Original Article

Evaluation of Disability Glare Caused by Headlights of Most Common Vehicles in Iran

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Abstract

Background and Objectives: Road traffic accident is one of the leading causes of death in some countries such as Iran. Disability glare due to headlights of vehicles can increase the risk of crashes and make dangerous conditions. This study aimed to investigate the level of glare induced by the headlights of most common vehicles in Iran. **Materials and Methods:** This cross-sectional study was conducted in a suburban road of Ilam province in 2019. The disability glare resulted from the headlights of Pride Saba GTX, Pride 131SL, Samand Soren, Peugeot 405, Megan, and Peugeot Pars was measured at the distances of 10–100 m away from the headlights. The Threshold Elevation index under the high-beam and low-beam conditions (headlight's operation modes) was obtained for the background luminance condition including 1 and 50 cd/m^2 for the age groups of 20, 35, 70, and 83 years old. **Results:** When the background luminance was 1 cd/m^2, the mean glare level caused by the high-beam mode of illumination exceeded the recommended disability glare thresholds of all age groups. When the background luminance was 50 cd/m^2, at certain longitudinal distances, glare level exceeded the disability glare thresholds of the elderly drivers (aged 70 and 83 years). At the background luminance of 1 cd/m^2, low-beam mode of illumination caused disability glare at certain distances but not in general. At the background luminance of 50 cd/m^2, low-beam mode of illumination did not cause disability glare at any distance. **Conclusion:** The results showed the mutual effect of luminance and the angle of line of sight with respect to glare source on the emergence of disability glare. The age also exhibited a significant association with the disability glare, as the highest glare levels were obtained for older drivers.

Keywords: Age, disability glare, headlight, vehicles

Introduction

Road transport plays a key and effective role in the progress toward sustainable development objectives, and therefore, maintaining its safety all the time is of particular importance in this regard.[1,2] Traffic crashes cause about 50 million injuries and 1.5 million death per year, accordingly accounting for more than 2.1% of all fatalities worldwide.[3] Road traffic crashes are the ninth leading cause of death worldwide. In Iran, the incidence of road traffic crashes and the casualties is

Access this article online	
Quick Response Code:	**Website:** www.archtrauma.com
	DOI: 10.4103/atr.atr_39_20

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How to cite this article: Mehri A, Abbasi M, Zakerian SA, Yeganeh R, Mousavi Kordmiri SH, Mohammadian F, *et al*. Evaluation of disability glare caused by headlights of most common vehicles in Iran. Arch Trauma Res 2021;10:73-9.

Received: 12-05-2020, **Revised:** 21-09-2020, **Accepted:** 26-01-2021, **Published:** 28-06-2021.

considerably higher than the global standard.[1,4] The rate of traffic fatalities is 32/100,000/year, making the traffic crashes to be the second leading cause of death and the most common cause of injuries among Iranians.[5] Driving is a visual activity and it is estimated that more than 90% of the information needed for driving are obtained through visual observation. According to statistics, the majority of roadway fatalities occur at night. In fact, traffic crashes are 3–7 times more likely to occur at night.[6,7] The high risk of traffic crashes in the nighttime can be attributed to high speed, alcohol consumption, and fatigue as well as impaired night vision.[8,9] Safe driving at night is a function of illumination,[10] and particularly, the illumination provided by vehicle's headlights.[11] On the one hand, headlights provide the illumination which is necessary to spot possible obstacles, vehicles, pedestrians, and traffic signs, but on the other hand, they may dazzle eyes of drivers approaching from the opposite side.[12-14]

The glare in the context of driving is typically caused by the headlights of oncoming vehicles.[15] Several studies have shown a relationship between glare sensitivity and night driving performance.[16,17] It has been reported that glare sensitivity increases the risk of traffic crashes.[18] Glare is also associated with slower target detection and slower driving speed on dark and winding roads.[19,20] Despite the existence of extensive evidence regarding the effects of glare on vision, there are still limited data on the actual impact of disability glare on the incidence of traffic crashes.[21] Glare is rarely seen as the sole cause of nighttime traffic crashes. A study by Hemion has shown that headlight-induced glare is the cause of 0.5%–4% of nighttime crashes.[22] In general, glare is classified into two categories: disability glare and discomfort glare.[11,20] Discomfort glare refers to difficulty in seeing, headache, fatigue, and visual discomfort.[23,24] Disability glare however refers to the loss of retinal image contrast due to the scattering of stray light within the eyes.[25] Flannagan suggests that, typically, discomfort glare is only associated with the driver's comfort, whereas disability glare is associated with his visual performance; hence, the driving safety is more influenced by the latter phenomenon.[20] The effects of disability glare are also associated with the age of the observer. This association can be attributed to the changes in the cornea and ocular media and therefore increase in the light scattering at older ages.[26] Headlights should be able to provide appropriate illumination and visibility without causing disability glare problems for the oncoming drivers.[27] Despite the importance of headlight-induced disability glare for driving safety, there has been no study on the disability glare from the headlamps of most common vehicles in Iran. To bridge this gap in the literature, this study aimed to investigate the disability glare induced by the headlights of these vehicles at both low-beam and high-beam modes.

Materials and Methods

Study type and environment

This study was a cross-sectional study that was conducted in a suburban road in Ilam province in the summer of 2019. The headlight characteristics of the studied cars can be seen in Table 1.

Inclusion and exclusion criteria

Inclusion criteria

The vehicles were all new manufactured, headlights were fault-free, and vehicle's tire pressure was optimized.

Exclusion criteria

The vehicles with impaired headlights were left out from the study. Moreover, any vehicles with nonstandard headlights were left out too.

Study instruments, equations, and procedure

Quantitative evaluation of headlight's disability glare was carried out using the Threshold Elevation Index. As shown in Equation 1, this index measures the disability glare based on the background luminance ($L_{Background}$) and the headlamp's veiling luminance (L_{veil}) (equation 2). Based on this definition, threshold elevation values >2 induce disability glare.[28]

$$\text{Threshold}_{\text{elevation}} = \frac{0.01}{0.01(\text{L}_{\text{Background}})/\text{L}_{\text{Background}} + \text{L}_{\text{veiling}}} \quad (1)$$

The veiling luminance due to stray lights depends on the luminance of the glare sources on the eye of the observer, the angle of line of sight with respect to glare source (θ), age, and pigmentation.[25,29] For 1°<θ<30°, veiling luminance can be accurately obtained by the "Age-Adjusted Stiles-Holladay Disability Glare" equation provided by Commission Internationale de l'Éclairage (CIE):[30]

$$L_{veil} = \sum\left[\frac{10}{\theta^2}.E.\left[1+(\frac{age}{70})^4\right]\right] \quad 1^{\cdot} < \theta < 30 1^{\cdot} < \theta < 30^{\cdot} \quad (2)$$

$$\theta = \frac{\left(\frac{180}{\pi}\right).d}{R} \quad (3)$$

Where:

E: Illuminance on the eye from the glare source in the plane normal to the line of sight (Lux)

θ: Angle between the line of sight and the center of the glare source (degrees)

Age: (years)

R: Longitudinal distance between the two vehicles (m)

d: Lateral distance between the two vehicles (m)

Considering the variability of road surface luminance during the night, the background luminance was considered at two levels: (i) 1 cd/m^2 for midnight, and (ii) 50 cd/m^2 for late twilight/early dawn.[28]

In this study, we had not any human subjects and the effect of age only had been seen in Equation. 2 for the calculation of L_{veil}. Since the objective was focused on the most common vehicles in Iran, we investigated the headlamps of the best-selling vehicles in the Iranian auto market.

Front screenshots of the studied headlights are provided in Figure 1.

To eliminate interfering factors such as wear and dirt, all measurements were made using new vehicles[29,31] with perfectly calibrated headlamp aim. As shown in Figure 2, measurements were made in a deserted straight roadway with two standard 3.7 m lanes without any fixed roadway lighting.

The vehicles were parked 100 m apart such that there would be a 2 m lateral distance between the driver's line of sight and the midpoint of the opposite vehicle's headlights. The distance between the vehicles was marked with traffic cones placed 10 m apart (at 10 m, 20 m, 30 m, 40 m, 50 m, 60 m, 70 m, 80 m, and 90 m marks). Considering the effect of the angle of the eyes with respect to each headlight on the resulting disability glare, at each interval, measurement was made twice, one time with one headlight covered (with dark cloth) and another time with the cover switched to the other headlights. Luminance induced by each headlight was measured with a calibrated Luxmeter (EC1, Hagner) positioned inside the vehicle in front of the driver's eye and fixed toward the driving direction at the height of 131 cm from the ground (average eye height of Iranian drivers).[32-34]

Table 2 shows, for each vehicle, the angle of line of sight with respect to each headlight (driver side and passenger side) and their midpoint. Having the luminance of headlights and their angles with respect to line of sight, Equation 1 was used to calculate the veiling luminance at the aforementioned intervals. All procedures were repeated in both low-beam and high-beam modes of headlight operation.

Results

The mean threshold elevation obtained for the studied vehicles is plotted in Figure 3.

As shown in Figure 3, when background luminance was 1 cd/m^2, the mean threshold elevation induced under high-beam condition of all headlights exceeded the threshold of disability glare, regardless of age. When background luminance was 50 cd/m^2, none of the glare levels exceeded the threshold of disability glare for ages 20 and 35 years old, regardless of distance. However, for older ages, and particularly the age of 83 years old, the illuminations coming from closer distances caused disability glare. Based on one_way ANOVA test, in both 1 cd/m^2 and 50cd/m^2 background luminance, the effect of age on the sensitivity to high-beam illumination was more apparent at distances more than 30 m. And there was a statistically significant difference between the threshold elevation in the observers who aged 83 years and those who aged 20 or 35 ($P < 0.05$) years. When background luminance was 50

Figure 1: Screenshots of the headlights of the studied vehicles

Table 1: The headlight characteristics of the studied cars

Vehicle model	Distance to the ground from headlight (cm)	Bulb power (watt)	Bulb voltage (volt)	Reflector type
Pride Saba GTX	67	55	12	Reflector
Pride 131 SL	67	55	12	Reflector
Samand Soren	71	55	12	Reflector
Peugeot 405	70	60	12	Reflector
Renault Megane	71	55	12	Reflector/projector*
Peugeot Pars	69	55	12	Reflector

*Projector in low-beam mode and reflector in high-beam mode cd/m^2, none of the low-beam-induced glare levels exceeded the thresholds of disability glare.

Table 3 shows the average illuminance (lux) level of headlights at different longitudinal inter-vehicle distances (D).

In the high-beam mode, as D decreased from 100 m to 80 m (corresponding to 1.15° to 1.43°), the increase in headlight luminance from 2.4 to 4.11 lux resulted in a gradual increase in disability glare. However, as D decreased from 80 m to 10 m (1.44° to 11.49°), based on one-way ANOVA test despite the significant increase in luminance from 4.11 to 33.83 lux, disability glare decreased by a significant amount ($P < 0.05$).

The disability glare induced by low-beam illumination exhibited more extensive variations.

The high-beam-induced levels of glare of studied vehicles in background luminances of 1 and 50 cd/m^2 are plotted in Figures 4 and 5, respectively.

Figure 2: Picture of how to measure illuminance in the eyes of drivers

As shown in Figure 4, with the background luminance of 1 cd/m^2, the levels of glare induced by all vehicles were higher than the disability glare thresholds and significantly increased with age. As shown in Figure 5, it was found that Samand Soren has the highest and Peugeot Pars has the lowest levels of glare among the studied vehicles.

Figures 6 and 7 illustrate the low-beam-induced threshold elevation of studied vehicles in the background luminance of 1 and 50 cd/m^2, respectively. As shown in Figure 6, in the longitudinal inter-vehicle distances (D) of between 100 and 50 m, the levels of glare of all vehicles were below the threshold of disability glare. As shown in Figure 7, with a background luminance of 50 cd/m^2, the threshold elevation of all vehicles was lower than the disability glare threshold of all ages.

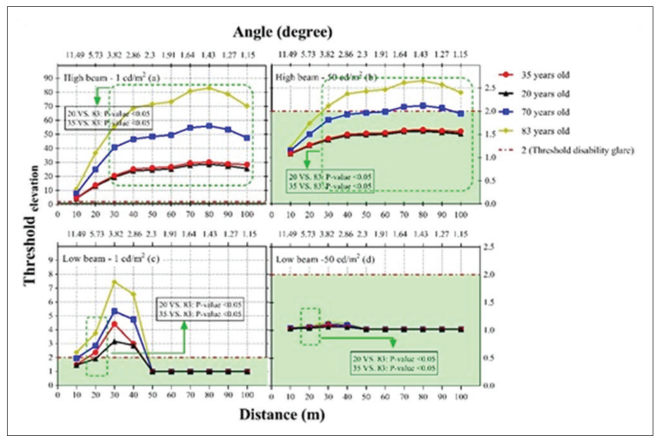

Figure 3: Mean score of threshold disability glare in the studied vehicles

Table 2: The angles of each headlight and the average car's angle to the visual line

Car headlightsangle (°)	Distance (m)									
	10	20	30	40	50	60	70	80	90	100
Driver's seat side	10°	5°	3.33°	2.5°	2°	1.66°	1.42°	1.25°	1.1°	1°
Back-seat driver side	12.9°	6.45°	4.3°	3.22°	2.58°	2.15°	1.84°	1.6°	1.43°	1.3°
Midpoint angle	11.49°	5.73°	3.82°	2.86°	2.3°	1.91°	1.64°	1.43°	1.27°	1.15°

Table 3: Illuminance (lux) at the different distances

	Longitudinal distance and angle									
	10 m and 11.49°	20 m and 5.73°	30 m and 3.82°	40 m and 2.86°	50 m and 2.3°	60 m and 1.91°	70 m and 1.64°	80 m and 1.43°	90 m and 1.27°	100 m and 1.15°
High-beam illuminance (lux) of headlight										
Mean	33.83	29.5	20	12.83	9.06	6.51	5.46	4.11	3.12	2.4
SD	22.98	13.92	9.54	5.81	3.88	2.85	2.38	1.75	1.18	0.92
Low-beam illuminance (lux) of headlight										
Mean	5.5	2.66	3.5	2	0	0	0	0	0	0
SD	3.56	3.2	2.12	1.41	0	0	0	0	0	0

SD: Standard deviation

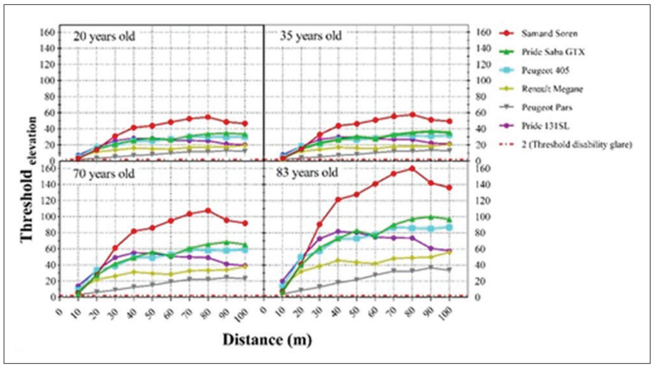

Figure 4: Mean score of threshold disability glare at high beam for nighttime driving (1 cd/m²)

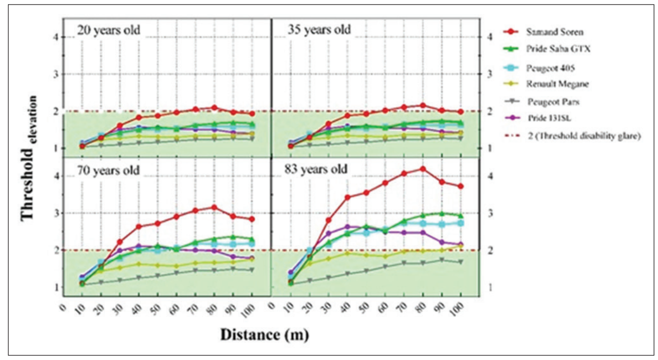

Figure 5: Mean score of threshold disability glare at high beam for late twilight/early dawn lighting driving (50 cd/m²)

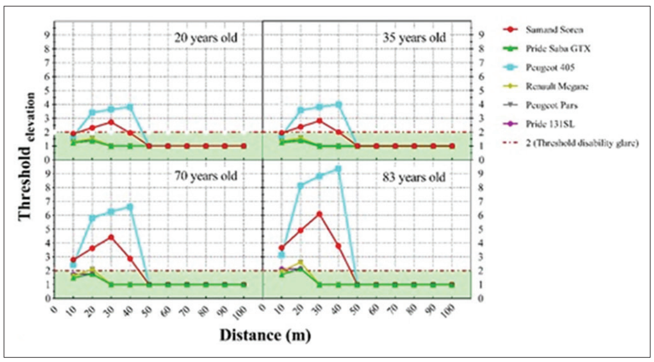

Figure 6: Mean score of threshold disability glare at low beam for nighttime driving (1 cd/m²)

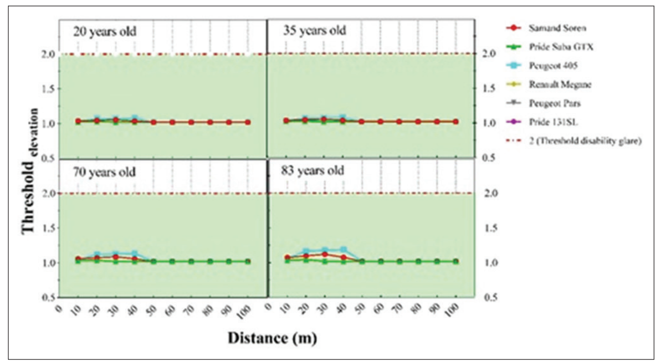

Figure 7: Mean score of threshold disability glare at low beam for late twilight/early dawn lighting driving (50 cd/m²)

Discussion

In this study, the effect of age on disability glare was included in the investigation using CIE Age-Adjusted Stiles-Holladay Disability Glare equation. Figures 3-7 show the effect of age on disability glare according to the Threshold Elevation Index. The comparison of results of different vehicles for different ages in these figures showed that there is no statistically significant difference between the levels of threshold elevation of drivers who aged 20 and 35 years; however, the levels of threshold elevation experienced by the drivers who aged 70 and 83 years were significantly higher than that of drivers who aged 20 and 35 years. An experimental study showed that the stray light produced in the eyes of 65 and 75-year-old drivers was 2 and 3 times higher than that of young and healthy drivers who aged 20–30 years, respectively.[35] A study conducted in Pakistan indicated that there is a significant relationship between driver's age and road accidents.[36] Statistics show that the world's elderly population is growing; older people over the age of 65 years also use vehicles to perform 80% of their daily routine activities.[37] In the elderly, the sensitivity to glare due to light sources increases and defects in the visual system are known to be one of the main causes of high accident rates in the elderly.[38] Therefore, disability glare is one of the main reasons for the high rate of accidents in older drivers compared to young drivers.[39]

Figure 3 shows the effect of background luminance on disability glare. As can be seen, increasing the background luminance from 1 cd/m² to 50 cd/m² has effectively reduced the levels of threshold elevation which indicates the effective effect of the background luminance in reducing the levels of disability glare.

One way to reduce disability glare is to increase the luminance of the background by installing road light. In a study conducted by Chenani *et al*., it was shown that the installation of lighting systems and increasing the luminance of the road background caused the frequency and severity of accidents to be effectively reduced.[3] Moreover, in the modeling done by Fulu Wei *et al*., it was shown that with increasing the luminance of the road background, the rate of road accidents decreased significantly.[40] It should be noted that in the meta-analysis study in Elvik *et al*., it was shown that the improvement of road lighting in 11 countries improved the background luminance resulted in a reduction in mortality and injuries of 65% and 30%, respectively.[41] Therefore, it can be concluded that the background luminance caused by light sources installed on the roads has an important role in visual performance and reducing deafening glare.

In this study, measurements were made on a straight two-way road and the distance of driver's line of sight to the headlights of oncoming vehicle was 2 m. An increase in the median width will increase the lateral distance between the vehicles in turn decreasing the levels of glare induced by opposing headlights. In addition, an increase in lateral distance of approaching vehicles can make an effective change in the light pattern received by the drivers and decrease the illuminance in their eyes.[42] Studies have shown that the roads with wider medians are safer,[43] and this argument is also consistent with the studies of Knuiman *et al*. who assessed the effect of median width on the frequency and severity of crashes in homogeneous segments of highway.[44] Accordingly, some transportation authorities have suggested that road lanes should be widened to decrease glare by increasing the lateral inter-vehicle distance and consequently the angle of line of sight with respect to the headlight.[45] This study for the first time focused on the main reasons for vehicle's crashes including disability glare of oncoming vehicle's headlights in the nighttime in Iran which is the main strength of this study. As a limitation, we could not assess the real performance of drivers in the study because of the safety reasons.

Conclusion

In this study, it was found that in the studied vehicles, high-beam modes induce higher levels of glare than the low-beam modes; however, this disability glare can be decreased by increasing the background luminance. The results showed that the mutual effects of luminance and the angle of line of sight with respect to glare source (θ) play an integral role in emergence of disability glare. The age also exhibited a significant association with the disability glare, as the highest glare level was obtained for older drivers. Other factors associated with the level of disability glare include the vertical and horizontal aim of headlights, headlights mounting height, lamp voltage, beam pattern, optical design, and lamp type. The authors' suggestions for reducing levels of glare include the use of Adaptive Forward- lighting System (AFS) system to not only increase the driver's visual performance but also control disability glare to the drivers of oncoming vehicles. Another solution is to increase the angle of line of sight with respect to headlight by increasing the lateral distance of vehicles and widening the median strip. The last suggestion is the installation of a fixed roadway lighting system to control the disability glare by increasing the background luminance.

Acknowledgments

This study was supported by a grant from Neyshabur University of Medical Sciences (Grant Number: 29741-27-04-95). The authors are grateful for the financial support provided by the mentioned center.

Financial support and sponsorship

This article is the result of a research project entitled "Evaluation of disability glare caused by headlights of most common vehicles in Iran" with code: 96226 that is approved (Approval research ethics ID IR. NUMS. REC.1396.24) and funded by the Neyshabour University of Medical Sciences.

Conflicts of interest

There are no conflicts of interest.

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