# BLINDED BY THE LIGHT – THE EFFECTS OF VEHICLE HEADLIGHT GLARE ON NIGHTTIME DRIVING

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Paper Number: 26-280

## ABSTRACT

Vehicle headlight glare remains an important road safety concern amid evolving vehicle lighting technologies and designs. This study presents a novel on-road assessment of both discomfort glare and disability glare by integrating subjective ratings, objective detection–response performance, and driver self-reports under realistic nighttime driving conditions. Twenty-three drivers completed controlled test-track drives while exposed to nine vehicles with varying headlight system types and mounting heights. Results showed that discomfort glare was strongly influenced by illuminance and mounting height, while disability glare effects were smaller but systematic, with longer response times observed under HID and LED conditions. Questionnaire findings revealed frequent real-world glare exposure, visual disturbances, and emotional responses, including stress and irritation. Together, these findings help inform performance-based evaluation approaches to reduce glare while preserving optimal nighttime visibility as vehicle lighting technologies continue to evolve.

**Keywords: Vehicle Headlight Glare, Road Safety, Discomfort Glare, Disability Glare, Human Factors**

## INTRODUCTION

Driving is primarily a visual task that requires clear visibility of the road ahead, other road users, and potential road hazards. However, trends in vehicle design, particularly the adoption of brighter headlights and the increasing prevalence of taller vehicles, have renewed attention on the potential impact of vehicle headlight glare on driving performance and overall visibility of the road (1). The increasing use of advanced lighting technologies is partly driven by the need to support advanced driver assistance systems (ADAS) (2, 8, 9, 11). These systems rely on high-quality forward illumination to ensure proper camera performance in low-light conditions. The use of HID (high-intensity discharge) and LED (light-emitting diode) bulbs provide an advantage with enhanced energy efficiency, design flexibility (i.e., different shapes) and longevity. However, with newer technologies, these types of headlights are not only more prevalent in vehicles in the market today, but often provide higher luminous output and are more frequently installed on vehicles with higher mounting positions (20, 22). With increased use of brighter and higher mounted headlights comes with increasing concern and complaints of vehicle headlight glare. Across North America and Europe, consumers are reporting worsening problems with nighttime vehicle headlight glare. Transport Canada (TC) identifies vehicle headlight glare as a frequent source of consumer complaints, reflecting reported public concern rather than confirmed safety defects.

Vehicle headlight-related glare is classically distinguished into two types: discomfort glare and disability glare (14, 15). Discomfort glare is the subjective experience of annoyance, irritation, stress, and/or visual pain when exposed to vehicle headlights. These are typically measured using subjective rating scales such as the *De Boer Scale for Rating Discomfort Glare* (17) and collecting drivers' perceptions, attitudes, and opinions through surveys. Although many define discomfort glare as a psychological experience, driver responses collected from a European Consumer Study in 2024 reported that prolonged exposure to bright light has led to physiological and physical experiences such as seeing afterimages, light haze, and pain to the eyes (5). In contrast, disability glare is reflected in objectively assessable decrements in visual performance, such as reduced contrast sensitivity and visibility, leading to poorer driving performance and delayed or missed detection of road hazards. The two forms of glare do not always co-occur (1, 15). Although there is growing literature addressing the concern of discomfort glare, there is limited empirical evidence for disability glare and how vehicle headlight glare affects visibility, driving performance and reaction times to road hazards. Much of the existing disability-glare literature is either laboratory-based or limited in ecological validity, conducted in a controlled laboratory setting with little to no real-life scenarios, (4) or results were restricted to an unrepresentative sample of road users (e.g., younger drivers only) (24).

In a recent study conducted by the Transportation Research Laboratory in the United Kingdom (UK) (12), a total of 1,850 responses were collected in nationwide survey distributed across the UK to gain insights on drivers' perception and experience with vehicle headlight glare. Findings show that drivers perceived headlights to be too bright, with more than half of the respondents reported that they have stopped or reduced driving at night to avoid encountering them (12). Thirty-nine percent reported that they regularly get dazzled by oncoming vehicle headlights. Similarly, a study done in the Czech Republic found that the majority of their drivers (n=539) experienced glare at least once a week or daily citing white-bluish light to be the source (3). At Transport Canada, investigations are ongoing by examining the headlight glare related consumer complaints received to their Motor Vehicle Safety Call Center from 2024-2025 (22). The study highlights public concern regarding headlight glare and its effects on visibility, comfort, and perceived road safety. Results show that drivers felt glare has intensified in recent years, which may reflect recent trends of newer and brighter lighting technologies. Several drivers identified daytime running lights (DRLs) as a source of discomfort in low-light conditions. Many likened glare to impairment ("as dangerous as drunk driving") and reported being unable to identify the make or model of offending vehicles due to the intensity of the light. Drivers also reported physical and emotional effects such as headaches, eye strain, anxiety, and explicit avoidance of night driving. The findings suggest that glare is a multifactorial issue, shaped by a combination of vehicle-related factors (lighting intensity, LED colour, headlight height, alignment, automated high-beam) (23). The strong influence of environmental conditions, such as darkness, other sources of lighting, wet pavement, rural roads, and adverse weather, also underscores glare's context-dependent nature (12, 13). Objectively, research has found that higher levels of illuminance (i.e., brighter headlights) were associated with higher reports of glare. Sport Utility Vehicles (SUVs) and pickup trucks equipped with LED headlights as well as environmental factors were also key factors that increased the likelihood of glare (12). The Insurance Institute for Highway Safety (IIHS) in the U.S. developed a headlight test and rating protocol for measuring and rating on-road illumination provided by passenger vehicle headlights. This procedure measured LUX on different road curvatures and segments to examine illumination levels associated with reported discomfort glare as subjectively measured by the *De Boer Scale for Discomfort Glare* (17). In summary, they found that at distances between 5 and 10m, vehicles with a LUX value of greater than 10 were more likely to cause discomfort glare (18, 19). However, when headlights are acceptable according to their rating system, the IIHS have found that good headlights would not only aid in increasing road visibility but also not cause excessive headlight glare and reduce overall night-time single vehicle and pedestrian crashes by 19% and 23% respectively (25).

There are still knowledge gaps on which key properties of the headlight play a significant role in inducing vehicle headlight glare. The goal of this study is to address this knowledge gap by examining how vehicle headlight glare affects both discomfort and disability glare under on-road conditions. Different vehicle headlight configurations, varying in mounting height, were evaluated to identify key factors and thresholds influencing glare. Drivers' perceptions and opinions were collected to assess discomfort glare, while objective measures - including a visual reaction time task - were used to quantify disability glare and examine how subjective perceptions relate to measurable impacts on visual performance. The broader objective is to inform ongoing research, policy development, and potential regulatory considerations related to vehicle lighting, supporting Transport Canada in developing evidence-based guidelines and potential regulations for vehicle headlight design that balance improved driver visibility from new technologies with safety for all road users.

**Research Questions**

In summary, our research aims to address the following questions:

1) Do vehicle headlights affect both discomfort and disability glare? If so, what subjective and objective measures reflect the experience of vehicle headlight glare? Our hypotheses are as follows:
   - $H_1$: Vehicle headlight glare will induce discomfort glare as reflected by worse subjective glare ratings.
   - $H_2$: Vehicle headlight glare will induce disability glare as indicated by slower response times and increased number of misses to events on the road.

2) Which specific headlight design element has significant relevance in influencing discomfort or disability glare? Our hypotheses are as follows:

- $H_3$: Vehicle headlight system type (halogen, HID, LED) will differentially affect glare outcomes, reflected in drivers' discomfort glare ratings and objective measures of disability glare (e.g., reaction time).
- $H_4$: Higher mounted headlights will be associated with increased glare outcomes.

## METHODS

### Motor Vehicle Test Centre (MVTC)

The on-road study occurred at Transport Canada's Motor Vehicle Test Centre in Blainville, Quebec. The private test track used for the experiment is a 6.9 km loop. Nine target vehicles, each equipped with different headlight characteristics (e.g., headlight type, mounting height) were selected from TC's existing fleet based on availability and placed all around the track. The target vehicles were parked at set locations on the opposing lane of the test track (***Figure 1.***). The spacing between target vehicles was 415 meters (m) along the straight sections of the track. Headlight illuminance was measured using a LUX meter mounted at drivers' eye level following the IIHS protocol (19).

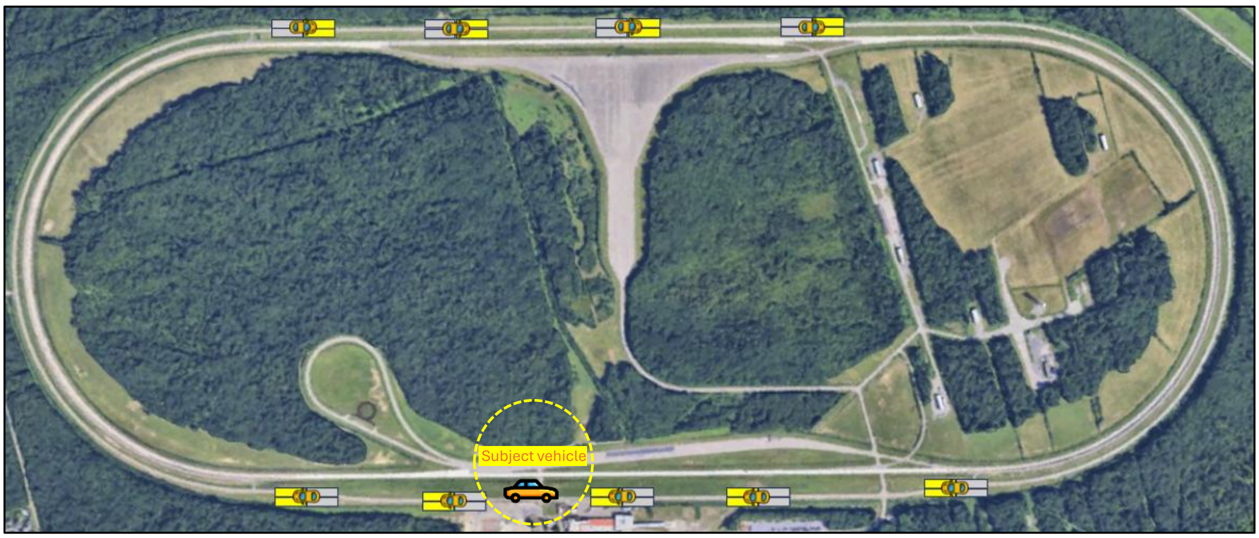


***Figure 1.*** A 6.9 km private track was used for on-road testing. Nine target vehicles were placed around the track as indicated by the pin icons on the figure. Subject vehicle starting position remains the same for all laps.

Participants all drove the same subject vehicle, a common sedan in Canada (***Figure 2.***), equipped with a data acquisition system to collect real-time driving data at 100Hz. The system collects data on vehicle position and dynamic data such as longitudinal and lateral speed / position. The accuracy of the GPS was augmented using a portable GPS base station. The infotainment screen was turned off, and no driver assistance features were active during the study. Video and audio data were also recorded using night cameras.

***Figure 2.*** Subject vehicle that all participants drove during the experiment.

To assess discomfort glare, the *De Boer Scale for Discomfort Glare* (17) was administered. Participants were asked *"from a scale of 1 – 9, how did the glare affect you?"* The original scale ranged from *1 = unbearable to 9 = unnoticeable.* To reduce response error, we presented a reversed numeric mapping and then explicitly anchored the endpoints verbally; scores are reported such that higher values indicate greater discomfort (thus *1 = unnoticeable and 9 = unbearable*). A self-report post drive questionnaire was administered to collect data on drivers' opinions and experiences with headlight glare.

A head-mounted Detection Response Task (DRT) device was fitted onto the participants ***(Figure 3.)***, following the ISO 17488 Section 6.3.2.1 protocol (20). Although not intended to measure performance under glare, the DRT serves as a standardized detection task. The metrics collected with this DRT system, specifically response times and misses, offer insights into the potential impact of disability glare, impairing drivers' ability to detect visual stimuli. The DRT system presented a red-light stimulus on a light stalk at randomized intervals of 3-5 seconds. Like the red light from a traffic signal or lead vehicle braking. A finger switch attached to the index finger and thumb of the participant's non-dominant hand was used to record responses. Participants were instructed to press the switch each time they detected the red-light stimulus and their response performance was recorded.


***Figure 3.*** Head-mounted DRT equipped with a participant. Red stimulus was presented on the light stalk. Participants were expected to click on the finger switch every time they saw the red light.

**Participants & Procedure**

Participants had to have a valid driver's license of Ontario G or Quebec Class 5 or equivalent and be at least 18+ years of age to participate in the study. A total of 23 participants completed the study, with the median age of 27.5 years old. When it comes to driving experience, the median of the *average kilometers driven per year* is ~15,000 km with more than half of the participants reporting that they drive at night almost every day / a few days a week. The study was approved by the Research Ethics Board of Veritas (reference #2017-30). Participants were told to bring any visual aid they require when driving (e.g., prescription glasses).

Participants arrived at the MVTC during timeslots that occurred after the sun had set and it was completely dark. Upon arrival and a brief introduction, they were provided with an informed consent form, which they read and signed before proceeding. A calibration exercise followed, during which participants were exposed to several headlights such as daytime running lights, low beams, and high beams. They rated their level of discomfort glare of each one using the *De Boer Scale for Discomfort Glare* (17). Participants started with a practice drive that was completed in a clockwise direction to allow familiarization of the road layout, the subject vehicle controls, and the DRT. Participants were instructed to drive manually and maintain a speed of 50km/h. Following the practice drive, data collection began with all experimental drives conducted in a counterclockwise direction. A within-subjects design was implemented for this experiment where each participant completed 3 laps around the test track, with a short break between laps. During the experimental drives, participants encountered 9 target vehicles with their low beam headlights on. The headlights of the target vehicles were not visible during the practice drive due to the reverse direction of travel. All headlight encounters occurred on straight segments of the track due to potential performance confounds of driving on curved roads. After passing each target vehicle, participants were given approximately 7s before being asked to verbally report their discomfort glare rating using the *De Boer Scale for Discomfort Glare* (17). The 7s interval was selected based on research indicating that this is the approximate time required for visual recovery following glare exposure (6, 7). Upon completing all 3 laps, participants filled out a post-drive questionnaire on a laptop. This included demographic questions and items assessing their general experiences and perceptions of vehicle headlight glare.

## RESULTS

### Analysis – Independent Variables

Refer to ***Table 1.*** for detailed values of the independent variables for each target vehicle. The independent variables are defined and grouped by the following:

1) Headlight system type: physical properties of the light bulb used in the headlights and how light is being generated:
    - Halogen
    - HID
    - LED

2) Headlight mounting height grouping (low vs. medium vs. high): taken from low beam headlights measured in millimeters (mm).
    - Low: 740 - 780
    - Medium: 808 - 815
    - High: 880 - 1075

| TARGET VEHICLE | HEADLIGHT TYPE (HAL – HID – LED) | HEADLIGHT MOUNTING HEIGHT (mm) (LOW-MED-HI) | HEADLIGHT ILLUMINANCE (LUX) |
|---|---|---|---|
| Acadia | Halogen | Medium (808) | 3.78 |
| Highlander | Halogen | High (885) | 9.28 |
| Q8 | LED | Medium (815) | 2.24 |
| GLC | LED | Low (780) | 4.60 |
| Edge | HID | High (880) | 2.92 |
| XT4 | HID | Medium (810) | 14.51 |
| HRV | Halogen | Low (740) | 1.44 |
| Silverado | LED | High (1075) | 47.1 |
| Outback | HID | Low (770) | 3.92 |

***Table 1.*** Headlight properties of each target vehicle that was selected based on availability from TC's fleet.

### Analysis – Dependent Variables

The mean subjective glare ratings were calculated across the 3 laps for each target vehicle and grouping variables (vehicle headlight type and mounting height) as indicated above.

The impact of disability glare on participants' visual detection performance were examined using the DRT data. Data were segmented in 250m event windows for each target vehicle (200m from the leading edge and 50m after). This resulted in 3 -5 DRT events per segment. Data were filtered following ISO 17488, where any response time (RT) less than 100ms or greater than 2500ms were screened out from analysis. The ISO document was used as a guide for our approach and analyses of the detection response data. Both detection response times and missed detections were examined. For response time analyses, baseline-corrected DRT response times were used. This was the difference in response times between the lighting event window and before. The baseline was calculated using participants' first responses when they approached a vehicle location. For example, for a 0.30 second baseline-corrected DRT response time, the participant responded 0.30 seconds slower than baseline. For missed detection analyses, counts of missed events are recorded per participant summed across the three laps driven for each vehicle. Of the 23 participants, two were removed from the dataset due to 65% of their DRT data being missing due to equipment issues. Analyses were conducted using a repeated-measures analysis of variance (ANOVA). Where the data did not meet ANOVA assumptions, Friedman's nonparametric ANOVA was used. Tests of means were conducted using post-hoc tests (LSD or Wilcoxon) as appropriate.

Box and whisker plots are used to represent the results. The box shows the interquartile range (Q1 – Q3) with median indicated as a line. The whiskers show the range of the data and the X markers represent means.

**Results: Subjective Discomfort Glare – De Boer Ratings**

**Headlight Illuminance**

A bivariate Pearson's correlation analysis was conducted to observe the relationship between LUX values with overall mean subjective glare ratings for each target vehicle. Lux at the driver's eye was positively correlated with mean *De Boer* ratings ($r$ (204) = 0.62, $p < 0.01$) (***Figure 4.***).

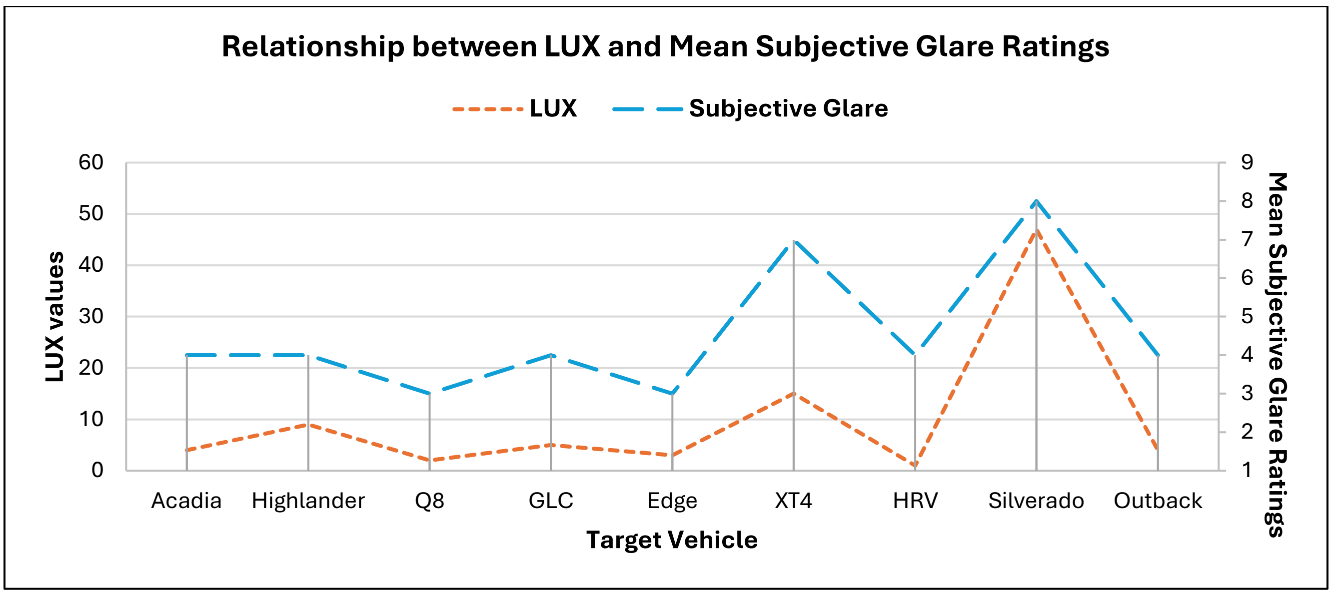


***Figure 4.*** Results show LUX positively correlated with subjective measurements of glare.

**Target Vehicles**

A 1x9 repeated measures analysis of variance (ANOVA) general linear model (GLM) showed a significant main effect of target vehicle ($F_{(8,176)} = 61.21$, $p < 0.01$). Tukey's post-hoc tests reveal that target vehicles with HID-MED headlight properties ($M = 6.74$, SD = 1.69) and LED-HI ($M = 7.91$, SD = 1.48) significantly increased overall mean subjective glare ratings compared to the other target vehicles (*Figure 5.*). The LED-HI is also significantly worse than the HID-MED vehicle, $p < 0.01$.

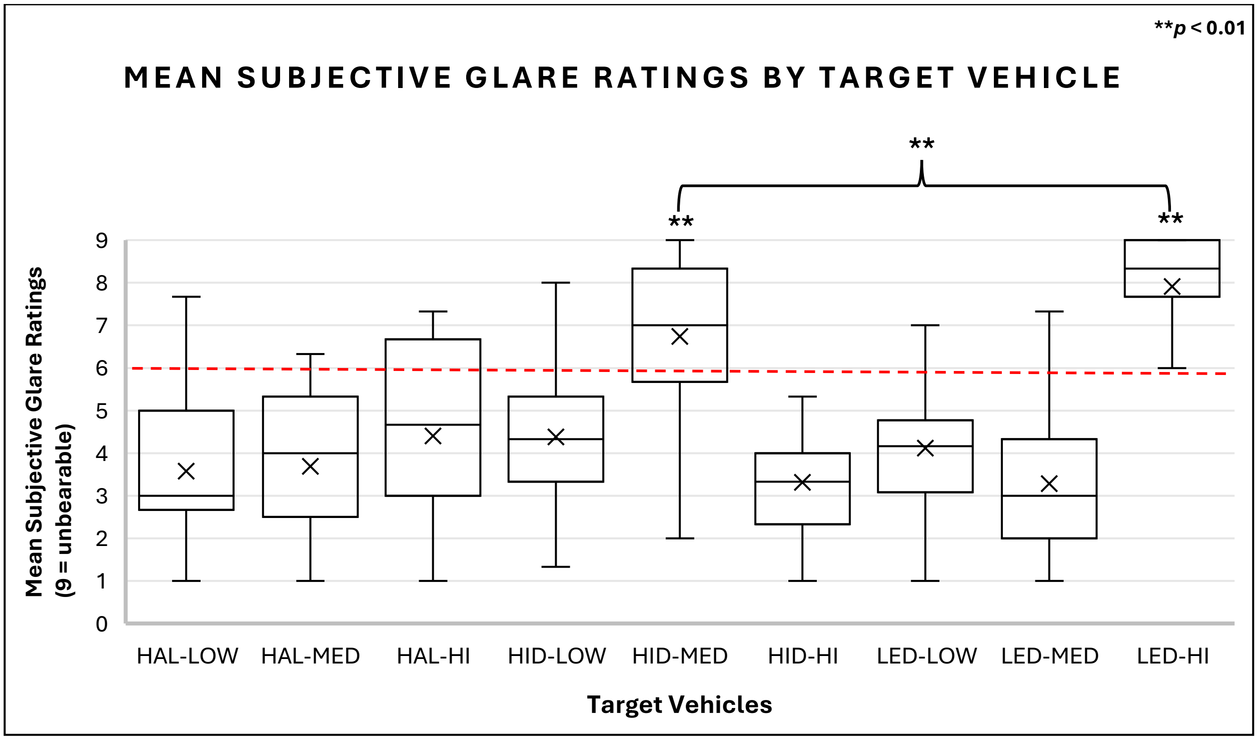


***Figure 5.*** Results show that target vehicles with HID-MED and LED-HI properties had significantly higher mean subjective glare ratings than all the other target vehicles. The LED-HI vehicle was also significantly worse than HID-MED. Horizontal dotted line indicates rating when glare becomes problematic (~ rating of 6+).

**Comparison of the Effects of Headlight Type x Mounting Height**

A 3x3 repeated measures ANOVA (GLM) was used to look at the interaction between the two independent variables (headlight type (HAL, HID, LED) and mounting height (LOW, MED, HI)) on overall mean subjective glare ratings. Results show a significant interaction between headlight type and mounting height ($F_{(4,88)} = 82.33$, $p < 0.01$) suggesting that the effect headlight type has on subjective glare ratings is dependent on how high the headlights were mounted on the vehicle. Specifically, Tukey's post-hoc tests show that LED-HI headlights ($M = 7.9$, SD = 1.48) and HID-MED headlights ($M = 6.74$, SD = 1.6) were both significantly problematic in inducing subjective glare ($p < 0.01$) compared to all of the other groups. LED-HI were also significantly worse than HID-MED ($p = 0.01$). The two factors remain to have a significant influence on subjective glare, headlight type ($F_{(2,44)} = 43.57$, $p < 0.01$) and mounting height ($F_{(2,44)} = 26.06$, $p < 0.01$) (***Figure 6.***). LED and HID headlights significantly increase mean subjective glare ratings compared to halogens ($p < 0.01$) though the two did not differ significantly from each other ($p = 0.16$). For headlight height, vehicles with HI mounting height significantly had the worst mean subjective ratings compared to MED and LOW heights.

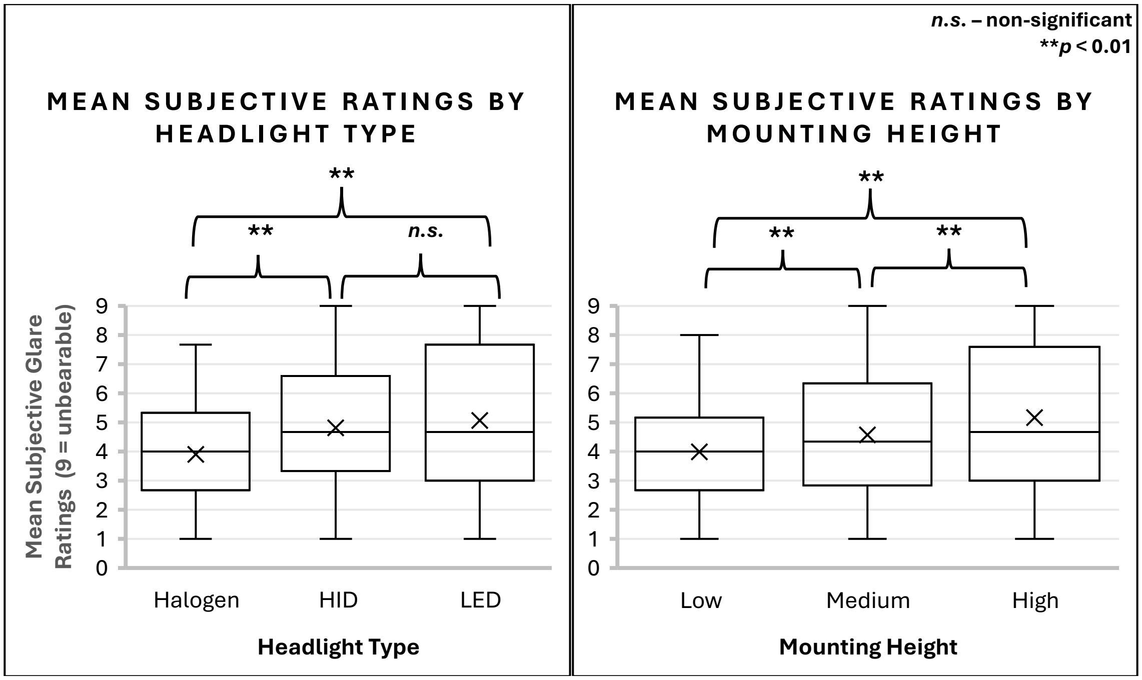


***Figure 6.*** Both factors remain to have a significant main effect on subjective glare ratings. HID and LED headlights significantly worsen mean subjective glare ratings compared to halogens, the two did not significantly differ from each other. High-mounted headlights had the highest mean glare ratings.

**Results: Objective Disability Glare - Visual Detection Performance**

**Comparison of Baseline-Corrected Response Times for Target Vehicles**

The data in ***Figure 7*** represent the baseline-corrected response times as a function of approaching the different vehicles. The RTs observed for the 9 vehicles varied from a low of 0.15s (HAL-MED) to a high of 0.30s (HID-LOW). The 1x9 repeated measures ANOVA (GLM) were significant ($F_{(8,160)} = 2.32$, $p = 0.02$). Exploration of the RTs by target vehicle indicated that the fastest responses occurred for HAL-MED ($M = 0.15$) and that 6 of the 8 other vehicles had significantly longer response times. In addition, response times were significantly lower for HAL-LOW compared to LED-MID and HID-LOW ($p < 0.05$).

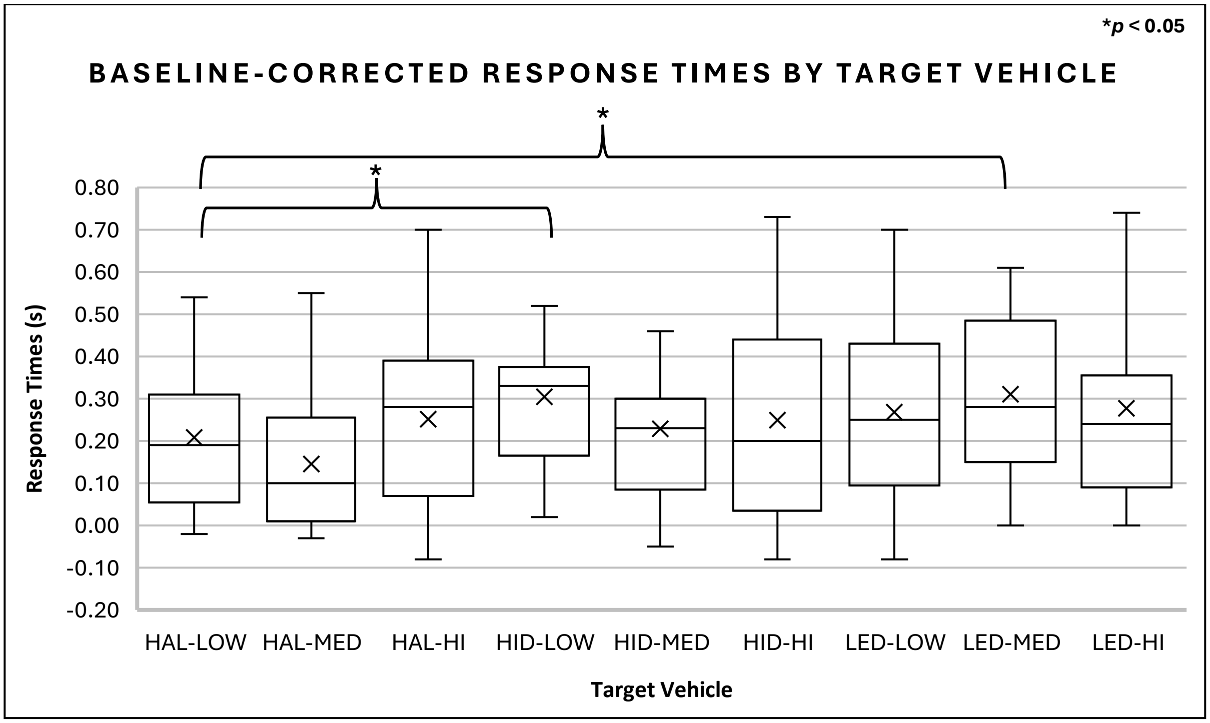


***Figure 7.*** Results show that target vehicles with HAL-MED headlight properties had the fastest response times compared to the other groups. Baseline-corrected response times to HAL-LOW headlights were also significantly lower compared to HID-LOW and LED-MED.

**Comparison of the Effects of Headlight Type x Mounting Height on Baseline-Corrected Response Times**

The effects of headlight type (HAL, HID, LED) and height (LOW, MED and HI) on the baseline-corrected response times were compared in a 3x3 repeated measures ANOVA (GLM). No significant effects were observed for the interaction or the main effect of headlight mounting height. There was, however, a main effect of headlight type ($F_{(2,40)} = 4.94$, $p = 0.01$). As shown in ***Figure 8***., participants took longer to respond to the detection light signal in the LED ($M = 0.29$, SD = 0.17, $p < 0.01$) and HID ($M = 0.26$, SD = 0.21, $p < 0.04$) conditions than in the Halogen ($M = 0.20$, SD = 0.17) condition. HID and LED headlights did not significantly differ from each other ($p = 0.64$).

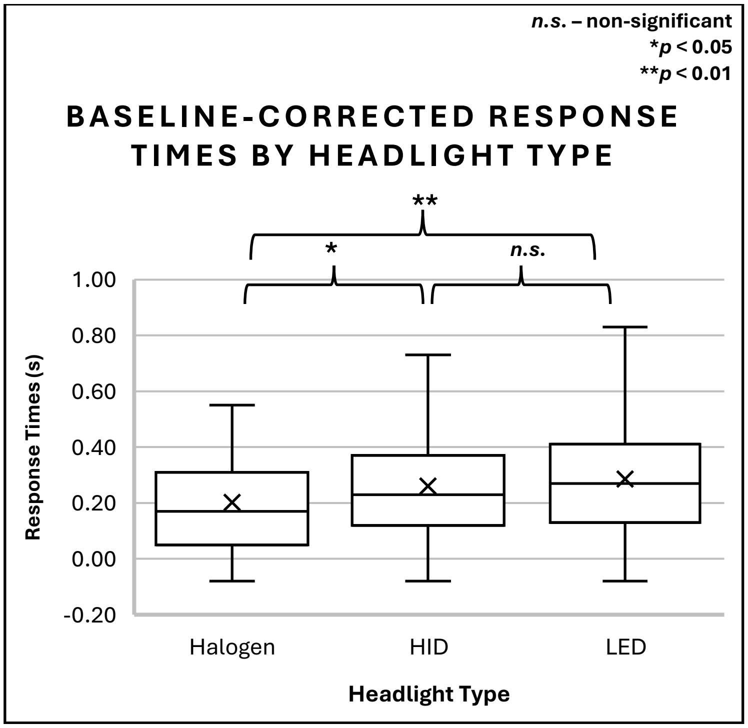


***Figure 8.*** Box and whisker plot for headlight type on baseline-corrected response times. Results show a significant main effect of headlight type where participants took longer to respond to HID and LEDs compared to Halogens.

**Comparison of Missed Detections for Target Vehicles**

Counts of missed detection presentations were analyzed when approaching the 9 vehicles on the track. Counts are summed across all 3 laps for each participant to represent their interaction with a given vehicle. Individual participant data was analyzed using 1x9 nonparametric Friedman ANOVA for repeated measures and are presented in ***Figure 9***. Mean number of missed events varied across vehicles from 0.52 (LED-LOW) to 1.67 (HID-LOW), however the analysis was not significant ($p = 0.30$).

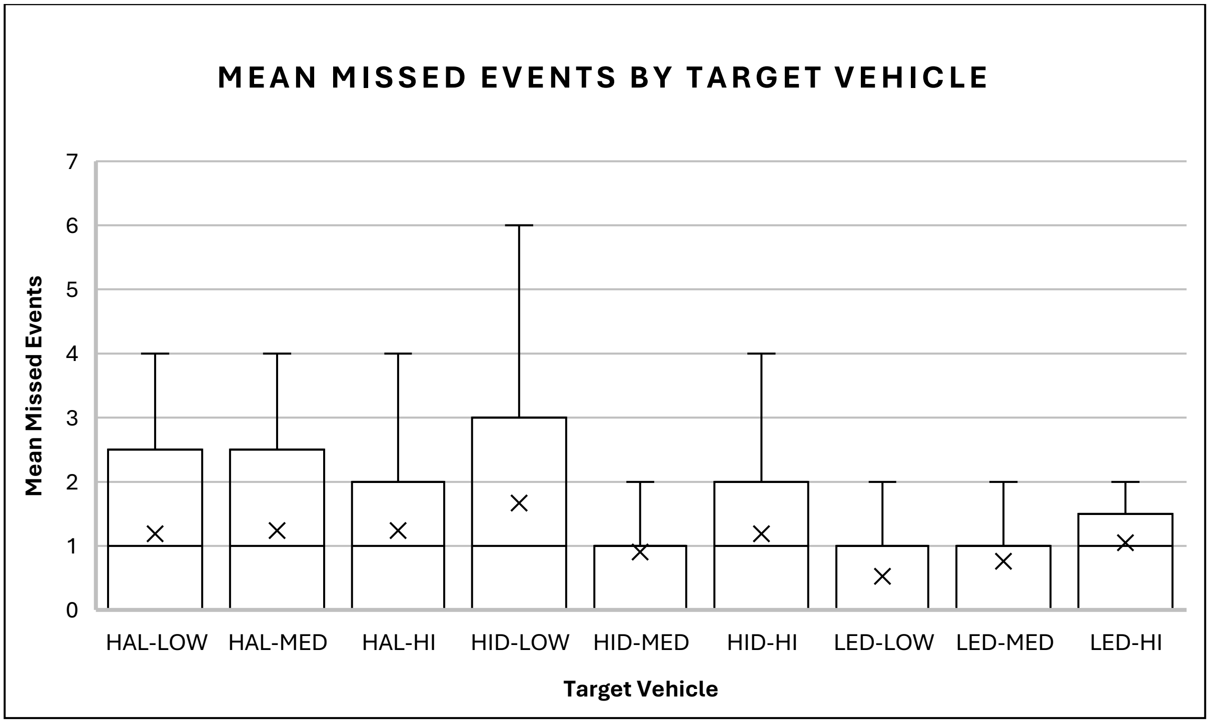


***Figure 9.*** Mean number of missed events varied by target vehicle although the analysis was not significant.

**Comparison of Missed Detections by Headlight Type**

The nonparametric Friedman ANOVA used to analyze the effects of headlight type on missed events showed that results were marginally significant at $p = 0.06$ (HAL $M = 3.66$, SD = 3.21, HID $M = 3.76$, SD = 3.59, and LED $M = 2.33$, SD = 2.44). Mean missed events were significantly lowest for LED (2.33) compared with HID (3.76) ($p < 0.02$). No other effects were significant (***Figure 10.)***. Miss rates were low across all conditions, limiting sensitivity to glare-related differences.

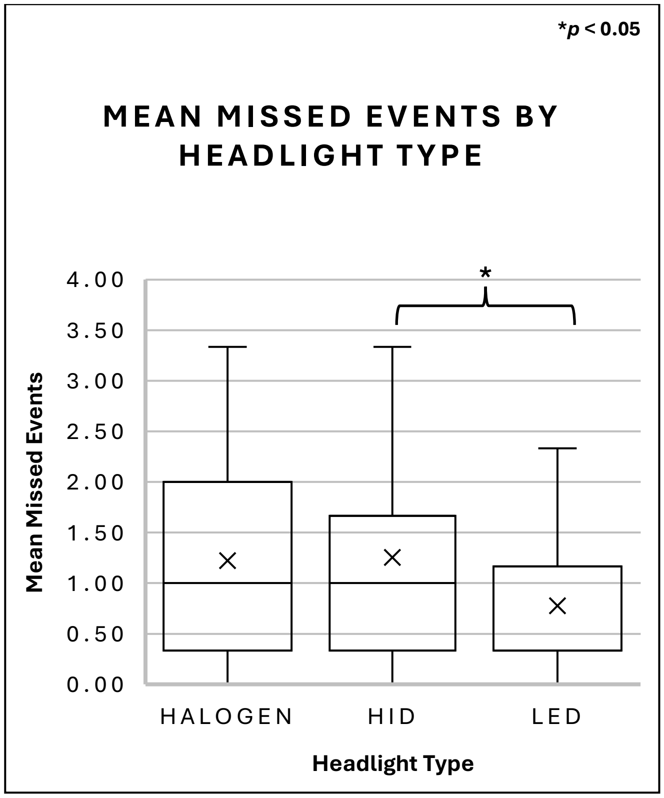


***Figure 10.*** Results show that LED headlights had significantly lower mean missed events compared to HIDs.

**Comparison of Missed Detections by Mounting Height**

Non-parametric Friedman ANOVA found no significant differences for missed event detection analyses for varying headlight mounting heights, LOW ($M$ = 3.38, SD = 2.92), MED ($M$ = 2.90, SD = 2.26), HI ($M$ = 3.46, SD = 3.27) with ($p$ = 0.76).

**Post-drive Questionnaire (Driver Experience and Behaviours)**

According to the post-drive questionnaire, 19 of the 23 participants most often drove a passenger / small SUV, while 1 reported driving large SUV/pickup truck and 3 drove mini vans. Eight participants reported not knowing what type of headlights their vehicle had. Most of the participants preferred having HIDs and LEDs headlights on their own vehicles for better road visibility.

When it comes to their general experience with headlight glare at night, 40% of the participants reported that they experienced headlight glare at night daily with most (20/23) experiencing glare at least once a week. When asked what kinds of vehicles they experienced vehicle headlight glare from the most, the majority cited glare came from all types of vehicles (passenger sedans, small and large SUVs, and pickup truck etc.). Vehicle height, headlight colour and light intensity were the top 3 physical properties that participants thought made vehicle headlight glare worse.

Participants were also asked about their behavioural responses when experiencing vehicle headlight glare from different traffic sources (e.g., rear-traffic and oncoming traffic). Overall, people adjusted their mirrors when they experienced headlight glare from the vehicle behind. When they experience headlight glare from oncoming traffic, participants tend to look away from the source and/or squint their eyes. As drivers themselves trying to prevent glaring others road users, participants reported turning off their high beams and keeping a distance from other vehicles. When asked how vehicle headlight glare affected them physically, many reported having trouble seeing,

seeing lights spots in their field of vision (e.g., after-image), and having difficulty seeing everything around the light source. Participants reported feeling stressed, annoyed, irritated and angry.

## DISCUSSION

This study examined how contemporary vehicle headlight configurations influence both discomfort glare and disability glare under realistic on-road conditions by combining subjective ratings with objective detection–response measures. Overall, the findings indicate that glare outcomes are driven primarily by the amount of light delivered to the observer's eye and its geometric relationship to the driver, rather than by headlight technology alone.

Discomfort glare was strongly affected by the interaction between headlight system characteristics and mounting height. Headlights mounted at medium to high positions (≥ 808 mm) produced substantially higher subjective glare ratings when paired with higher-output systems, particularly HID and LED configurations. In contrast, mounting height had little effect on discomfort glare for halogen-equipped vehicles. These results are consistent with prior laboratory, field, and survey studies indicating that luminance and headlight height together play a central role in perceived glare (2, 5, 14). Importantly, variability within headlight technology categories highlights that glare cannot be attributed solely to bulb type; rather, optical properties such as luminance, beam pattern, colour, and cutoff characteristics are likely contributing factors. The relatively low illuminance of one high-mounted LED vehicle further illustrates that not all high-mounted or LED-equipped headlights necessarily produce problematic glare.

Objective performance effects associated with disability glare were smaller in magnitude than subjective discomfort effects but were nevertheless systematic. Participants showed longer detection response times, relative to baseline, when exposed to HID and LED headlights compared to halogen headlights, indicating that glare can impair visual detection. In real-world driving, small delays in detection can be safety-relevant even in the absence of outright failures. Slower detection of hazards, pedestrians, or signals may increase stopping distance or reduce available reaction margins, particularly at higher speeds or in complex environments. The absence of a significant mounting-height effect on detection response performance may reflect differences in sensitivity between perceptual discomfort and task-based detection measures, rather than an absence of visual impairment. This dissociation aligns with prior research showing that discomfort glare and disability glare are related but not tightly coupled phenomena (26).

Questionnaire findings further contextualized the experimental results by demonstrating the prevalence and behavioral consequences of vehicle headlight glare in everyday driving. Forty percent of participants reported daily glare exposure, with most experiencing glare at least weekly. Glare was reported across all vehicle classes, and participants consistently identified headlight height, light colour, and intensity as primary contributors, aligning with the experimental findings. Participants described compensatory behaviors such as mirror adjustment, gaze aversion, and changes to their own driving to reduce glare to others, as well as visual disturbances and emotional responses including stress and irritation. Despite these negative experiences, many participants preferred HID or LED headlights on their own vehicles due to perceived improvements in forward visibility, highlighting the ongoing challenge of balancing driver visibility with glare impacts on other road users.

## LIMITATIONS

This study has several limitations. The selection of target vehicles was constrained by fleet availability, limiting the ability to systematically examine vehicle class, colour temperature, and a wider range of optical designs. Headlight aim was treated as a default and not experimentally manipulated, although vehicles were checked for obvious misalignment. Additionally, the relatively small sample size and controlled test-track environment may limit generalizability.

Future research should examine a broader range of headlight properties and driving contexts to better inform the safety and performance implications of both discomfort and disability glare, including how subjective glare experiences relate to measurable changes in visual detection, response behaviour, and driving decisions under real-world conditions. Such evidence is needed to support the development of performance-based evaluation criteria, thresholds, and countermeasures for vehicle lighting, particularly as newer lighting technologies become more prevalent. Further work should also consider the interaction between vehicle lighting and advanced driver assistance and automated driving systems (ADAS/ADS), including how headlight design and glare may interact with sensor performance, human-system interaction, and driver supervision during partial or conditional automation. Incorporating naturalistic driving data and assessing emerging technologies such as adaptive driving beams and matrix lighting systems will be critical for informing future standards, guidance, and potential regulatory approaches.

## CONCLUSION

This study examined how a selection of contemporary vehicle headlight configurations affect both discomfort glare and disability glare under realistic on-road conditions. By combining subjective ratings, objective detection–response measures, and driver self-reports, the results show that glare is driven primarily by measurable optical and geometric properties - particularly illuminance and mounting height - rather than lighting technology alone. Discomfort glare increased when higher-output headlights were mounted at higher positions, while objective performance effects associated with disability glare were smaller but systematic, with longer detection response times observed under HID and LED conditions compared to halogen. Questionnaire results further showed that glare is frequently experienced during nighttime driving, prompts compensatory behaviors such as gaze aversion and mirror adjustment, and is associated with visual disturbances and negative affect. Despite this, many drivers preferred HID or LED headlights on their own vehicles due to perceived visibility benefits. The dissociation between perceived discomfort and objective performance underscores the need to evaluate multiple dimensions of glare when assessing headlight safety.

Taken together, the findings indicate that vehicle headlight glare is best understood as a performance-relevant interaction between optical output, mounting geometry, and human factors, rather than as a function of lighting technology alone. These results help inform performance-based evaluation approaches to reduce glare while preserving optimal nighttime visibility, particularly as vehicle lighting systems increasingly support advanced driver assistance and automated driving functions. The on-road evidence provided here supports future research, standards development, and policy discussions aimed at balancing driver visibility with safety for all road users.

## DISCLAIMER

The views and conclusions expressed in this paper are those of the authors and do not necessarily represent the official views or policies of Transport Canada.

## ACKNOWLEDGEMENTS

The authors thank the researchers at PMG Technologies (Guillaume Pierre, Guillaume Bergeron, Guillaume Boies, and Annie Saleh) for their technical support during track testing and data collection. The authors also gratefully acknowledge the participants who took part in this study.

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