Beam distribution. For this purpose, it would be appropriate to prescribe minimum values inside the regulation for adequate basic illumination of the road and to allow the adaptive part of the light distribution to be freely designed by the OEM. Thus, adaptive light distributions for the combined low and high beam range would be possible, providing the best possible illumination for the driver while avoiding glare for other road users.

5. Conclusion

This work deals with the subject of glare prevention in nighttime road traffic to increase safety. For this purpose, studies were considered that addressed various aspects of glare. The results of these studies show that the glare illuminance at the driver's eye can be

identified as the main cause of glare, whereas the luminance of the headlights plays a significantly subordinate role in comparison.

Subsequently, various actions to avoid glare are presented, which can be divided into basic actions and extended actions. While the basic actions, such as correct headlight adjustment, headlight cleaning, and automatic headlight leveling, should fundamentally be fulfilled in order to achieve a certain level of glare avoidance, extended actions like Adaptive Low Beam distributions represent a crucial step to avoid glare for other road users in more complex situations without compromising road illumination. However, the regulatory framework must be established for the realization of such Adaptive Low Beam distributions.

In summary, it can be stated that each contributor in the product life cycle of a vehicle (suppliers, OEMs, legislators, and vehicle users) can significantly contribute to minimizing glare and thus increasing safety. On the one hand, societal understanding of the relevance of the fundamental conditions for glare prevention must be generated. On the other hand, legislators must establish the regulatory framework so that OEMs and suppliers can develop, optimize, and bring corresponding intelligent lighting systems to market.

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