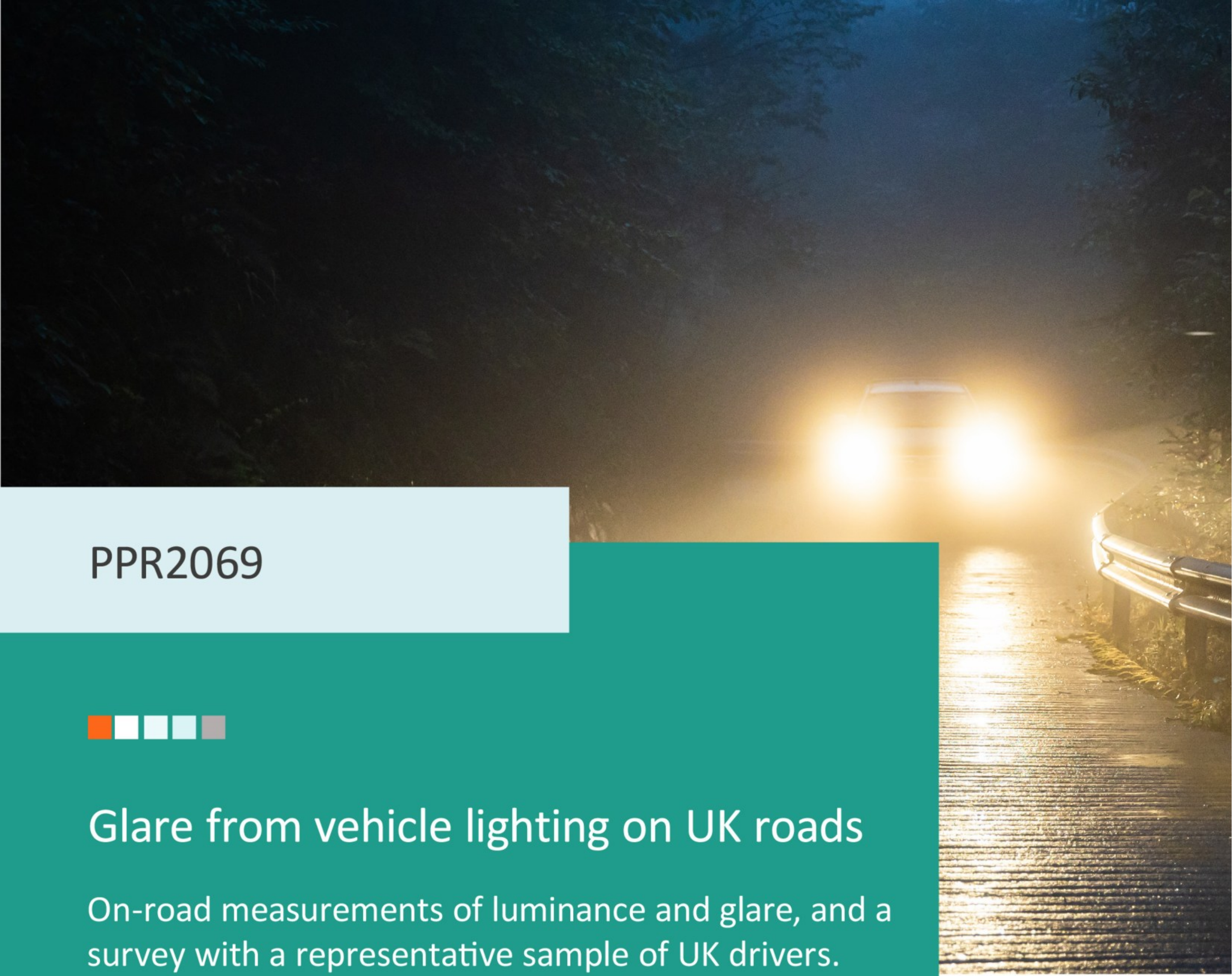

PPR2069

Glare from vehicle lighting on UK roads

On-road measurements of luminance and glare, and a survey with a representative sample of UK drivers.

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Contents

PPR2069

Executive summary

Executive summary

Overview

This project sought to gather objective data to understand the extent to which glare from vehicle lighting may occur in everyday driving, and to understand potential root causes. This report discusses the findings from two pieces of work on the project. These were on-road data collection of luminance and glare data, and a survey with a nationally representative sample of UK drivers.

The on-road data collection used an instrumented car driven at night. This was a left-hand-drive car, enabling the luminance camera to be placed in the position of a driver of a right-hand-drive car. Sensors on this vehicle measured luminance and various characteristics of the driving environment such as the orientation (pitch and roll) of the instrumented car, its location and other vehicles present. The observer in the car pressed a button any time that they experienced glare that they felt might interfere with their driving. Machine learning analysis was used to discover patterns in this data, to understand which variables were associated with glare and with high levels of luminance.

The survey was administered through the RAC panel (a regular survey administered to UK drivers by the RAC); 1,850 people answered questions about their own experience of glare, including vehicle types and driving situations in which they suffered from its effects.

Findings

Survey

The main findings from the survey were:

- The driving public perceived glare from vehicle headlamps to be an important and widespread issue when driving at night.
- Headlamps were perceived to be too bright.
- "Whiter" headlamps and those on larger vehicles were generally perceived to be especially problematic for causing glare.
- Finally, more than half of drivers reported they have stopped or reduced driving at night (or would if they could) due to their perceptions of headlamp brightness.

Glare is therefore an issue for which action to improve the situation for the driving public would be welcomed.

On-road data collection and machine learning

The main findings from the on-road data collection were as below.

For glare:

- Higher levels of luminance were associated with an increased likelihood of glare being experienced by observers (as noted above, the observers were instructed to press the glare button any time that they experienced glare that they felt might interfere with their driving). This suggests that brighter headlamps are more likely to cause glare.
- As luminance levels in the driving scene increased over the value of 40,000 cd m^{-2} the likelihood of glare being experienced by the observer showed a step change and only went up, suggesting this may be an important threshold for the experience of glare being more likely.
- Around 20% of the luminance photos in the study had maximum luminance values above this value of 40,000 cd m^{-2}, with most of these expected to be related to vehicle headlamps. This does not mean that glare is likely to be experienced around 20% of the time, as other factors also play a part (see below).
- Vehicle types (make and model) present in the scene also influenced glare. It is not known which aspects of vehicle type are influential although there is some tentative indication that larger body shapes such as SUVs and models with light-emitting diode (LED) headlamps may be more likely to be associated with glare. The vehicle type findings should be treated with extreme caution, however, and require further research to confirm. This is due to the difficulty of vehicle identification in a moving car at night, meaning there were fewer vehicles identified than was ideal. Nonetheless the vehicle type (make and model) was identified as important, and future work should seek to confirm this and expand understanding.
- The pitch and roll of the instrumented car also influenced the likelihood of glare being experienced by the observer. Occasions on which the instrumented car was travelling uphill or around a right-hand bend were associated with more likelihood of a glare event. Because a driver's eyes are more likely to fall within the "throw" of headlamps from oncoming vehicles in these situations, this is to be expected.
- Individual location was also an important variable in the model. This is presumably because there will be specific locations (for example raised features of the road such as traffic calming and crests of hills) that alter the aspect of *oncoming* vehicles such that, again, headlamp throw is more likely to fall on a driver's eyes.

For luminance:

- Location and pitch and roll of the instrumented car were the most influential variables on luminance; higher maximum luminance values were seen in some individual locations, and again in situations where the instrumented vehicle was travelling uphill or around a right-hand bend. Again this is expected based on road geometry and features at specific locations.
- The vehicle type variable had a much smaller influence on the levels of maximum luminance in the scene; this is compatible with the idea that its influence on glare was through variables

other than the brightness of its headlamps (for example vehicle height or headlamp technology rather than their absolute brightness).

Note it is not possible to state with precision what these findings mean for how often glare will be experienced when driving. This is because the perception of glare can vary with factors such as age and conditions of the eye. However, the findings provide a useful starting point to understand those variables in the driving environment that will increase the chances of a given driver experiencing glare. Put another way, it is reasonable to assume some link between the variables identified in the modelling and the experience of glare when driving, even if that link cannot currently be quantified.

Given this assumption, glare on UK roads is likely partly linked to factors that are in some way under the control of the Department for Transport (DfT) through its influence on lighting regulations (and wider influence on drivers and infrastructure design); due to the importance of individual location and vehicle orientation (pitch and roll) it is also the case that many instances of glare are likely to remain even with stronger regulation, since such real-world situations of “road geometry” are not realistically under DfT’s control. The following considerations are offered for DfT based on the findings as a whole:

Consideration 1: Improve understanding of road users’ experience of glare – for example through conducting annual glare surveys from representative samples of UK drivers to permit tracking of the issue over time.

Consideration 2: Run a public information campaign explaining to UK drivers those situations in which they may be more likely to experience glare, and those situations in which they may be more likely to cause glare to other road users when driving at night.

Consideration 3: Conduct further research to understand vehicle design parameters that result in glare focused specifically on identifying those factors that cause discomfort glare in real-world scenarios and ways in which this may be accurately, repeatably and representatively measured in a test scenario. This initial research project has provided some data suggesting that LED lighting and vehicle height may be important factors, but further research is needed to confirm this.

Consideration 4: Improve lighting regulations to reduce glare. Lighting regulations are currently based on testing the output of headlamps in relation to luminous intensity at various test points defined in relation to the headlamp itself, not the potential observer. Existing requirements in vehicle lighting regulations may therefore not be sufficient to address issues of glare from vehicle lights, since the property of light associated with glare is luminance, not luminous intensity. DfT could develop proposals for regulatory amendments building on findings from the research in Consideration 3.

Consideration 5: Conduct additional research to support further understanding of glare in driving. Several potential avenues for research are proposed.

Method

Two main activities inform the findings for this project – on-road data collection and a nationally representative survey with members of the driving public.

The on-road collection was undertaken using a bespoke instrumented vehicle. A left-hand-drive car was fitted with a forward-facing luminance camera at eye height in the passenger seat to measure luminance levels at the usual driver's eye position. Other measuring equipment installed in the car included a roof-mounted automatic number plate recognition (ANPR) camera to capture information about oncoming vehicles, an internal illuminance sensor to measure ambient lighting inside the vehicle, a dashcam to record the view of the road ahead along with GPS coordinates, and an inclinometer to measure the vehicle's pitch and roll. In addition, there was a button to be operated by an observer when they experienced "a level of glare that was felt might interfere with driving". For each drive, information was also collected about the observer's age, observer's eyesight, weather conditions and road conditions.

Approximately 50 hours of on-road data collection was carried out between March and May 2025; this was split between two datasets with different technical settings for the luminance camera. Data were collected on a variety of roads, primarily in Berkshire and Surrey, including urban and rural, lit and unlit and with a range of road geometries, features and traffic levels.

Following data collection, processing was undertaken on the datasets to synchronise the measurements from each piece of equipment. Luminance values (including mean and maximum) were calculated from the luminance images, and the ANPR data were processed (using specialist software and the government MOT API) to ascertain vehicle make and model and MOT status and expiry date for vehicles captured, where possible.

A machine learning approach (using a gradient boosting machine algorithm) was then used to analyse the data captured; this type of approach enables the identification of patterns and relationships within large multivariate datasets that are subject to noise. Two models were developed to identify factors associated with both high levels of luminance (measured by the luminance camera) and the experience of glare (measured by subjective observation).

In addition to the machine learning, case studies were extracted from the data to illustrate the findings more effectively in lay terms. Case studies were selected to show tangible examples of how variables identified in the modelling were related to the perception of glare by the observers.

The nationally representative survey was conducted with members of the driving public by the RAC to understand their perspectives and experiences of glare. Questions were asked about people's opinions on vehicle headlamps and their experiences in a variety of driving situations and contexts.

Limitations

Limitations in the study are also raised in the discussion, to aid the improvement of any methods in any future research. These are listed below in brief.

1 Data collection could be improved in any future work, particularly with respect to the number of successful ANPR identifications in driving at night, the amount of luminance data overall and the variation in things like weather conditions, which are dependent on context at the time of data collection.

2 There were challenges in synchronising ANPR measurements with associated luminance measurements and perception of glare, further complicated by the effect of road geometry and other vehicles on ANPR identification.

3 The temporal resolution of the data used in the machine learning analysis could be improved. This is particularly relevant for the luminance data.

4 The accuracy and precision of all variables could be measured and improved in future work.

5 Any future work focusing more on the subjective experience of glare could extend the positions in the vehicle at which luminance data are captured.

6 Any future work could also extend this work to use more representative samples of observers to estimate variability of glare in the population.

7 Any further analysis undertaken to quantify the light sources in the scene that are brightest (in addition to headlamps) would help to improve the conclusions drawn from this work.

8 Any future work on this dataset could also examine different luminance metrics (for example contrast).

PPR2069

Introduction

1 Introduction

1.1 Context for the current project

There are international requirements and national legislation governing vehicle lighting, designed to ensure that such lighting provides adequate illumination but does not cause problems for drivers of other vehicles. The Highway Codes in the UK are also clear that drivers should use lighting safely and without causing dazzle or discomfort for other drivers.

Despite these measures, the Department for Transport (DfT) continues to receive significant numbers of complaints from the public about glare caused by vehicle lights. DfT therefore commissioned this research with the objective of gathering scientific evidence on the extent to which glare induced by vehicle lighting may occur in everyday driving and trying to understand potential root causes.

Throughout this report we have used the term “headlamps” to refer to the main illuminating forward lights on vehicles, except when discussing the Highway Code and the survey questions (which use “headlights”). Other vehicle lighting could be relevant to the experience of glare (for example daytime running lights, brake lights) and where relevant in this report are encompassed by the more general term “vehicle lighting”.

The aim of the research was to provide information that DfT can use to reduce the likelihood of drivers experiencing glare on UK roads. The project used an instrumented vehicle to measure levels of luminance in real-world driving conditions and attempted to understand how these related to various features in the driving environment (for example vehicle headlamps present around the test vehicle, road geometry) and how these and other factors impacted the potential for drivers to experience glare. A short survey was also undertaken with a representative sample of UK drivers, facilitated by the RAC.

The project sought to provide answers to three research questions:

1. What proportion of luminance readings at driver eye height in real-world driving are likely to indicate values of luminous intensity higher than the regulatory maximum?
2. What are the factors that most predict self-reported glare in real-world driving?
3. What are the factors that most predict levels of luminance at driver eye height in real-world driving?

During the project, from the autumn of 2024 until the summer of 2025, a panel of stakeholders was engaged through initial meetings and a short survey, and then through monthly updates on project progress. Individual stakeholders also provided technical advice throughout. The stakeholders involved are listed in Appendix A.

1.2 This report

This report covers the main technical work on the project, using an instrumented vehicle to collect luminance and glare data from driving and undertaking a survey of UK drivers.

Section 0 provides some background on the terminology used to describe characteristics of light and glare and describes relevant lighting regulations and guidance.

Section 3 outlines the method (including the equipment used) and findings from the on-road data collection.

Section 4 presents the method and findings from the survey of UK drivers.

Section 5 discusses the overall findings from the project, considerations for DfT and limitations.

A previous report delivered as part of this project (Beard et al., 2025) provides a review of the literature on glare.

PPR2069

Characteristics of light and the UK regulatory framework

2 Characteristics of light and the UK regulatory framework

This section repeats part of the literature review delivered for this project (Beard et al., 2025) to define terms related to the characteristics of light (and the way it can affect human vision) and the regulatory framework for vehicle headlamps in the UK.

2.1 Characteristics of light

2.1.1 Glare

Glare is defined by the International Commission on Illumination (CIE, 2020) 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”. In short, glare can cause discomfort (discomfort glare) and can cause a reduction in visual performance (disability glare). These are defined in the following ways:

Discomfort glare: “glare that causes discomfort without necessarily impairing the vision of objects” (CIE, 2020). Another definition provided by Rae (2000, cited in Bullough et al., 2011) is “the annoying or even painful sensation that can be elicited from a bright source of light in the field of view”.

Disability glare: “glare that impairs the vision of objects without necessarily causing discomfort” (CIE, 2020). Rae (2000, cited in Bullough et al., 2011) defines this as “the reduction in visibility that a bright light might cause”.

2.1.2 Light and brightness

The absolute physical power of light is measured by radiometry as spectral flux or power (measured in watts). However, when we talk about light and brightness, we generally think of how things look. While this is obviously related to the power of the light in a scene, it is not directly related to it because, among other reasons, the visual system has different sensitivity to different colours. The perceived brightness of light experienced by the human eye is therefore measured using photometric (as opposed to radiometric) units that account for the visual system’s differing sensitivity to different colours by “weighting” the relative contribution of each colour proportionally to the eye’s sensitivity (the luminosity function). There are several photometric quantities relevant to the assessment of glare, which are defined in the following sections.

2.1.3 Luminous flux

Luminous flux is the total amount of light emitted from a light source and is measured in lumens. Luminous flux does not give us a good indication of brightness as brightness depends upon the observer’s distance from the light source and the spread of the light.

2.1.4 Illuminance

Illuminance is the total luminous flux that lands on a surface per unit area. It is measured in lux or lumens m^{-2}. As with luminous flux, illuminance does not give us a good indication of brightness since it is a measure of light incident upon a surface and thus is dependent upon the surface's distance from the light source, its perceived brightness depending upon the reflectance of the surface.

2.1.5 Luminous intensity

Luminous intensity is a measure of the colour-corrected power emitted by a light in a particular direction, measured in candelas. It is from this metric that we can derive a measure akin to perceptual brightness (luminance) by considering its average intensity over a unit of space.

2.1.6 Luminance

Luminance is the measure of luminous intensity per unit area of light travelling in a particular direction. It is measured in candelas m^{-2} and may be thought of as akin to our everyday understanding of brightness; indeed, brightness is the subjective counterpart of luminance.

2.1.7 Luminance contrast

Luminance contrast is the difference in luminance or brightness between two points (in space or time).

2.2 Vehicle lighting regulations and technologies

In this section, we refer primarily to the regulations governing vehicle lighting in England. It is noted that there are some slight differences to the wording of regulations in Scotland, Wales and Northern Ireland where responsibilities are devolved, but there are no meaningful differences in the content.

2.2.1 Regulations

The Highway Code for Great Britain sets out several rules that drivers must follow with regard to vehicle lighting:

- Rule 113 states that drivers *must*: ensure all sidelights and rear registration plate lights are lit between sunset and sunrise; use headlights at night, except on a road that has lit street lighting; use headlights when visibility is seriously reduced (further definition of reduced visibility is given in Rule 226 – see below).
- Rule 114 states that drivers *must not*: use any lights in a way that would dazzle or cause discomfort to other road users, including pedestrians, cyclists and horse riders, and; use front or rear fog lights unless visibility is seriously reduced (but that they *must* be switched off when visibility improves to avoid dazzling other road users).

- Rule 115 states that drivers *should*: use dipped headlights, or dim-dip if fitted, at night in built-up areas and in dull daytime weather, to ensure that they can be seen; keep headlights dipped when overtaking until level with the other vehicle and then change to main beam if necessary, unless this would dazzle oncoming road users, and; slow down, and if necessary stop, if they are dazzled by oncoming headlights.
- Rule 226 states that drivers *must*: use headlights when visibility is seriously reduced, generally when they cannot see for more than 100 metres (328 feet).

These rules are underpinned by The Road Vehicles Lighting Regulations (RVLR) 1989 (Statutory Instrument 1989, No. 1796), as amended. Of particular relevance to this project is Part III, Reg 27, which states that "no person shall use, or cause or permit to be used, on a road any vehicle on which any lamp, hazard warning signal device or warning beacon … in a manner … so as to cause undue dazzle or discomfort to other persons using the road". This applies to all types of lamp on the vehicle including but not limited to headlamps, front and rear fog lamps and work lamps. This regulation also defines the technical requirements that all vehicles must meet whenever used on a road, with Schedule 4 covering dipped-beam headlamps including requirements for their alignment.

In addition, all elements of lighting must conform to UK type approval regulations at the time of first vehicle registration to ensure that vehicle lighting is safe and fit for purpose. Type approval involves independent assessment of representative vehicles, rather than every single unit produced, and manufacturers are required to ensure that the specifications of the vehicles mass-produced for the market match those of the representative vehicles put forward for testing. In the UK, the Vehicle Certification Agency (VCA) is the designated approval authority that oversees vehicle testing, certification and conformity of production checks.

The technical requirements for vehicle lighting, which must be demonstrated through type approval, are specified in Assimilated Regulation (EU) 2018/858, with detailed technical rules laid down in UN Regulation (UNR) No. 48 and UN Regulations No. 98 and 112. (Note that the more recent UN Regulation No. 149 consolidates Regulations 98 and 112 into one and can be used in the future for type approval; currently the technical contents are identical.)

These regulations specify detailed requirements for all vehicle lighting, including the colour, light intensity, light distribution, height and positioning. A key objective of these requirements is to ensure adequate functionality and to prevent glare or confusion for other drivers. For main-beam and dipped-beam headlamps, key relevant requirements include:

- White colour.
- Two or four lamps permitted for main beam, two for dipped beam.
- Positioned at front of vehicle – with light emitted causing no discomfort to driver either directly or indirectly.
- Automatic control of main beam and dipped beam allowed, but manual control must also be available.

- Maximum luminous intensity (cd) of both main beams and dipped beams at various test points in relation to the driver.
- The transitions between main beam and dipped beam shall be achieved so as not to cause discomfort, distraction or glare.
- Orientation to the front and vertical orientation defined dependent on mounting height (see UNR48, 6.2.6.).
- Automatic headlamp levelling devices and headlamp cleaning devices (both are effectively required for light sources emitting over 2,000 lumens – see UNR48, 6.2.9).

While only vehicles with type-approved lighting systems can legally be sold in the UK (and EU) under the regulations described above, aftermarket lighting conversion kits are available on the market (RoSPA, 2021). It is not, however, legal to sell or use these conversion kits for converting halogen to xenon high-intensity discharge (HID) headlamps or to light-emitting diode (LED) headlamps for on-road use through replacing individual bulbs (see Section 2.2.2 for an explanation of the different technologies). This is because these bulbs are designed for use only as part of HID and LED headlamp units (encompassing lens and reflector) with type approval only for the whole unit (see DfT statement on aftermarket HID headlamps and the MOT inspection manual. A headlamp unit previously used with a halogen bulb will not be suitable for use with an HID or LED bulb and may contribute to an incorrect beam pattern with glare in some places and insufficient light in others. Therefore, to convert from halogen to HID or LED headlamps, the entire headlamp unit must be replaced in the vehicle.

2.2.2 Headlamp technologies

This section outlines the different types of headlamp technologies that exist in the market today.

Fundamentally, there are three main types of headlamps: (1) halogen, (2) xenon HID and (3) LED. Halogen bulbs consist of a thin tungsten filament encased in a small capsule that is filled with halogen gas.

Compared with standard light bulbs, halogen bulbs can emit more light per unit of energy and they last longer. Halogen headlamps emit a bright white light, producing 1,400 lumens and 30mcd/m^2 (RoSPA, 2021).

Xenon HID headlamps use xenon gas in a sealed system and an electric arc generated between two electrodes to generate a white-blue light. Xenon HID bulbs emit a brighter light than halogen bulbs – producing 3,000 lumens and 90mcd/m^2 (RoSPA, 2021).

LED bulbs produce “directional” light, which enables lighting designs to be used that make use of multiple LEDs in clusters or matrices (RoSPA, 2021). LEDs have a longer lifespan than halogen and xenon bulbs, since there is no filament, which in halogen and xenon bulbs tends to burn out over time. LEDs are also more energy efficient.

LED headlamps are the most modern, followed by xenon HID and halogen as the oldest technology.

In addition to the three types of headlamp bulb, there are several additional technologies that can impact the way the headlamps behave. These include:

- (Advanced) adaptive front lighting systems (AFLS), which enable adjustments to be made to the direction of the headlamp beams to face the direction of travel based on the angle of the steering wheel. This is used to improve visibility round corners and to enable narrower beams to be used on motorways.
- Matrix LED headlamps, which make use of the directional and focused light emitted by LEDs to produce a headlamp where sections of the headlamp beam can be masked out by automatically switching off some of the individual LEDs. This has benefits in that the part of the beam facing oncoming cars can be blanked out, in theory reducing the likelihood of causing glare.
- High beam assistant, which uses a camera to detect front or rear lamps of other road users and automatically switches between high and low headlamp beams as appropriate.

PPR2069

On-road data collection

3 On-road data collection

This section outlines the methods used (Section 3.1) and the findings for the on-road data collection (Sections 3.2 to 3.5).

3.1 Method

3.1.1 Materials and equipment

The vehicle used for trials was a left-hand-drive, UK-registered Ford Focus. Roof-mounted luggage bars were fitted for mounting a video camera to collect video recordings for later identification of oncoming vehicles. The car is shown in Figure 1.

Figure 1: Trials car, a left-hand-drive Ford Focus

Most of the data recording system's electronics were installed within the car's boot space. The laptop computer used to operate the forward-facing luminance camera and record data was carried within the rear passenger area, alongside the observer. The vehicle remained in standard condition.

For the purposes of collecting data from the usual driver's eye position in a right-hand-drive car, a left-hand-drive car was used so that the data collection equipment could be fitted in the right-hand seat (passenger seat). This section describes the various equipment used in this setup. Appendix B and Appendix C show further details of the equipment and setup.

The data collection system was custom-built to collect and record a wide range of objective and subjective data:

- Forward-facing video (windscreen-mounted camera); recorded the view of the road ahead (including GPS coordinates).
- Forward-facing video (roof-mounted camera); orientated to record oncoming vehicles, for subsequent identification of those vehicles using automatic number plate recognition (ANPR).
- Forward-facing luminance sensor; mounted internally onto the front passenger seat. This seat is on the right-hand side (RHS) of the vehicle at a height of 1,220mm from ground level, providing a driver’s view (UK, right-hand-drive vehicle) of the road ahead.
- Internal luminance sensor; mounted inside the vehicle’s passenger cabin, directly adjacent to the forward-facing sensor at eye height, orientated towards the roof at a distance of 180mm. This identified ambient lighting inside the vehicle that might affect the contrast and so a driver’s perception of higher luminance lighting from oncoming vehicles.
- Timestamp; video recorder and data gatherer kept to time via a network time protocol (NTP) server accessed with a 4G Wi-Fi router.
- Vehicle inclination; a solid-state inclinometer was used to identify the vehicle’s roll and pitch. This provided some information about the geometry of the road (for example hills, bends) and while it cannot in isolation tell us about interactions between the trial vehicle and the surrounding vehicles, it can provide data on inclination suitable for use in the analysis. Note that while the sensor was designed to filter out orientation changes due to external forces, the data may be affected by extreme or prolonged acceleration, deceleration or cornering.
- Subjective glare push button; operated by the rear-seat observer when they experienced a glare event, defined as “experiencing a level of glare that was felt might interfere with driving”.

Figure 2 shows a high-level schematic diagram of the data collection system as designed. A full connectivity diagram of the installed system is provided in Appendix C.

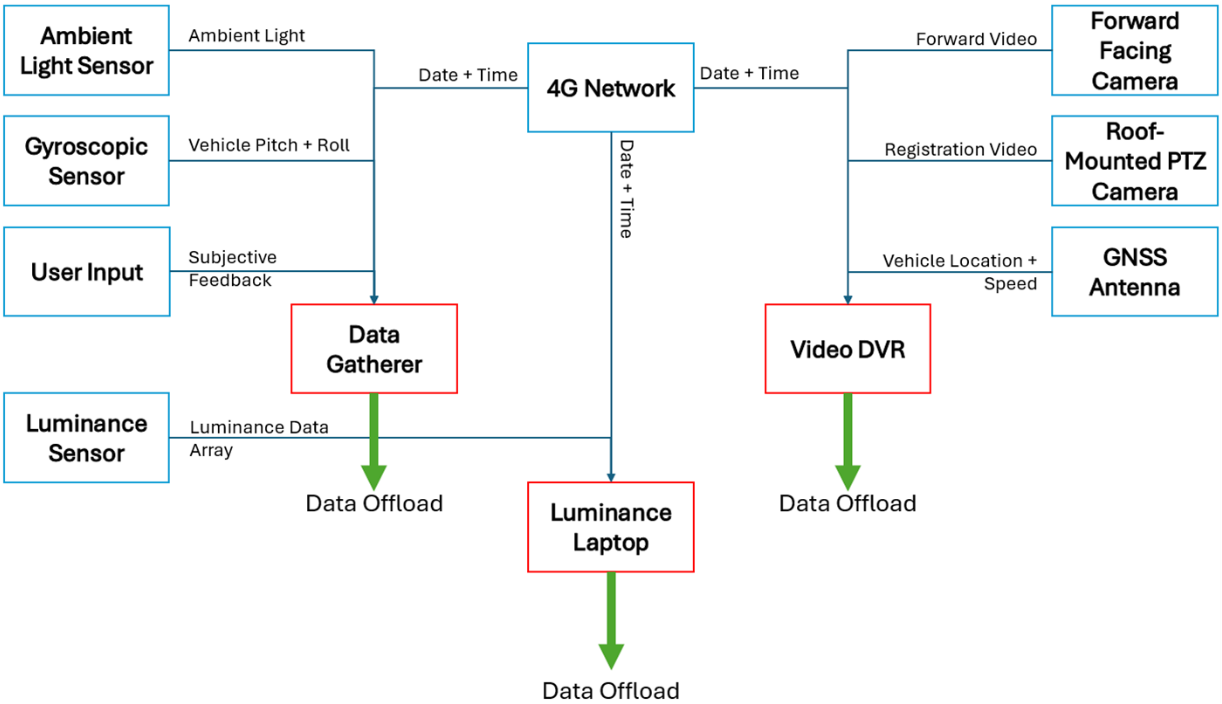


Figure 2: Schematic diagram of data collection equipment

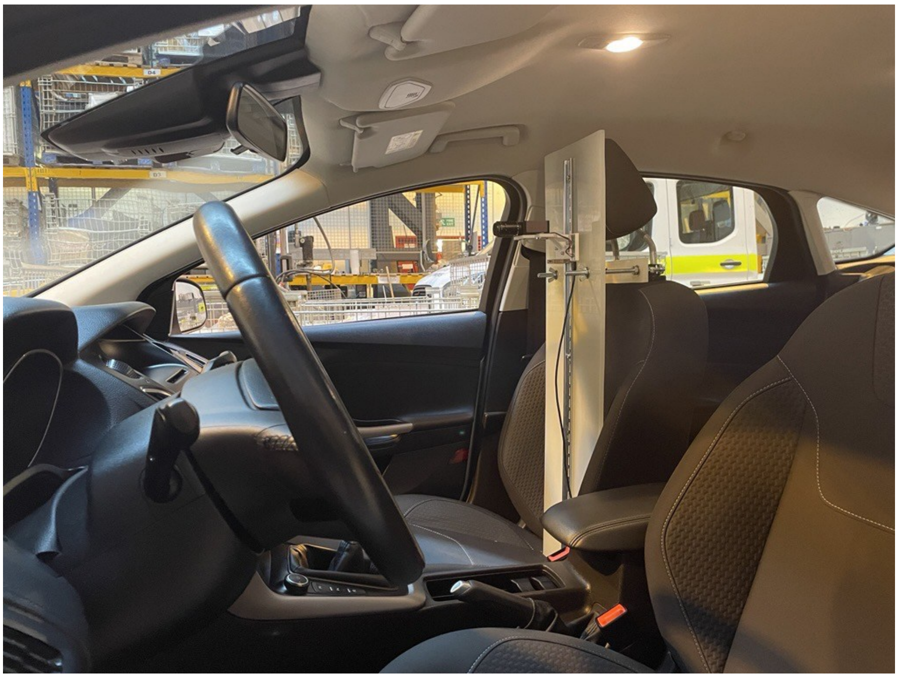


Figure 3: Luminance camera installed at RHS driver eye height. During trials the mounting plate was covered with black cloth to prevent reflection in the windscreen

Figure 4: Camera for ANPR installed on the trials vehicle (camera shown in “power off” orientation)

Data recording and processing system electronics installed in the vehicle boot space are shown in situ in Figure 5; Figure 6 shows a close-up of the equipment with key items identified by numbers. The laptop computer used to operate and store data from the main luminance sensor, and the observer’s button used to identify subjective glare, were located within the vehicle passenger area so are not shown.

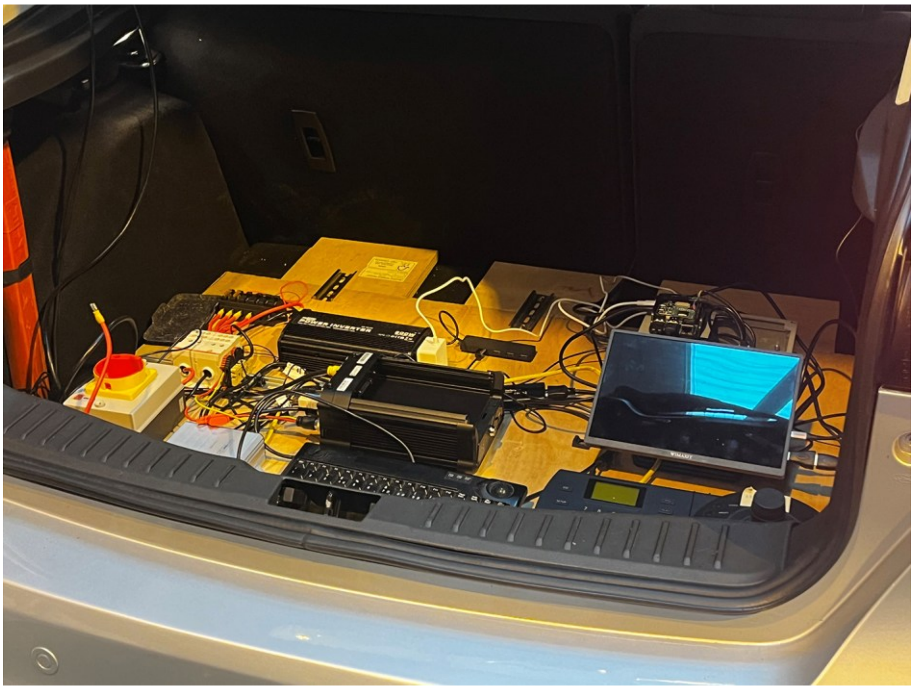


Figure 5: General view of data-processing equipment installed in the trial car’s boot space

Key

No.	Item	Purpose
1	Vehicle battery voltage	Initial fault finding
2	Digital video recorder (DVR) with removeable hard disk drive	Timestamps and stores video recording
3	Power switch	Power to all devices
4	4G Wi-Fi router	In-vehicle Wi-Fi
5	Raspberry Pi computer	Data gatherer for timestamped survey data
6	USB memory	Stores logged data
7	Monitor	Data gatherer and camera user interface
8	Joystick controller	Operates roof-mounted camera

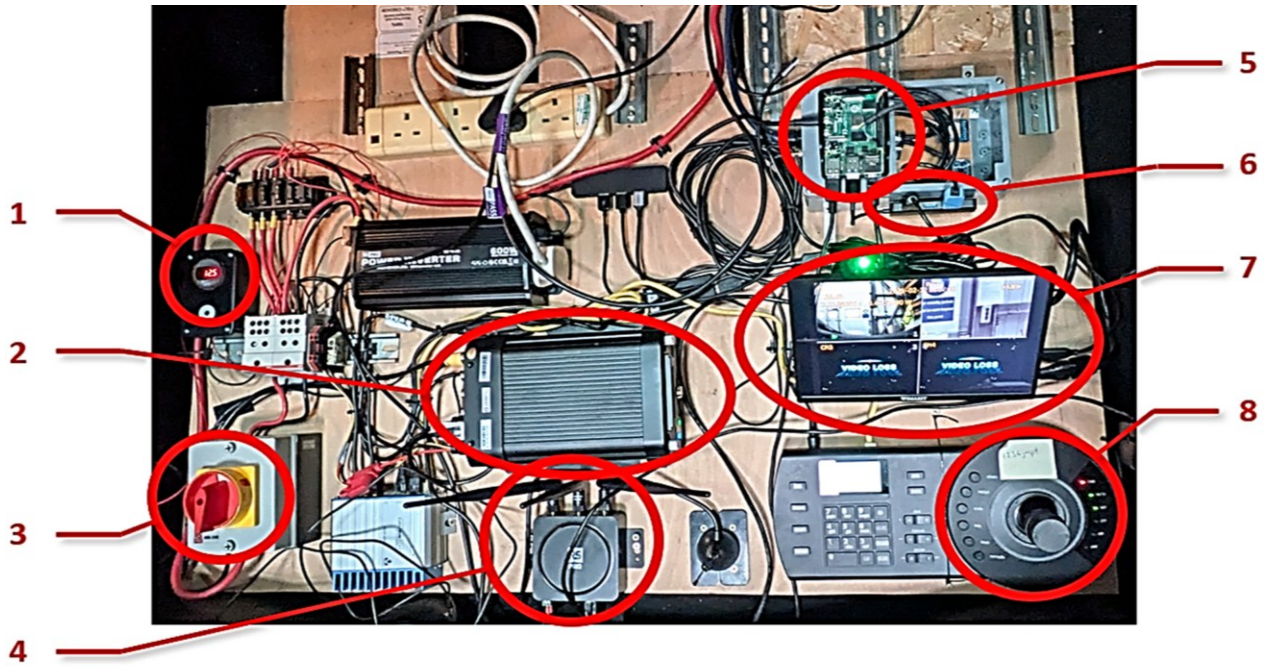


Figure 6: Main elements of in-car monitoring system, see key above

3.1.2 Participants

For each drive there was a driver and an observer. Table 1 shows the observers used in the on-road data collection and the hours of footage they observed. The observers were drawn from the project team, and all contributing to the final dataset were male. This project was not designed to capture data from a representative sample of UK drivers, but the observers were picked from available staff to ensure that a range of ages and eyesight correction types were present in those giving glare ratings.

The lack of any female staff available to serve in the observer role is unfortunate but does not affect the ability of the on-road data collection to gather the data required to answer the research questions. While there is some evidence that females can perceive glare differently to males in some circumstances (see Beard et al., 2025; see also the survey data reported here in Section 4), the approach here did not require a comprehensive balance of individual difference factors in observers. This is because the analyses of the on-road data were either concerning the physical characteristics measured about luminance or examining variation in subjective ratings of glare with these physical characteristics, not making comparisons between observer types or estimating absolute levels of glare that would be seen by a representative sample of individuals.

Table 1: Observer characteristics for the on-road data collection*

Observer ID	Age	Eyesight	Hours of footage
1	26	Glasses	6hrs 28mins
2	40	None	5hrs 7mins
3	48	None	2hrs 13mins
4	49	Glasses	8hrs 35mins
5	62	Contact lenses	4hrs 28mins
6	66	Glasses	8hrs 42mins
7	28	None	5hrs 40mins

*Note that the total hours here (just over 41 hours) include the "infinity" and "dialled back" data, after data cleaning to remove any failed runs and periods during which data collection was missing.

3.1.3 Procedure

After some initial piloting and calibration throughout February 2025, data collection for the "infinity" focus dataset (see Section 3.2.1) was carried out on 16 evenings between 3rd March and 31st March inclusive. For the "dialled back" focus dataset (see Section 3.2.2) data were collected on seven evenings between 30th April and the final night of testing on 12th May. In between these main data collection periods there was a four-week period in which various further calibration testing was done and data from static situations were collected to try to optimise sensor reliability and ANPR camera performance (see Section 3.2.1).

Each evening of testing started approximately 30 minutes before sunset and followed this sequence:

- Vehicle checks (driver): Visual vehicle safety and maintenance checks carried out for each drive, with any faults logged and escalated if necessary. Check for adequate fuel levels. Weekly checks for tyre pressure and washer fluid.
- Equipment checks (observer): Visual checks to confirm that the equipment remained aligned, fitting was secure, any data recording media was in place. Before drive, ensuring that data loggers and video recorder were operating.
- Drive route(s): During each drive, the observer operated the glare input button – pressing (and holding) the button according to the following instruction:

Look at the road ahead, as if you were driving in the usual seating position in a standard right-hand-drive car. Press and hold the button for as long as you experience a level of glare that you feel may interfere with your driving.

- Post drive: Data were downloaded at each session. The electronic trials log for each drive was completed, noting:
  - Start and end date, time
  - Driver and observer
  - Route taken
  - Weather conditions
  - Road conditions
  - Any additional information (incidents or other notable points)

All drives started and ended at TRL's offices in Crowthorne, Berkshire. The intention was to include all the following characteristics in trials routes used for the data collection:

- Urban
- Semi-rural
- Rural
- Street lit (predominantly urban)
- Unlit
- Single carriageway (potentially worst case for oncoming traffic)
- Dual carriageway and motorway (for comparison)
- Bends, level roads and rises, falls and crests
- Traffic-calming measures

Several routes were planned that incorporated these features; however, in practice these routes were adapted dynamically considering the required criteria and traffic levels that were encountered. Figure 7 shows all the roads on which data collection was carried out, and Figure 8 shows the data collection as a heat map, illustrating which roads were included most often.

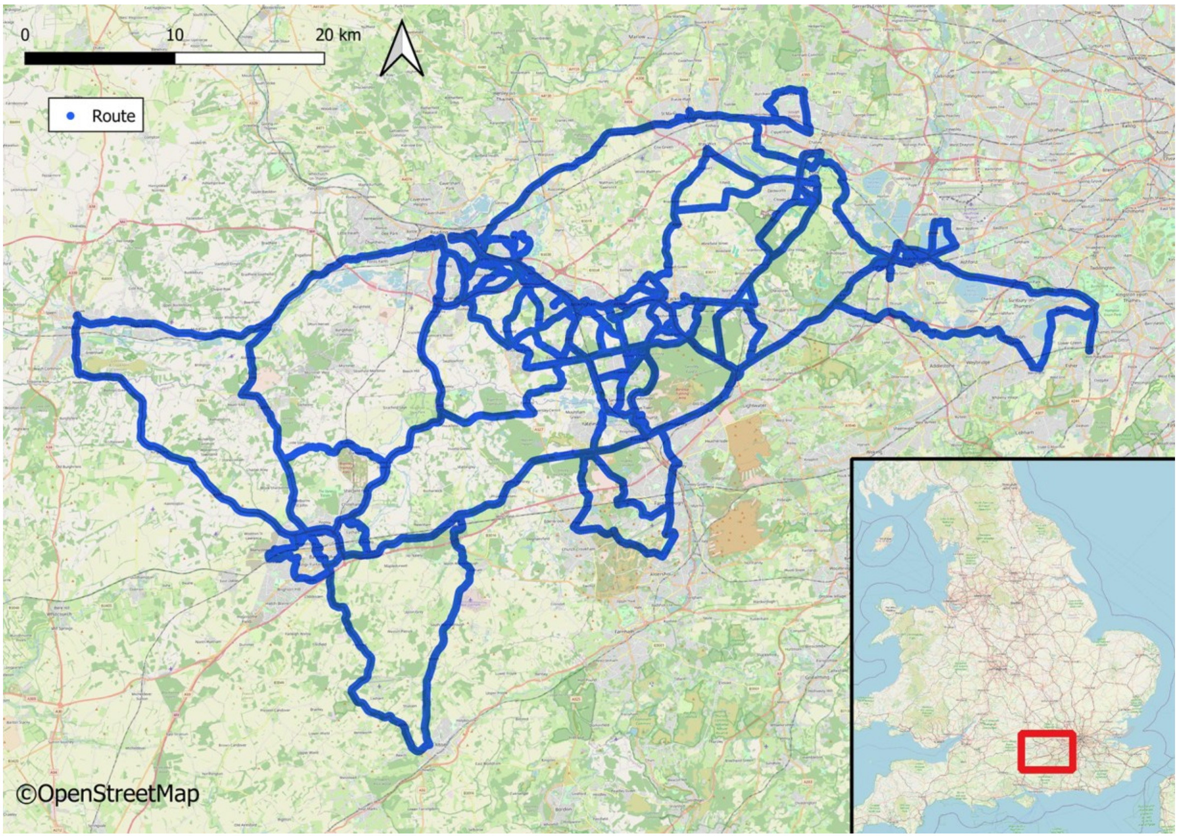


Figure 7: Map of all roads included in the on-road data collection

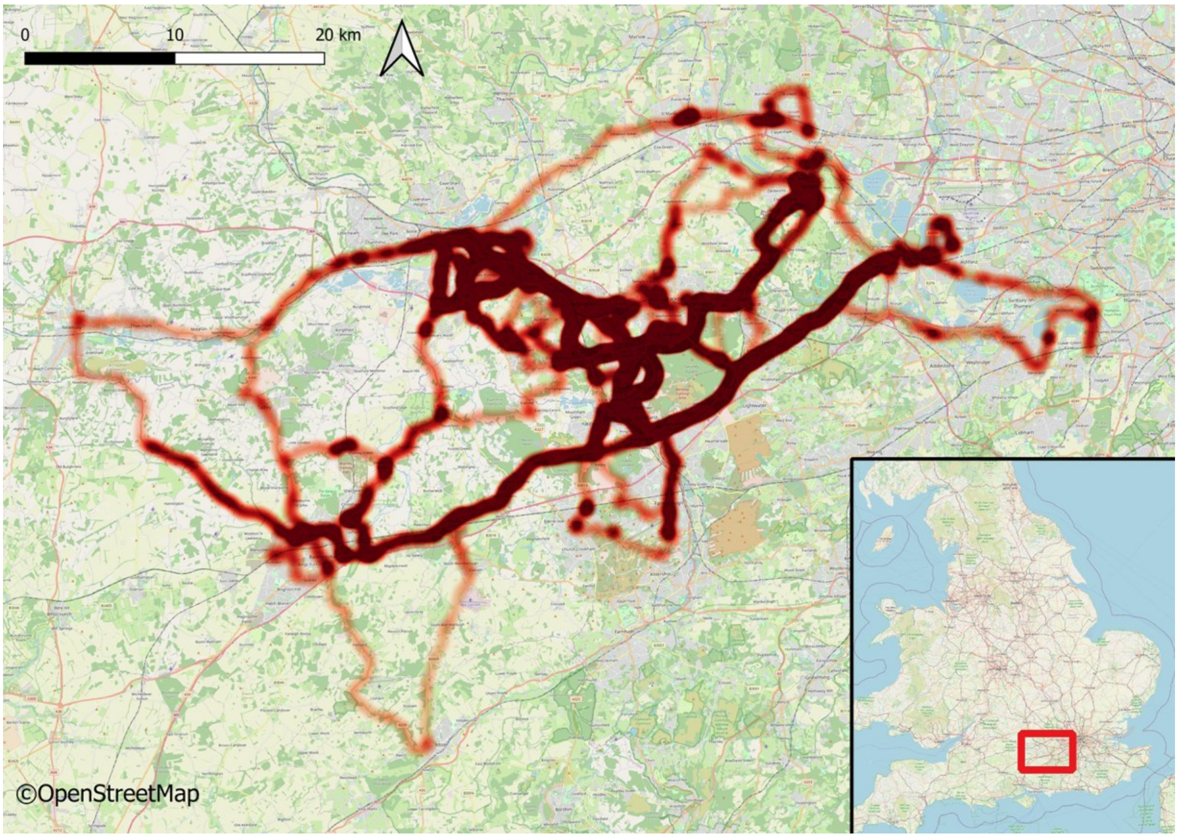


Figure 8: Heatmap of on-road data collection

These maps show that there was a focus of data collection on rural and urban single-carriageway roads, both lit and unlit, which are the locations where glare is most likely to be reported as an issue.

Figure 9 shows the age distribution for the vehicles in the dataset captured by the ANPR camera during the on-road data collection (see

Table 2 for information on the data variables captured). Figure 9 also shows the age distribution of the wider UK car fleet (SMMT Motorparc, 2025) for comparison; overall the vehicles captured within the trial are skewed slightly towards newer vehicles, perhaps due to the locations used.

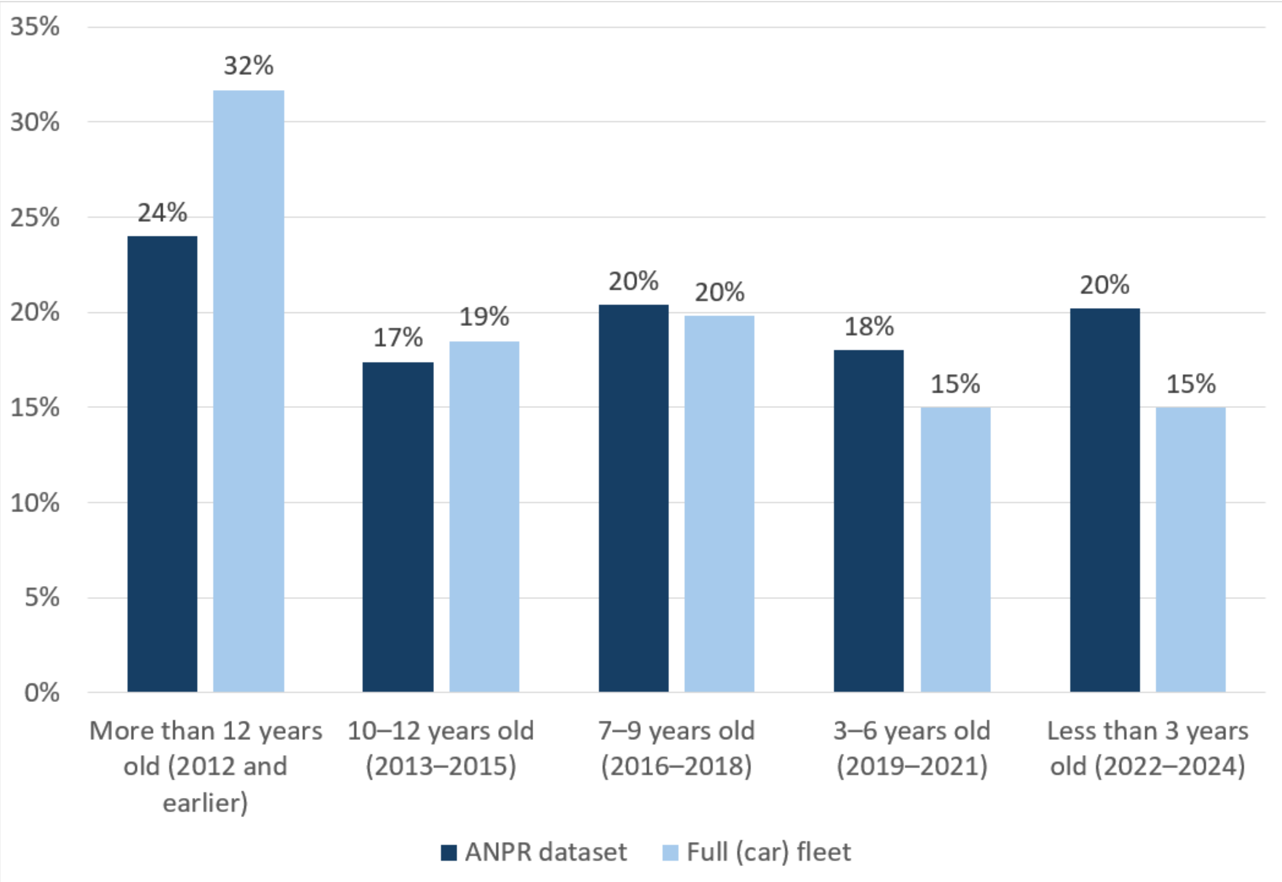


Figure 9: Age distribution for vehicles captured in the ANPR dataset, compared with the UK car fleet (SMMT Motorparc, 2025)

3.1.4 Design and analysis

3.1.4.1 Variables

The variables shown in

Table 2 were derived from the raw data collected from various equipment noted in Section 3.1.1.

Table 2: Variables in the dataset

Variable name	Approximate frequency	Units	Notes
Timestamp	At each measurement or value recorded	Unix epoch time	This was used to synchronise the various data sources in a way that made analysis of associations possible
Luminance image (matrix of luminance values)	Approximately every 2.5 seconds	cd m^{-2}	Frequency dependent on processing time for luminance image
Mean max luminance	Approximately every 2.5 seconds	cd m^{-2}	Derived from full luminance matrix
Maximum luminance	Approximately every 2.5 seconds	cd m^{-2}	Derived from full luminance matrix
Mean luminance	Approximately every 2.5 seconds	cd m^{-2}	Derived from full luminance matrix
Minimum luminance	Approximately every 2.5 seconds	cd m^{-2}	Derived from full luminance matrix
Ambient illuminance in the vehicle	Five times per second	Institutional units	-
Vehicle pitch	Five times per second	Institutional units	Trial vehicle: Pointing up – pitch value positive; pointing down – pitch value negative
Vehicle roll (leaning left or leaning right)	Five times per second	Institutional units	Trial vehicle: As the vehicle rolls right (clockwise), the roll value decreases As the vehicle rolls left (anti-clockwise), the roll value increases
Weather conditions	Once per drive	Integer code where 1= Dry, 2 = Light rain, 3 = Heavy rain	Very limited variability in this due to unseasonably dry weather – not used in modelling
Road conditions	Once per drive	Integer code where 1 = Dry, 2 = Damp (dry patches), 3 = Wet	Very limited variability in this due to unseasonably dry weather – not used in modelling
Observer age group	Once per drive	Integer code where 1 = age under 24, 2 = 25–34, 3 = 35–44, 4 = 45–54, 5 = 55–64, 6 = age 65 or above	-
Observer eye correction	Once per drive	Integer code where 1 = None, 2 = Glasses, 3 = Contact lenses	-

Variable name	Approximate frequency	Units	Notes
Vehicle manufacture year	Where ANPR was able to recognise and read a number plate of a passing car	Year	Gov MOT API query for recognised plate, plate then removed for GDPR purposes
Vehicle make and model	Where ANPR was able to recognise and read a number plate of a passing car	n/a	Gov MOT API query for recognised plate, with relevant variable retained
Last MOT month and year	Where ANPR was able to recognise and read a number plate of a passing car	Month and year	Gov MOT API query for recognised plate, with relevant variable retained
MOT expiry month and year	Where ANPR was able to recognise and read a number plate of a passing car	Month and year	Gov MOT API query for recognised plate, with relevant variable retained
Longitude (GPS coordinates from the dashcam)	Once per second	-	-
Latitude (GPS coordinates from the dashcam)	Once per second	-	-
Glare user input	Button press by observer	Boolean (1 = True, button pressed; 0 = False, button not pressed)	Instruction was to press and hold the button for as long as they were experiencing a level of glare they considered "could interfere with their driving"

3.1.4.2 Analysis design for question 1

The first research question was "What proportion of luminance readings at driver eye height in real-world driving are likely to indicate values of luminous intensity higher than the regulatory maximum?" This research question was not defined until near the end of the data collection.

It was initially intended that this question be addressed by plotting maximum luminance levels from the files captured by the luminance camera, thus establishing a distribution of cd m^{-2} at eye height in real-world driving, from which we could extrapolate to values of luminous intensity (as used in the relevant lightings regulations) using assumptions about distance from the source. It was agreed, however, after consultation with various experts on the stakeholder panel, that it was not possible to make the assumptions about distance and other variables that would be required to answer this question from the luminance values captured with any validity. Section 3.3 therefore presents the luminance data and outlines what can be concluded about this question from the data and from a consideration of the modelling findings.

3.1.4.3 Analysis design for questions 2 and 3

The second and third research questions were “What are the factors that most predict levels of glare in real-world driving?” and “What are the factors that most predict levels of luminance at driver eye height in real-world driving?”

These questions were defined at the beginning of the project and were addressed primarily through a machine learning approach; this type of approach enables the identification of patterns and relationships within large datasets that are subject to noise, such as this one.

In addition to the machine learning, case studies were extracted from the data to illustrate the findings more effectively in lay terms. Case studies were selected to show tangible examples of how variables identified in the modelling were related to the perception of glare by the observers.

For the machine learning we chose to use a gradient boosting machine (GBM) algorithm (Friedman, 2001) to predict both observers’ glare responses (a classification problem) and maximum luminance in each image (akin to a regression problem). The GBM approach was adopted since it performs well in both classification and regression problems, it is relatively robust to both outliers and missing values in the data, performance can be flexibly optimised by the tuning of hyper-parameters, and over-fitting can be avoided by introducing (computationally expensive) small learning rates. These features and GBM’s comparatively good performance among competing machine learning algorithms made it well suited to the current problem.

Appendix D provides critical information related to the processing and validation of the luminance value dataset. Appendix E to Appendix N contain all the detailed information and outputs from the two models (the glare model and the luminance model). The remainder of this section describes the main technical characteristics of the models, and Section 3.4 discusses the findings.

The glare model

Minimum luminance, weather code and road condition were found to have no variation and were therefore excluded from analyses. Similarly, the variable “observer age group” was excluded due to very small sample size. For the glare model, we chose to use the average maximum luminance, which is the mean of the five highest luminance readings in the image. This was motivated by the observations that (1) the correlation with maximum luminance was very high and (2) the resolution of one pixel was high in the context of human observers. Maximum luminance was excluded given its covariance with average maximum luminance. Thus, the final model for glare was given by the equation:

> *Glare response ~ Mean Max Lum + Mean Lum + Pitch + Roll + AmbientLight + Observer Eyesight + Vehicle Manufacture Year + Vehicle + Last MOT date + Latitude + Longitude*

A GBM algorithm was used to predict glare using the R package gbm (version 2.2.2) (Ridgeway, 2024). We chose a gaussian loss function (the “distribution” parameter in gbm) for both glare and luminance models (the Bernoulli function returned far higher root mean square error (RMSE) values than the gaussian [0.26 and 0.0837 respectively]). We determined optimal values (i.e. the values that returned the minimum RMSE during the training phase) for shrinkage, interaction depth, n.trees and n.minobsinnode by implementing a grid search (grid values in Table 3) with seed value held constant for reproducibility. Training and test sets were set at a ratio of 7:3. The grid-determined optimal hyper-parameter values yielded an RMSE of 0.0837 and are indicated in Table 3. The bag fraction parameter was held constant at 0.5. Full results of the grid search may be found in Appendix D.

Table 3: Initial grid search and optimal values of the GBM hyper-parameters

Hyper-parameter	**Search grid values**	**Optimal value (glare model)**	**Optimal value (luminance model)**
shrinkage	0.01, 0.1	0.01	0.1
interaction depth	6, 10, 12	12	12
n.trees	1,000, 2,000, 3,000	1,000	3,000
n.minobsinnode	20, 30, 40, 50	50	20

The luminance model

The model for luminance was given by the equation:

> *max_lum ~ Pitch + Roll + UserInput + Longitude + Latitude + VehicleManufactureYear + vehicle + last_mot_unix*

The same GBM algorithm used to predict glare was used to predict luminance. Note that here we have chosen to model maximum luminance (rather than average maximum luminance) since (1) the two variables are highly correlated (and thus the model is unlikely to be unduly influenced by outliers in the maximum luminance distribution during training) and (2) concerns regarding the high resolution of each pixel are not relevant to this model.

Optimal values of the hyper-parameters for shrinkage, interaction depth, n.trees and n.minobsinnode were determined by implementing a grid search (grid values in Table 3) with seed value held constant for reproducibility. Training and test sets were set at a ratio of 7:3. The grid-determined optimal hyper-parameter values yielded an RMSE of 11,807.80 and are indicated in Table 3. The bag fraction parameter was held constant at 0.5. Full results of the grid search may be found in Appendix F.

3.2 Summary of datasets

Two types of settings were used for the on-road data collection of luminance values, resulting in two datasets that differed in their characteristics. These are described below.

3.2.1 Infinity focus dataset

The first ≈35 hours of footage were collected using the lens on the luminance camera focused at infinity and using an aperture of f/1.8. The f/1.8 aperture was necessary to achieve the fast shutter speeds needed to avoid any motion blur in the low light conditions being tested, with moving objects and camera car. The focus at infinity was used as this was the focus point at which the camera had been calibrated, and it resulted in a defocused scene, like that seen in Figure 10 below. The left panel shows a pair of oncoming headlamps and the right panel the scene in front of the car in its final position at the depot before the bay doors were opened at the end of the evening's filming.

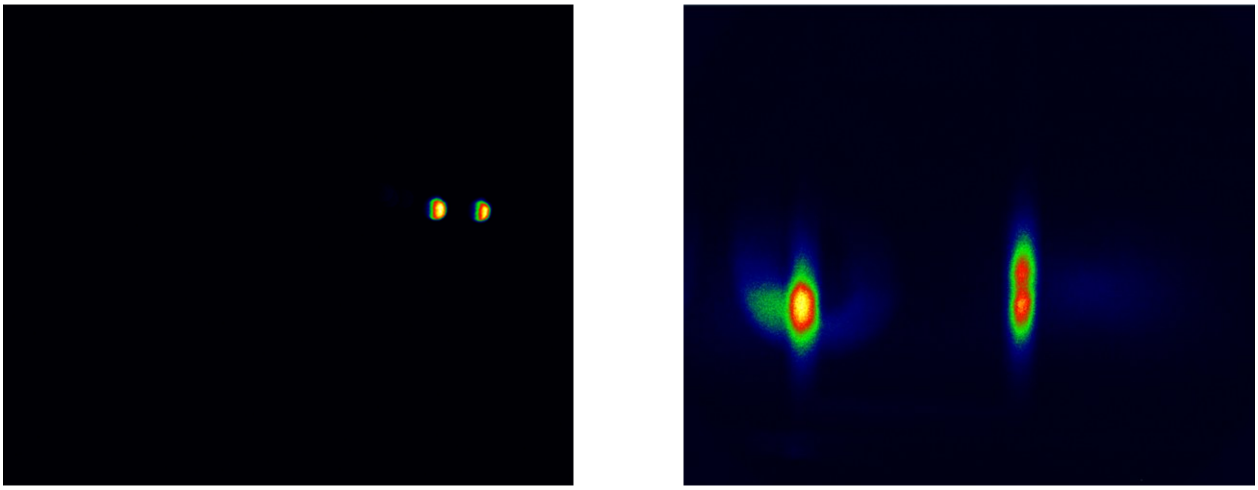


Figure 10: Scene from the luminance camera focused at infinity – f/1.8

The defocused nature of the scene was not initially deemed to be an issue, given the ways in which the dataset was to be used, namely that the luminance photos would be converted into .CSV files with a luminance value for each pixel, with metrics such as maximum luminance being calculated from these for use in the machine learning and other analyses. However, during the testing, conversations with the camera supplier did cause some concern as to the reliability of the absolute values of luminance being measured by the camera. While this would not be an issue for all the machine learning elements of the work, to answer questions about absolute levels of luminance it is not desirable. As a result of these discussions, some static testing was done at set distances from a vehicle in an off-road location to establish the distance-independence of the luminance values and this showed that the focus distance needed to be adjusted to achieve greater precision. This led to the creation of the "dialled back" focus dataset, described below.

3.2.2 "Dialled back" focus dataset

After some discussion with the camera supplier, it was decided that the final ≈15 hours of footage would be collected with the focus "dialled back" slightly to provide a greater depth of field in focus in the scene. Testing and calibration with a Konica Minolta LS-100 luminance meter suggested that these settings would provide a more reliable set of figures for maximum luminance in absolute terms, which were needed to answer the first research question with greater accuracy. An aperture of f/1.8 was still used to permit the fast shutter speeds needed. The photos produced by this new setting are like those seen in Figure 11. When compared with the images in Figure 10, note in the left panel the much sharper image of the headlamps, and on the right the much sharper resolution of the pillars on the bay doors, including the lower portion of the number decal (06) sharper in the bottom left-hand corner. Note the bay door shot is orientated slightly to the right compared with the similar shot in Figure 10.

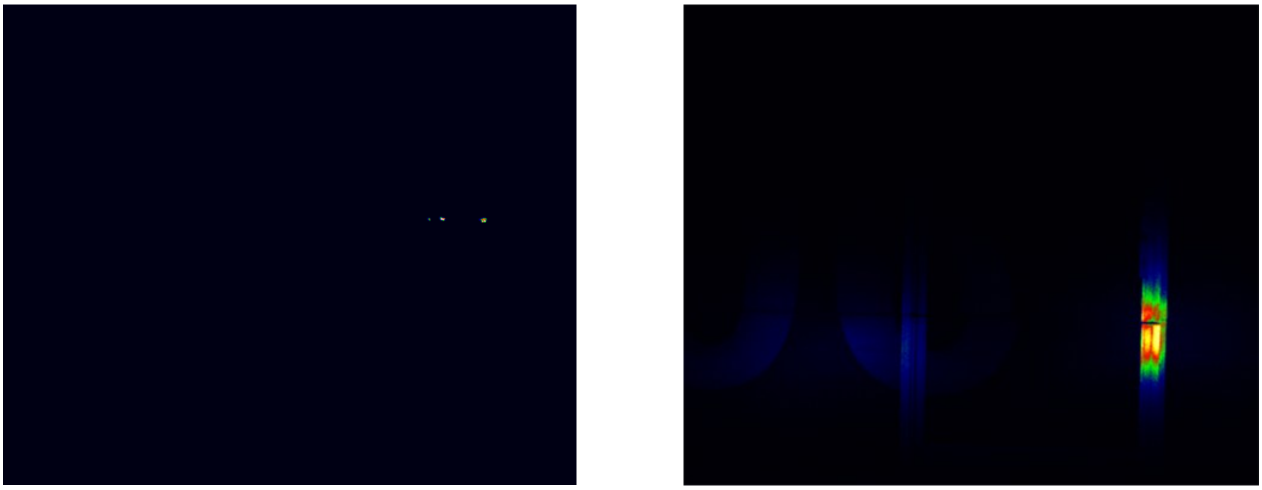


Figure 11: Scene from the luminance camera with focus slightly "dialled back" from infinity – f/1.8

Both datasets were used in the analysis; after initial testing of the machine learning algorithms, it was established that the "dialled back" dataset was sufficient for most analysis, with the "infinity focus" dataset serving as a check on the basic pattern of findings, which it confirmed.

3.3 Luminance values

Figure 12 shows the distribution of the maximum luminance values from the 22,800 values collected in the "dialled back" focus dataset. As noted above this dataset is the one that possesses the greatest validity of absolute values of luminance.

The maximum luminance frequency distribution had local maxima around 1,000 cd m^{-2} and 42,000 cd m^{-2}. The mean maximum luminance was 15,860.2 cd m^{-2} (standard deviation = 17,747.29). Maximum luminance ranged from 152.7 cd m^{-2} to 63,566.4 cd m^{-2}. The mean average maximum luminance was 14,626.6 cd m^{-2} (standard deviation = 16,728.9). The average maximum luminance ranged from 147.8 cd m^{-2} to 62,180.9 cd m^{-2}.

The peak in the distribution of luminance values in Figure 12 around 40,000–50,000 cd m^{-2} shows that values of luminance are associated with brighter light sources present in data points collected. The lower values (especially the first bar of 0–999 cd m^{-2}) will tend to be driving on unlit roads with few light sources present. As light sources occur in the scene, the maximum luminance values will change accordingly.

The relationship between luminance (the photometric property most associated with the experience of glare) and luminous intensity (what the current lighting regulations are based on) is complex. We can conclude that around 20% of the driving done at night on UK roads has luminance values above 40,000 cd m^{-2}. While it is not possible to equate this to the actual experience of glare without knowing other variables such as the angle of light relative to the observer, and observer characteristics, this does at least define the context of the issue in terms of the physical characteristic of light related to glare. Also see Section 3.4.1 for the modelling findings, which suggest that 40,000 cd m^{-2} may be an important threshold for the experience of glare.

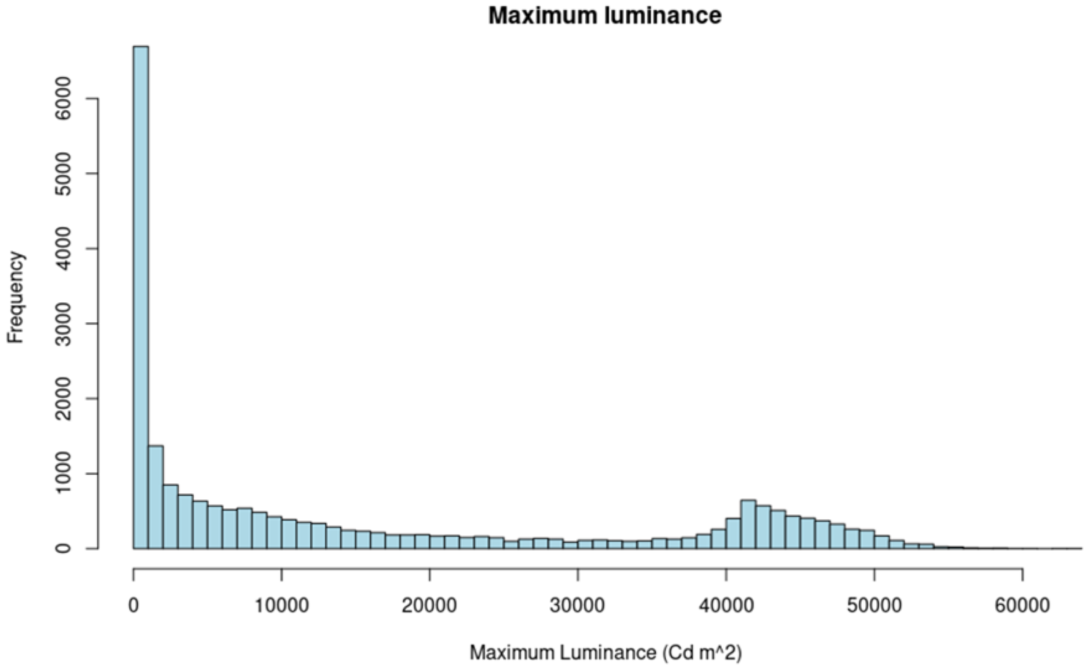


Figure 12: Frequency distribution of maximum luminance (each bar covers range of 1,000 cd m^{-2})

3.4 Machine learning models

The findings from the machine learning element of the work are presented in this section.

3.4.1 The glare model

The best-fitting glare model yielded a cross-validation RMSE of 0.837. The model was used to predict the novel 30% of the data that it had not been previously trained on. This test set comprised 32,252 non-glare observations and 221 glare observations (coded 0 and 1 respectively). The out-of-training predictions range was −0.03636157 to 0.941819. Given the sparsity of glare events within the data, it was necessary to determine the optimal threshold for classification of predictions as glare (1) or non-glare (0). This was determined by finding the maximum balanced accuracy of the model using a grid search (the values of this grid search are in Appendix G). The optimal value yielded a balanced accuracy of 0.78, an overall accuracy of 0.82, with sensitivity and specificity of 0.82 and 0.75 respectively. The confusion matrix (Table 4) indicates that the model correctly classified 74.66% of glare events and 81.64% of non-glare events.

The relative influence of each variable is plotted in Figure 13 (tabulated values are in Appendix H).

Table 4: Confusion matrix summary of the glare model's performance – 1 indicates a glare event, 0 indicates a non-glare event

Prediction	Glare response 0	Glare response 1
0	26,330 (81.64%)	56 (25.34%)
1	5,922 (18.36%)	165 (74.66%)

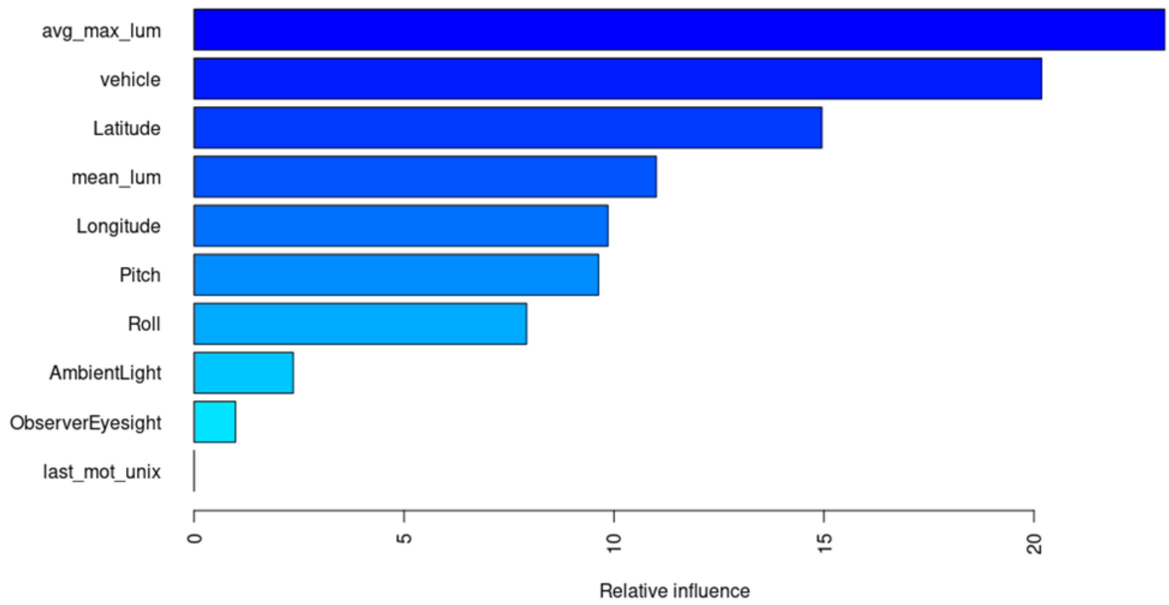


Figure 13: Relative influence of variables in the glare model

The average maximum luminance had the strongest influence on the model (23.11%), and mean luminance (11%) also played an important role. Other than the luminance measures the variables with high influence were the vehicle model (20.18%) or contextual variables such as latitude (14.95%) and longitude (9.85%), or the pitch (9.63%) and roll (7.92%) of the trial vehicle. The remaining variables had negligible (ambient light, eyesight and last MOT date) or no (vehicle manufacture year) influence on the model.

Examination of the partial dependencies (Figure 14) indicates that the effect of average maximum luminance nearly always increases at values above around 40,000 cd m^{-2}. The partial dependency plot (Figure 15) for mean luminance also nearly always increases (tabulated values are in Appendix I). What these plots show is that as luminance goes up, glare is more likely to be recorded. The increase in recorded glare at values of average maximum luminance above values of 40,000 cd m^{-2} suggests the very highest levels of luminance are the most likely to result in glare, as would be expected.

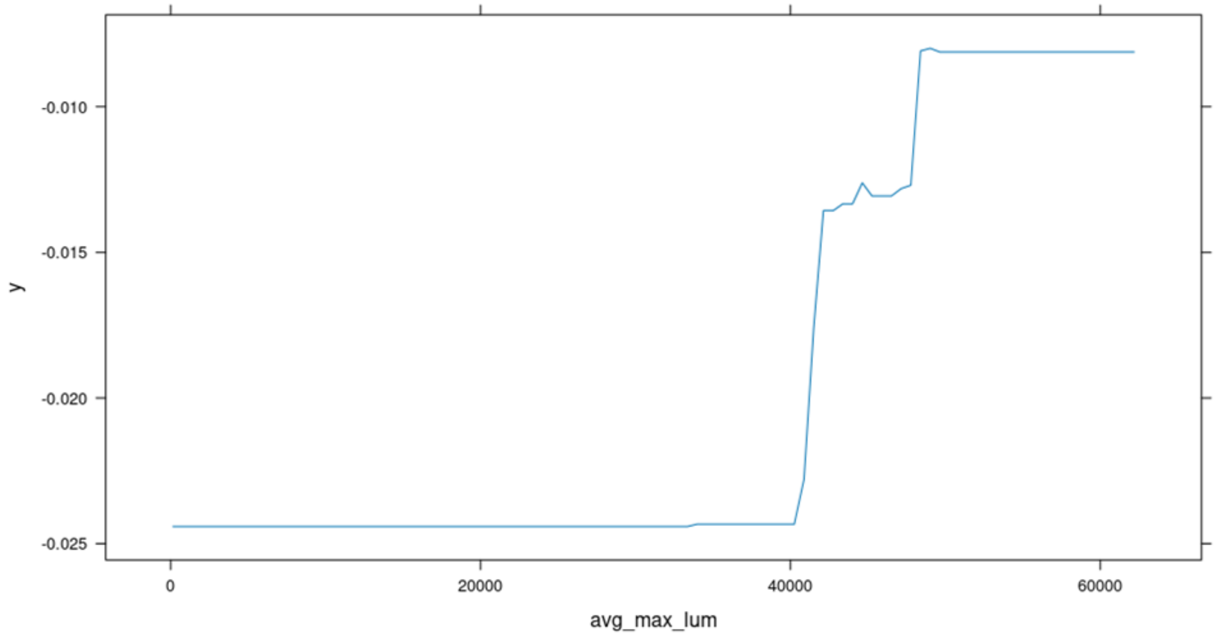


Figure 14: Partial dependency plot for average maximum luminance in the glare model

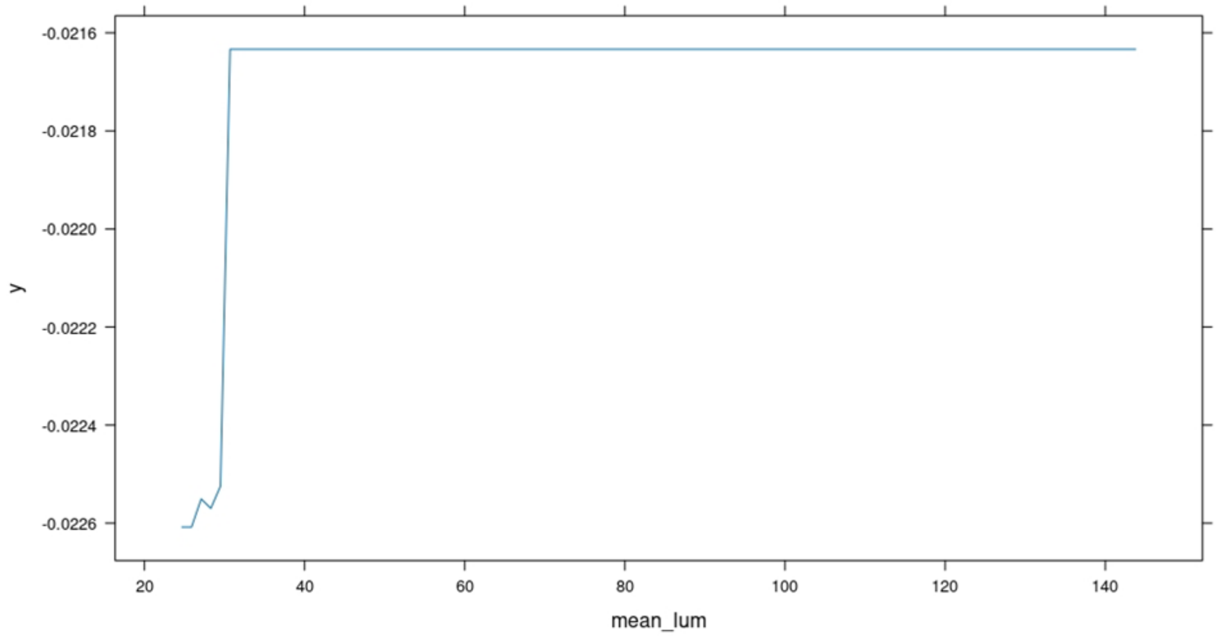


Figure 15: Partial dependency plot for mean luminance in the glare model

The effects of latitude and longitude suggest that specific locations are more likely to be associated with glare events. As noted in Beard et al. (2025) some research has shown that the geometric features of roads (for example the nature of bends) play a role in the experience of glare, so it is not surprising that the location variables were important in the model. However, we do not say anything more detailed about these variables here as we note that, while they reflect and say something about local conditions, they are of little practical use in explaining fundamental aspects of the experience of glare in ways that can be generalised, without higher-level classifications such as road type (which we do not have for the current dataset).

The influence of trial vehicle pitch and roll variables in the model is more instructive and allows interpretation that may have use in potential countermeasures or advice to drivers. Figure 16 and Figure 17 show the partial dependency plots for pitch and roll respectively, with tabulated values in Appendix J.

The plot for pitch shows that negative values of pitch (which correspond to the trial vehicle travelling uphill) are associated with glare events. This is what would be expected based on the impact that an upward elevation has on the geometry of the road situation; in short, if the trial vehicle is travelling uphill it is more likely to experience light throw from the headlamps of an oncoming vehicle, especially where that oncoming vehicle is coming over a crest.

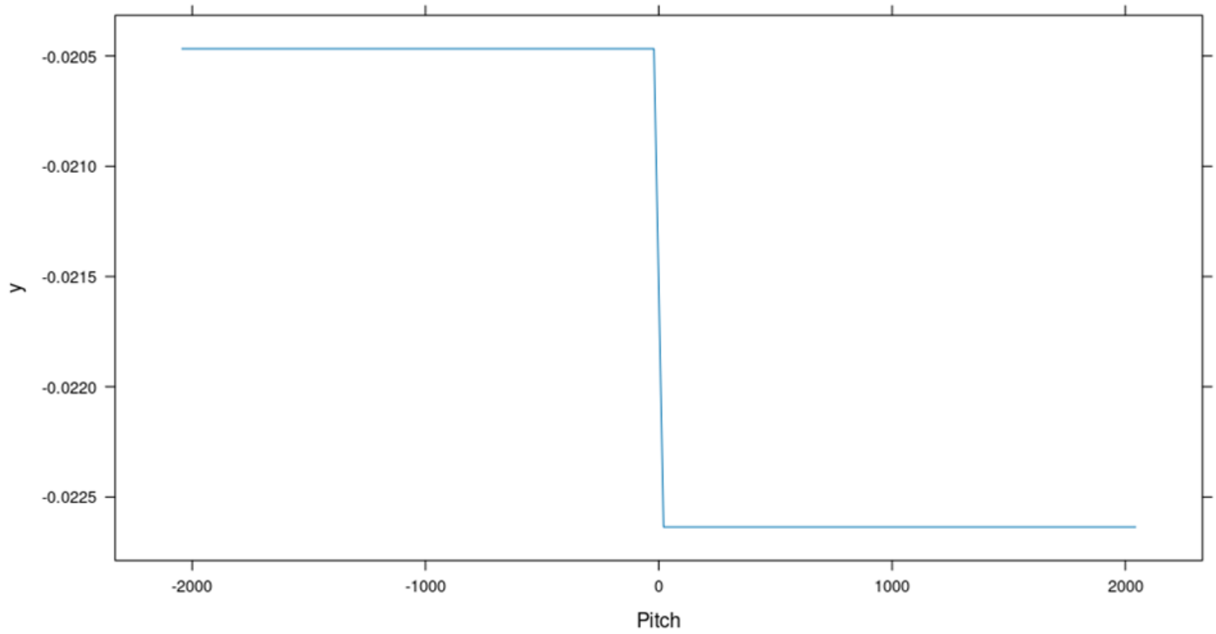


Figure 16: Partial dependency plot for pitch in the glare model

The plot for roll again shows a clear pattern in that a positive value (which in this case represents when the trial vehicle is travelling around a right-hand bend, experiencing a lean in the opposite direction) is associated with glare. Again, this makes sense regarding the geometry of the road situation, as the trial vehicle will be more likely to fall within the dipped-beam area of vehicles coming in the opposite direction.

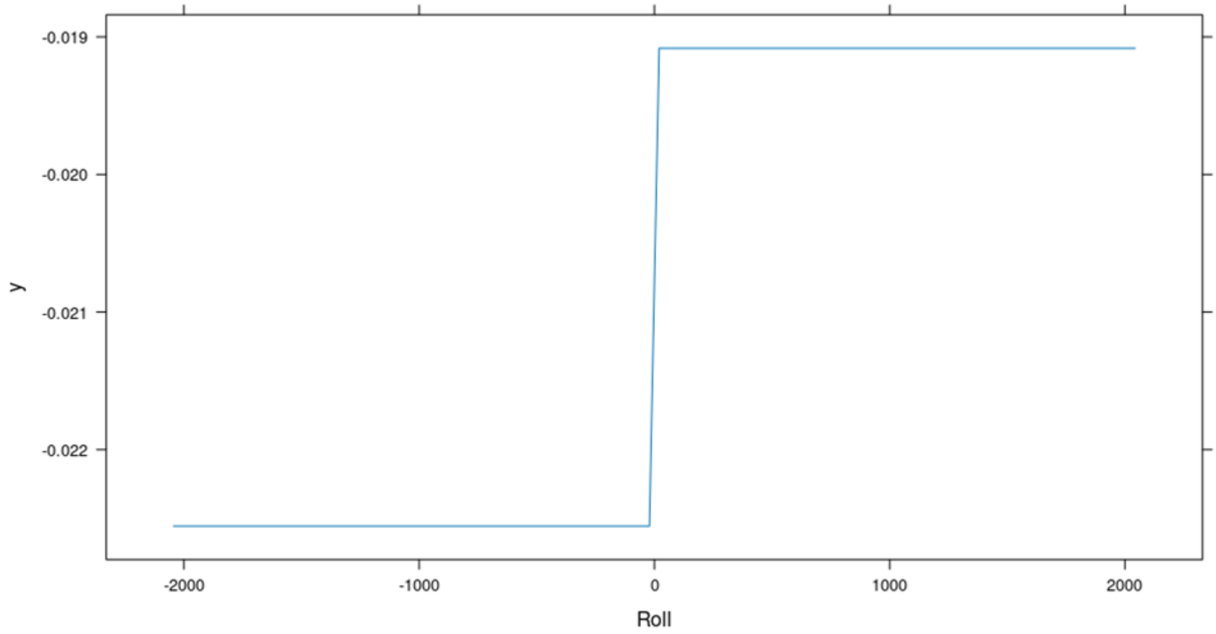


Figure 17: Partial dependency plot for roll in the glare model

The influence of vehicle in the glare model (the second highest influence at 20.18%) suggests that, separately from the luminance and contextual variables, the specific vehicles in the scene can have an impact on whether glare is experienced. Table 5 shows the partial dependency values for the highest-scoring vehicles in the glare model (tabulated values are in Appendix K). Unfortunately, the ANPR data collection was not as successful as the collection of other variables, meaning that for many data points there was no corresponding vehicle data. Due to this limitation, confidence in individual vehicle make and models is relatively low and hence each has been replaced with a descriptor of vehicle category. The fact that the model still uncovered the influence of the vehicle variable, even with the constraints on the available data, is testament to the power of this machine learning model approach, and presumably to the importance of individual differences in vehicles in the dataset. For each vehicle make and model shown in Table 5, manufacturer websites and specifications were used to identify whether each would likely have LED headlamps installed as standard.

Table 5: Partial dependency values for the highest-scoring vehicles in the glare model

Vehicle	Partial dependency value	LED headlamps
MEDIUM SUV (ICE)	0.86561626784249	Yes
SUPERMINI (EV)	0.86561626784249	Yes
LARGE SUV (PHEV)	0.439732779878188	Yes
SMALL VAN (ICE)	0.376940046325069	No
LARGE SUV (EV)	0.315747106523512	Yes
MEDIUM SUV (ICE)	0.299730448604275	Yes
SMALL SUV (PHEV)	0.295871742671983	Yes
SMALL SUV (PHEV)	0.293584574288119	Yes
LARGE SUV (ICE)	0.287551451147524	Unknown
MEDIUM SUV (EV)	0.284886546943125	Yes

Due to the constraints in the vehicle data collected, however, and to the averaging of timestamps that needed to be undertaken to align the variables in the dataset (see limitations in Section 5.2), it is not possible to be sure which vehicle makes and models are to blame for greater or lesser amounts of glare. While there is a hint in the table above that SUVs and larger vehicles (9 of 10) and models likely to be fitted with LED highlights (8 of 10) may be more associated with glare, this needs to be treated as speculation and needs to be tested in research focused specifically on such questions.

3.4.2 The luminance model

A grid search was conducted to determine the optimal hyper-parameters for the luminance model prior to testing the model (Table 3 and Appendix F). The model was subsequently trained on 70% of the data and tested on the remaining 30%. The cross-validation RMSE of the model was 12,045.63 cd m^{-2} during the training phase. The correlation (Pearson's r) of the model's predictions with the test data was 0.78 ($t = 227.77$, $df = 32,471$, p-value < 2.2e-16) – see Figure 18.

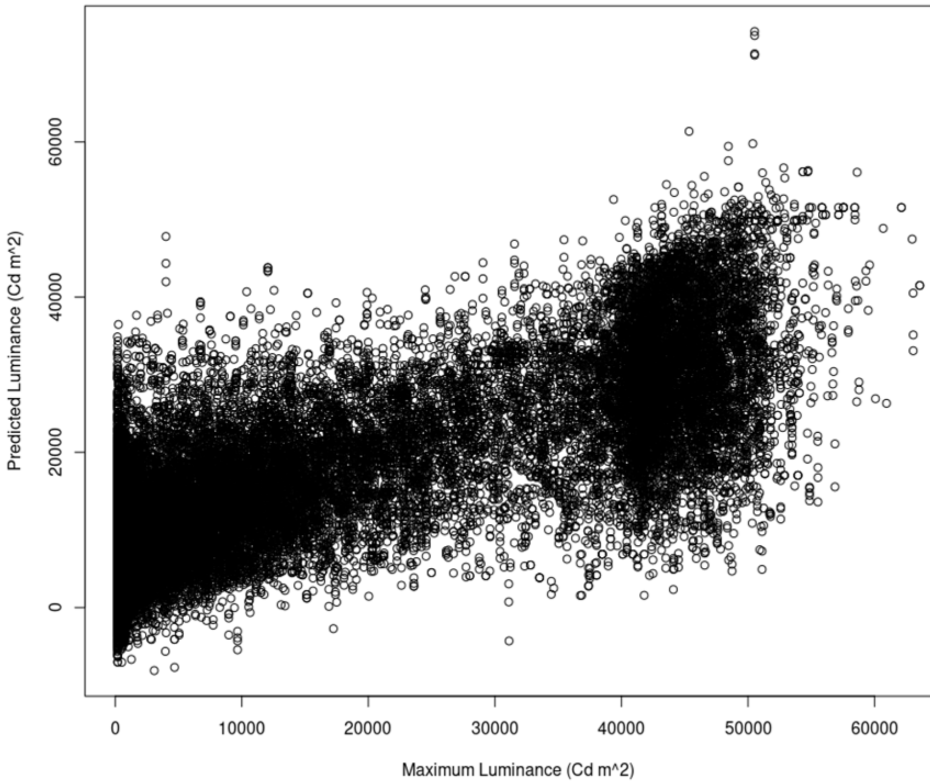


Figure 18: The luminance model's predicted luminance as a function of maximum luminance in the scene

The relative influence of each variable is plotted in Figure 19 (tabulated values are found in Appendix L).

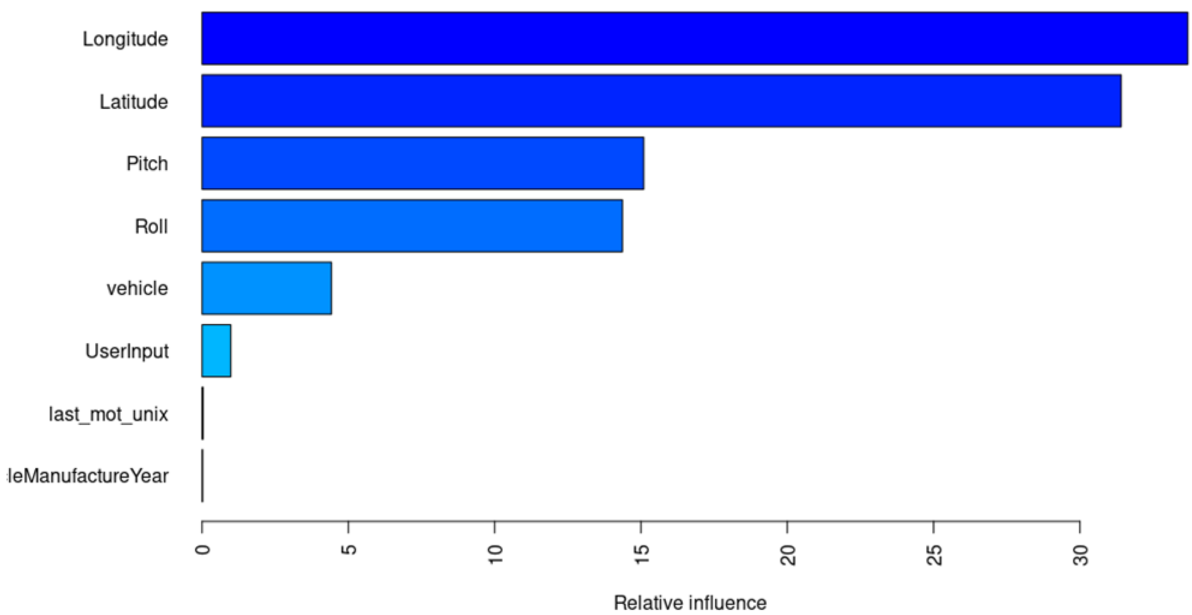


Figure 19: Relative influence of variables in the luminance model

Longitude and latitude had the strongest influence on the model (33.68% and 31.41% respectively). The next most influential variables in the model were pitch and roll (15.09% and 14.36 % respectively). Vehicle model influence was 4.42%. The remaining variables (glare response, vehicle manufacture year and MOT date) had negligible influence on the model. The fact that vehicle manufacture year was not an important variable by itself suggests that the important characteristics of vehicles were captured by the make and model variable.

The importance of latitude and longitude in the model suggest that, as with glare, specific locations are more likely to be associated with high luminance events. Again, we do not explore this further here as there does not appear to be a generalisable benefit without specific linking to other potential road features such as road class.

The pitch and roll of the trial vehicle had an influence on luminance, as shown in Figure 20 and Figure 21 (tabulated variables in Appendix M). These show a less obvious association with the outcome than in the glare model. A pitch indicating that the trial vehicle was heading uphill or going around a right-hand bend (leaning to the left) was associated with higher luminance values, but some high values were also observed at some values heading downhill or around a left-hand bend (leaning to the right).

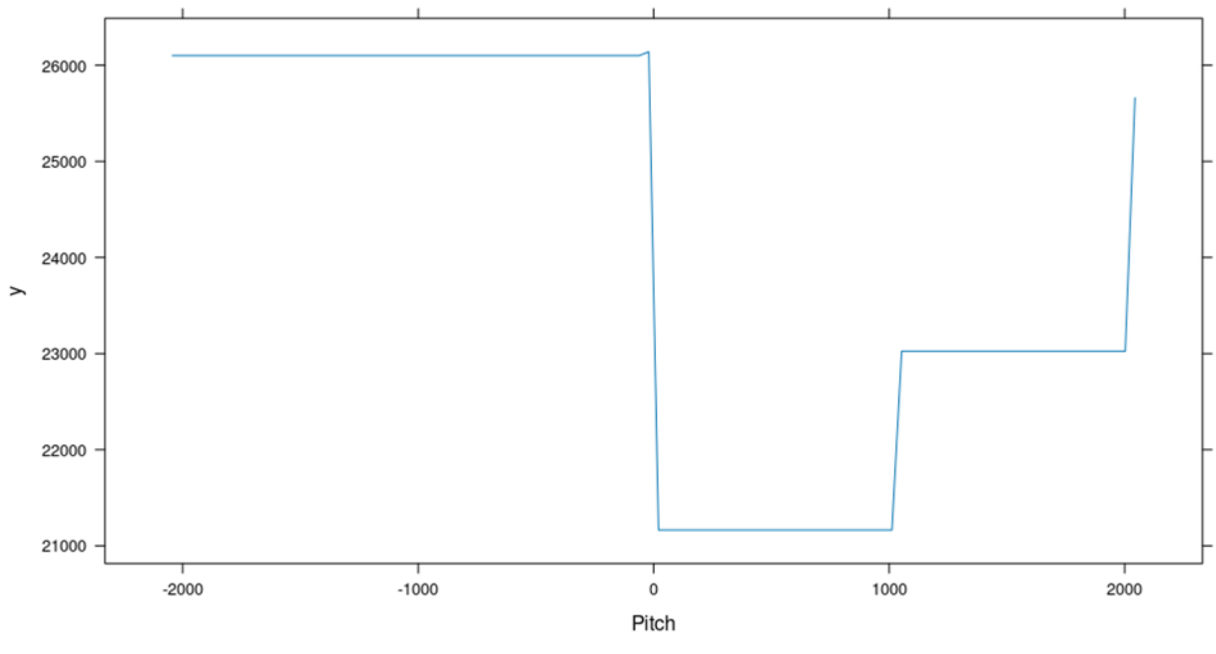


Figure 20: Partial dependency plot for pitch in the luminance model

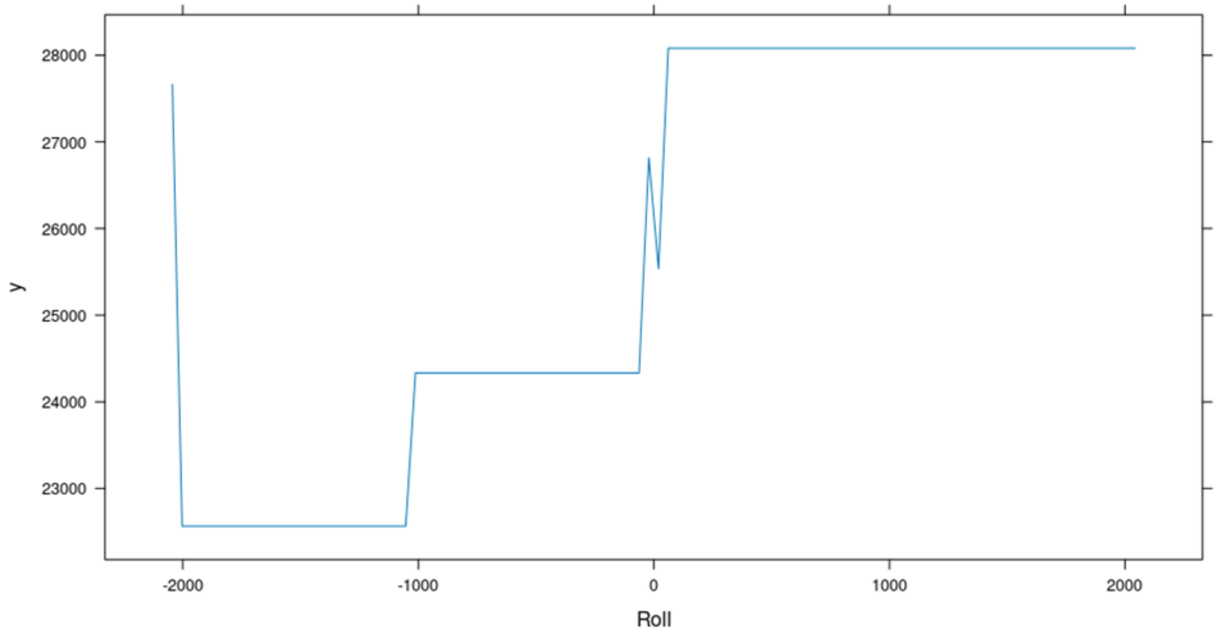


Figure 21: Partial dependency plot for roll in the luminance model

As in the glare model, there was an independent effect of vehicle model on the luminance values experienced. The top ten vehicle partial dependencies may be found in Table 6 and the partial dependency values for each vehicle may be found in Appendix N. As previously, manufacturer websites and specifications were used to identify whether each vehicle would likely have LED headlamps installed as standard.

Table 6: Partial dependency values for the highest-scoring vehicles in the luminance model

Vehicle	Partial dependency value	LED headlamps
ARTICULATED HGV (ICE)	93052.5484849111	No
MEDIUM SALOON (ICE)	86584.1762790982	No
MEDIUM SUV (ICE)	73650.1728288015	Yes
MEDIUM HATCHBACK (ICE)	68622.1783155301	Yes
SMALL HATCHBACK (ICE)	66610.0286250925	No
LARGE VAN (ICE)	65510.2522077084	No
MEDIUM SUV (ICE)	65118.2237032375	Yes
MEDIUM SUV (ICE)	64952.9098525407	Unknown
MEDIUM SUV (EV)	64174.7382117856	Yes
SMALL SUV (PHEV)	63897.5718362335	Yes

As with the glare model, the presence of vehicle in the model should be treated as indicative, as the ANPR data collection was sparse, and there were other limitations (see Section 5.2). The only hint in the table above that might be worth testing in future work is the apparent over-representation of SUVs and larger vehicles (7 of 10). The lack of a clear bias towards vehicle models likely fitted with LED lights in the luminance model (there was one in the glare model) is returned to in the discussion; it suggests that while LED lights may be associated with the perception of glare, it is not necessarily because they have greater levels of luminance.

3.5 Case studies

The GBM modelling suggests that a complex set of factors is associated with the experience of glare in observers, and with the presence of high levels of luminance in the road scene. Glare is associated with high luminance values in road geometries associated with heading uphill and around right-hand bends, also at some specific locations and possibly when specific types of vehicles (larger ones, and possibly those with LED lights) are oncoming. High luminance is associated again with specific locations, to some degree with travelling uphill and around right-hand bends, and again possibly with specific vehicle types (larger ones). Vehicle type has more of an influence on glare than on luminance, which is compatible with the hypothesis that the impact of vehicle on glare is mediated by things other than high luminance (for example lighting types, model types).

Figure 22 and Figure 23 show plots of measured average maximum luminance values over 40,000 cd m^{-2} and glare button presses on the routes driven. These provide a visual indication that high luminance and the experience of glare appear to be highly correlated and dispersed across many locations on the routes driven. They also show that sometimes glare button presses occur in locations without high levels of luminance being recorded, and that high luminance can occur without a glare button press (see examples in both plots marked with arrows). This further underlines the complexity and multi-factorial nature of the relationship between driving conditions and the experience of glare.

To illustrate further some of the specific circumstances in which glare was experienced (or not) and how the various factors combine to make this more or less likely, this section includes several case studies showing dashcam footage and other variables for each. These are shown in Sections 3.5.1 to 3.5.15 below. Unless otherwise stated these are from the “dialled back” focus dataset. Pitch, roll and road layout information provided in these case studies refers to the trial vehicle and its location.

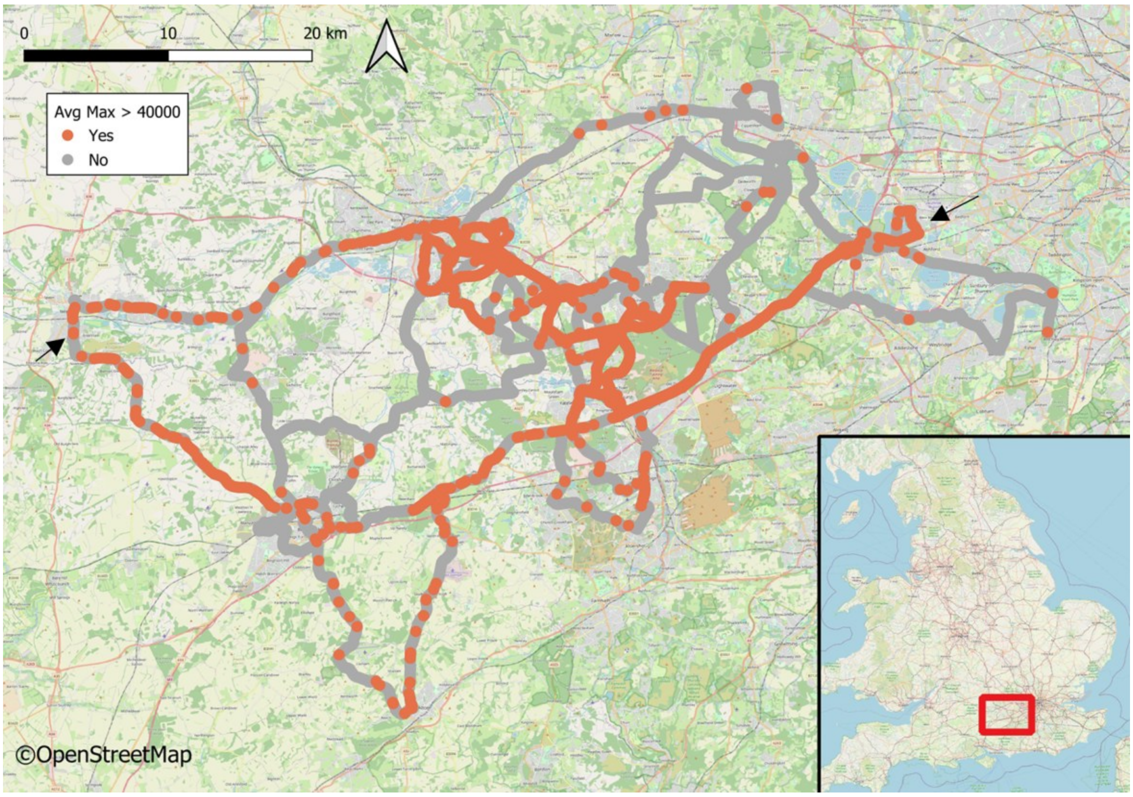


Figure 22: Plot of average maximum luminance values over 40,000 cd m^{-2} (arrows indicating luminance > 40,000 without corresponding glare button press) – both datasets

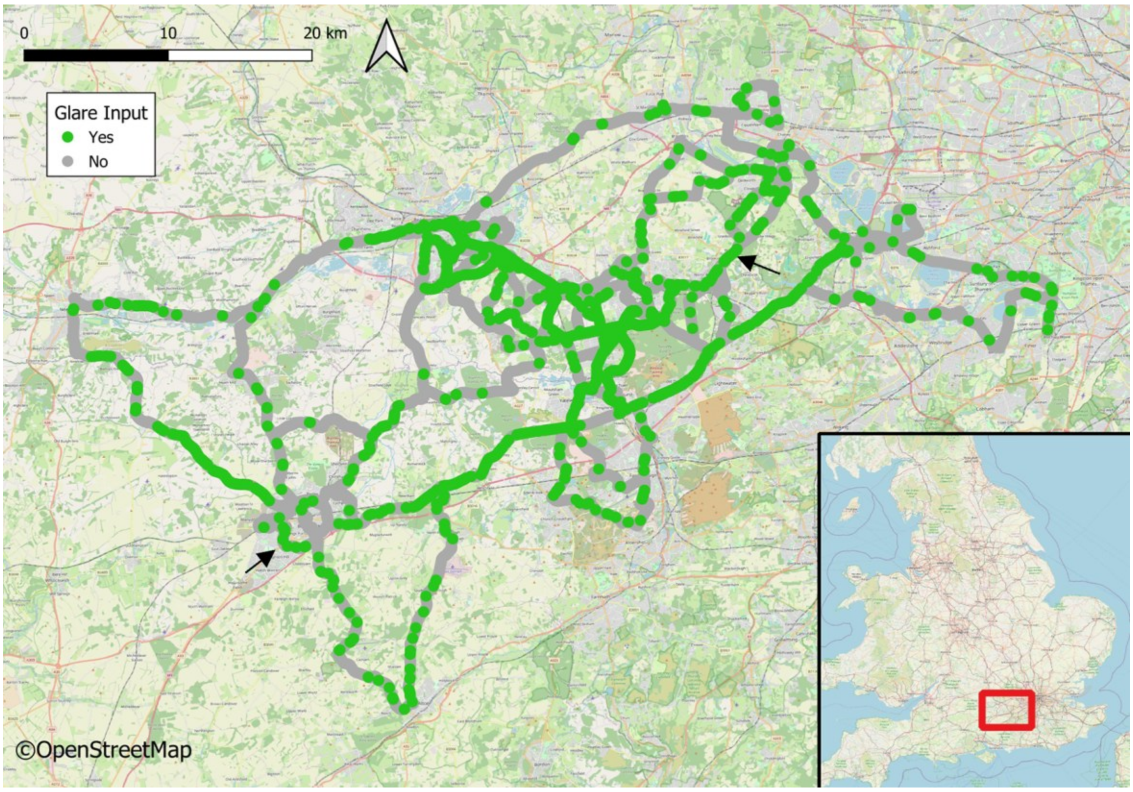
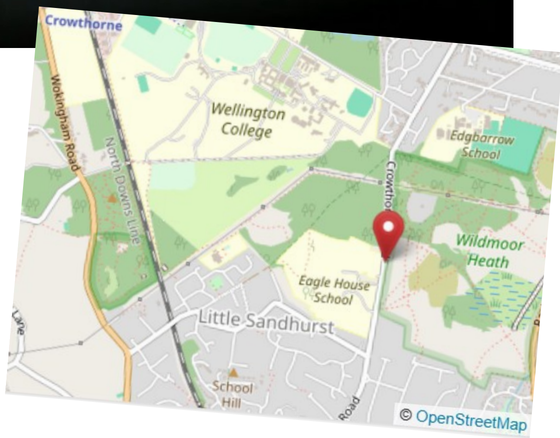
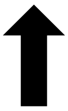


Figure 23: Plot of glare button presses (arrows indicating glare button press without corresponding high luminance) – both datasets

3.5.1 Case study #1: Location of interest – semi-rural



Date and time	Glare button	Observer
7 May 2025 20:55:22	Pressed	Age group 25–34 Wearing glasses

Pitch	Roll	Road layout
		Slight downhill as part of undulating road 

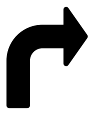
Luminance values				Oncoming vehicle(s)	
X avg. max.	X max.	X min.	X mean	Vehicle details	Most recent MOT
43,239	45,097	0	25	Large diesel SUV Manufactured 2019	Oct 2024

Comment

Example of when the glare button was pressed, with high luminance values recorded, on a semi-rural, undulating road with no streetlighting in the immediate vicinity. Very slight left roll, maybe due to camber, and slight downhill pitch. The time of this event was in the evening around twilight.

3.5.2 Case study #2: Location of interest – semi-rural

Date and time	Glare button	Observer
1 May 2025 21:01:26	 Pressed	Age group 55–64 Wearing contact lenses

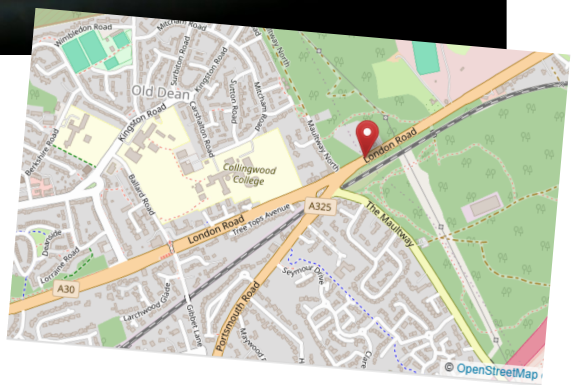
Pitch	Roll	Road layout
		Approaching right-hand bend ahead 

Luminance values				Oncoming vehicle(s)	
X avg. max.	X max.	X min.	X mean	Vehicle details	Most recent MOT
50,912	53,018	0	26	Petrol SUV Manufactured 2024	n/a (less than 3 years old)

Comment

Another example instance of when the glare button was pressed, again with high luminance values recorded, in this case approaching a right-hand bend in a street lit area. The oncoming vehicle was an SUV, manufactured in 2024 and a petrol fuel type. The time of this event was in the evening around twilight.

3.5.3 Case study #3: Location of interest – semi-rural



Date and time	Glare button	Observer
1 May 2025 23:16:07	Pressed	Age group 55–64 Wearing contact lenses

Pitch	Roll	Road layout
		Uphill, straight, towards a signalised roundabout

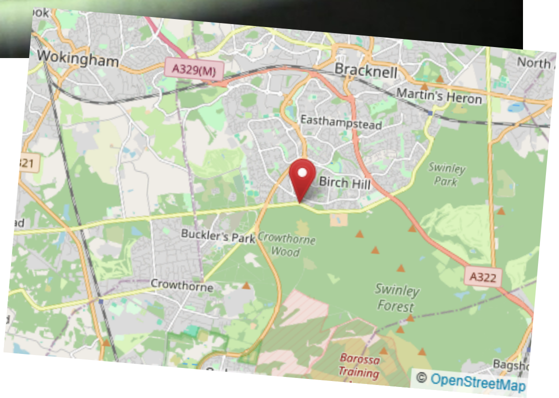
Luminance values				Oncoming vehicle(s)	
X avg. max.	X max.	X min.	X mean	Vehicle details	Most recent MOT
43,078	44,232	0	26	Mild-hybrid SUV Manufactured 2024	n/a (less than 3 years old)

Comment

This is an example of where the glare button was pressed on a straight road travelling towards an urban area. It was on an upwards gradient, on the approach to a signalised roundabout. The SUV vehicle causing glare was some distance away, occurring as it turned off the roundabout.

*Pitch (positive gradient uphill) ascertained from dashcam footage and local knowledge of route.

3.5.4 Case study #4: Location of interest – semi-rural



Date and time	Glare button	Observer
14 March 2025 19:23:18	Pressed	Age group 65 or above Wearing glasses

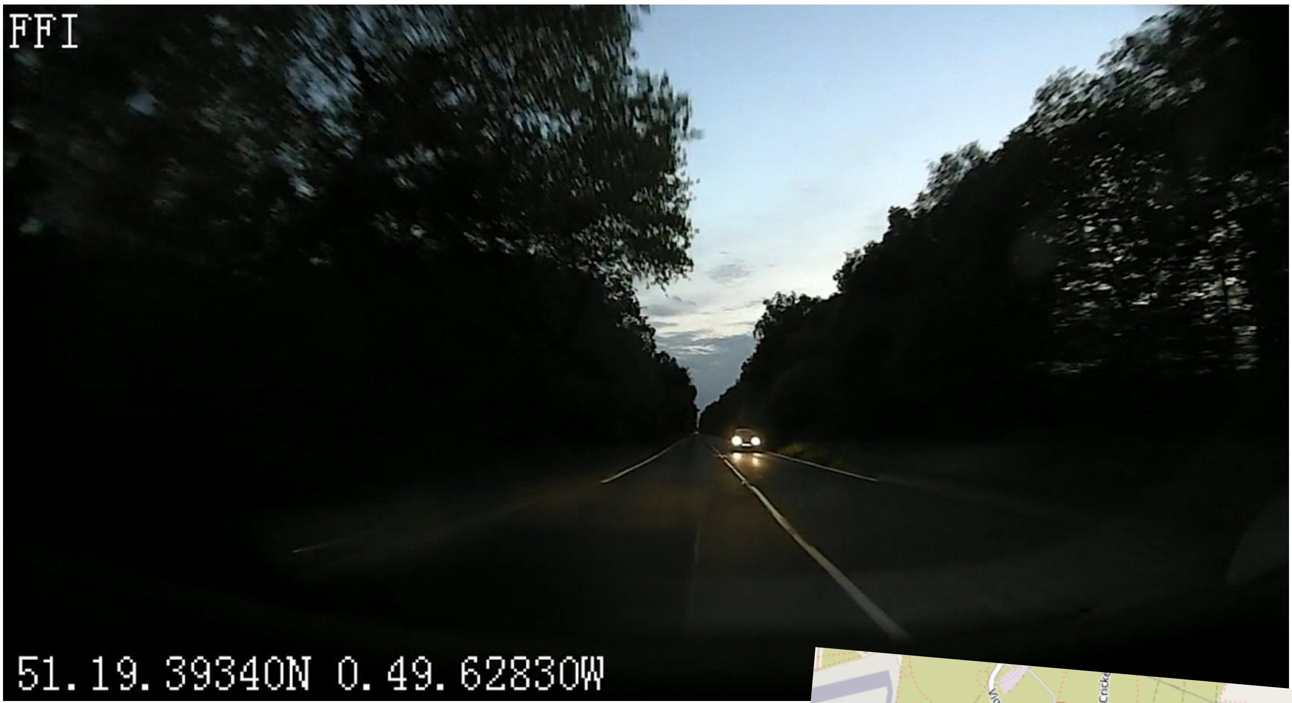
Pitch	Roll	Road layout
		Right-hand bend ahead, over crest

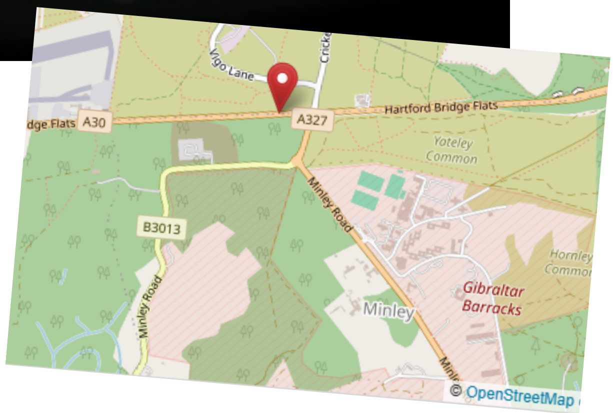
Luminance values				Oncoming vehicle(s)	
X avg. max.	X max.	X min.	X mean	Vehicle details	Most recent MOT
Exact measurement not available				Manufactured 2023 Electric SUV	n/a (less than 3 years old)

Comment

Example instance of the glare button being pressed on a semi-rural road, with no street lighting. It was approaching a right-hand bend with a slight crest. The oncoming electric SUV was approaching over the crest from the other direction.

3.5.5 Case study #5: Location of interest – rural





Date and time	Glare button	Observer
7 May 2025 21:03:37	Pressed	Age group 25–34 Wearing glasses

Pitch	Roll	Road layout
		Straight A road, uphill

Luminance values				Oncoming vehicle(s)	
X avg. max.	X max.	X min.	X mean	Vehicle details	Most recent MOT
40,998	41,700	0	25	Small hybrid electric car Manufactured 2018	March 2025

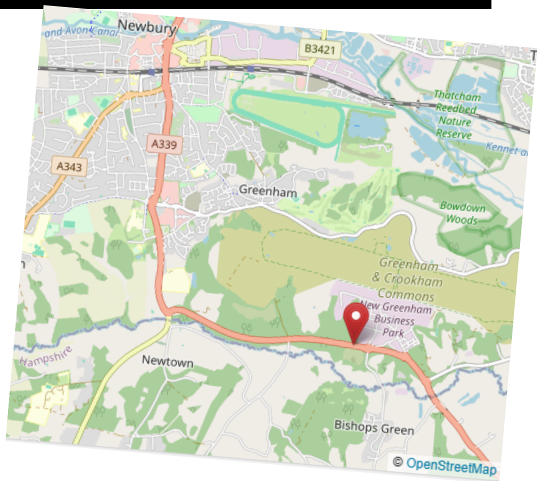
Comment

On this straight road, the glare button was pressed, supported by high luminance values recorded; however, note that no clear visual indication of glare appears in the dashcam view on this occasion. This may relate to the subjective nature of glare and be dependent on the position of the observer in the rear of the vehicle. The time of this event was in the evening around twilight.

3.5.6 Case study #6: Location of interest – rural

Date and time	Glare button	Observer
30 April 2025 22:40:35 – 22:40:39	Pressed	Age group 25–34 Wearing glasses

Pitch	Roll	Road layout
		Straight A road, relatively flat

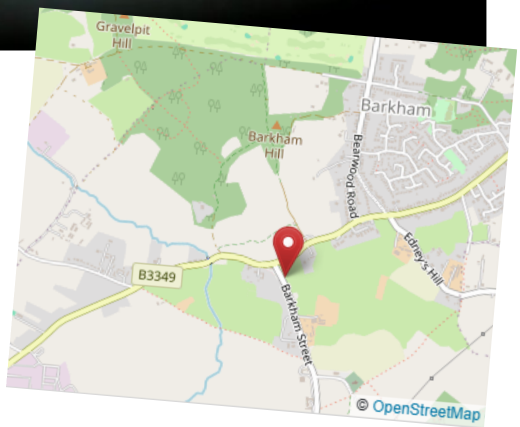


Luminance values				Oncoming vehicle(s)	
X avg. max.	X max.	X min.	X mean	Vehicle details (two lorries in quick succession)	Most recent MOT
47,207	48,207	0	27	Lorry 1 manufactured 2023	Sept 2024
49,747	52,339	0	27	Lorry 2 manufactured 2022	Oct 2024

Comment

This is an example of two large lorries passing, where a glare button input was recorded for each vehicle, on a fairly level, straight length of road, with no streetlighting in this section. The luminance values recorded were also high. Many lorries were seen using this A339 route.

3.5.7 Case study #7: Location of interest – rural



Date and time	Glare button	Observer
6 March 2025 19:50:52	Pressed	Age group 25–34 No eyesight correction

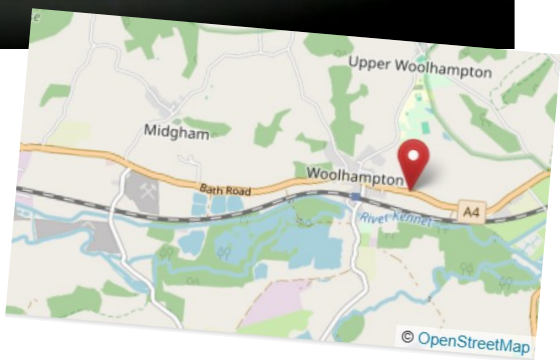
Pitch	Roll	Road layout
		Slightly uphill towards a right-hand bend

Luminance values				Oncoming vehicle(s)	
X avg. max.	X max.	X min.	X mean	Vehicle details	Most recent MOT
No measurement available at moment of glare				Hatchback Manufactured 2013	Jan 2025

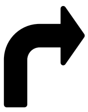
Comment

Example of instance of glare button being pressed on a rural road. This was going slightly uphill towards a right-hand bend, with no streetlighting in the immediate vicinity.

3.5.8 Case study #8: Location of interest – semi-rural



Date and time	Glare button	Observer
30 April 2025 22:58:41	Pressed	Age group 25–34 Wearing glasses

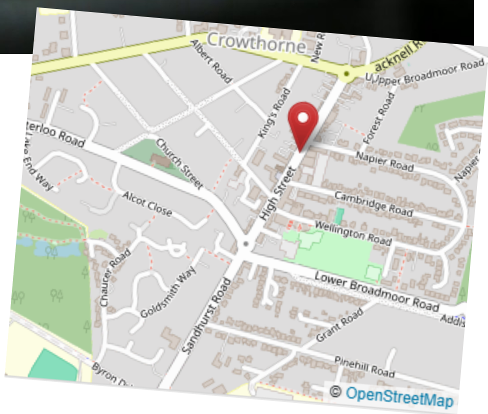
Pitch	Roll	Road layout
		Fairly level approaching right-hand bend 

Luminance values				Oncoming vehicle(s)	
X avg. max.	X max.	X min.	X mean	Vehicle details	Most recent MOT
40,789	45,515	0	26	Small hatchback Manufactured 2005	Feb 2025

Comment

In this example, having travelled through a small residential area, heading into a national speed limit area approaching a right-hand bend, a small hatchback caused high luminance values, and the observer pressed the glare button as it approached.

3.5.9 Case study #9: Location of interest – urban



Date and time	Glare button	Observer
12 May 2025 21:22:22	Pressed	Age group 65 or above Wearing glasses

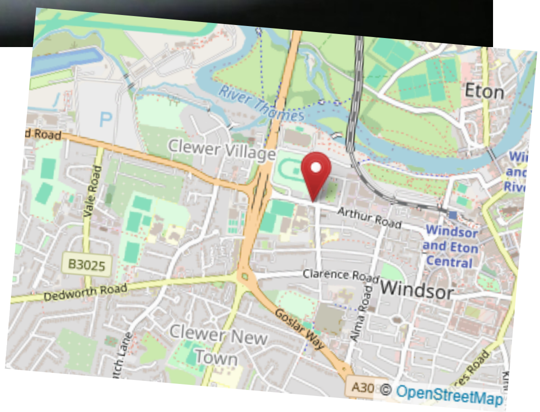
Pitch	Roll	Road layout
		Straight stretch, slightly uphill towards crest

Luminance values				Oncoming vehicle(s)	
X avg. max.	X max.	X min.	X mean	Vehicle details	Most recent MOT
22,553	23,129	0	26	Diesel mild-hybrid SUV Manufactured 2025	n/a (less than 3 years old)

Comment

This is an example of where a glare button input was recorded, noting that the oncoming vehicle was going over a raised zebra crossing over a slight crest. The luminance values recorded were not as high as some previously seen, indicating that the experience of glare is not always dependent on the very highest levels of luminance. The time of this event was in the evening around twilight.

3.5.10 Case study #10: Vehicle of interest causing glare – urban



Date and time	Glare button	Observer
12 March 2025 19:31:40	Pressed	Age group 35–44 No eyesight correction

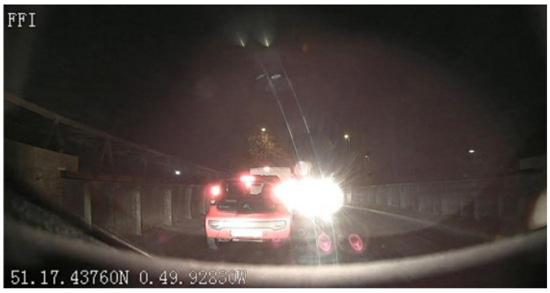
Pitch	Roll	Road layout
		Straight, in urban location at signalised junction

Luminance values				Oncoming vehicle(s)	
X avg. max.	X max.	X min.	X mean	Vehicle details	Most recent MOT
No measurement available at moment of glare				Sports car, petrol Manufactured 2024	n/a (less than 3 years old)

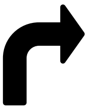
Comment

This is an example of a modern sports car in an urban area causing glare at a traffic signal-controlled junction, where a glare button input was recorded. Again, this illustrates that sometimes glare can occur without the most obvious variables (in this case a larger vehicle) being present.

3.5.11 Case study #11: Multiple glare button presses while stationary in traffic – urban



Date and time	Glare button	Observer
17 March 2025 19:17:48 – 19:18:45	 Pressed	Age group 45–54 Wearing glasses

Pitch	Roll	Road layout
		Stationary on a bridge, ahead of right-hand bend with slight downward gradient 

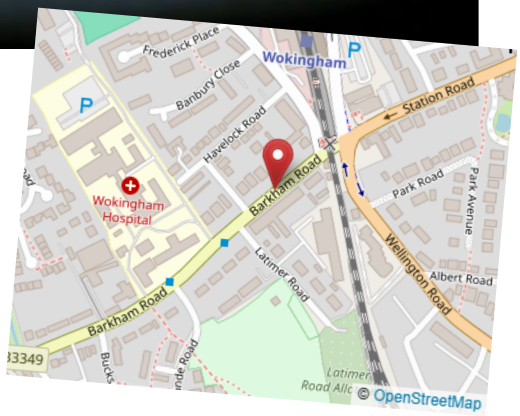
Luminance values				Oncoming vehicle(s)	
X avg. max.	X max.	X min.	X mean	Vehicle details	Most recent MOT
52,376 45,524 50,466	52,869 45,722 50,658	0 0 0	96 93 72	Twenty vehicles (see comment below)	Not applicable

Comment

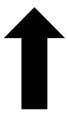
While stationary on a bridge in a queue of traffic in an urban location, within approximately 60 seconds, 20 vehicles passed by, causing repeated presses of the glare button. Noted multiple types, ages and sizes of vehicles, including compact cars, saloons, SUVs and a van all appearing to cause glare, just as each approached the bridge on the bend, noting the vehicles all travelling up a slight positive gradient. This is a further example of glare being present due to specific road conditions.

* Not absolute luminance values, as from infinity focus dataset.

3.5.12 Case study #12: Location of interest – urban



Date and time	Glare button	Observer
8 May 2025 21:50:16	Pressed	Age group 25–34 Wearing glasses

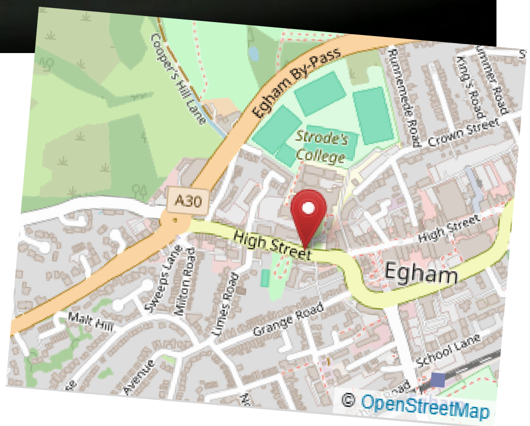
Pitch	Roll	Road layout
		Straight, approaching level crossing 

Luminance values				Oncoming vehicle(s)	
X avg. max.	X max.	X min.	X mean	Vehicle details	Most recent MOT
19,365	20,309	0	25	Compact diesel car Manufactured 2010	Nov 2024

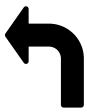
Comment

Although this example occurred on a straight road, an oncoming small car was seen about to pass several parked vehicles on its side of the road, and glare was experienced.

3.5.13 Case study #13: Location of interest – urban



Date and time	Glare button	Observer
6 May 2025 21:56:06	Pressed	Age group 55–64 Wearing contact lenses

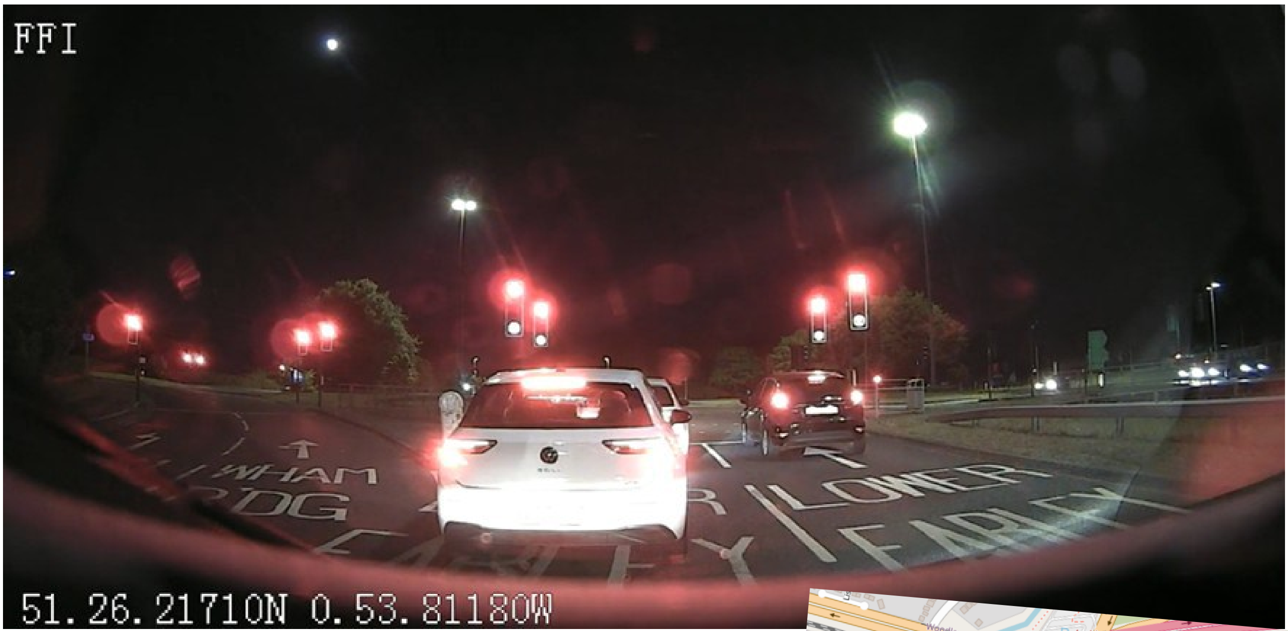
Pitch	Roll	Road layout
		On straight approaching left-hand bend 

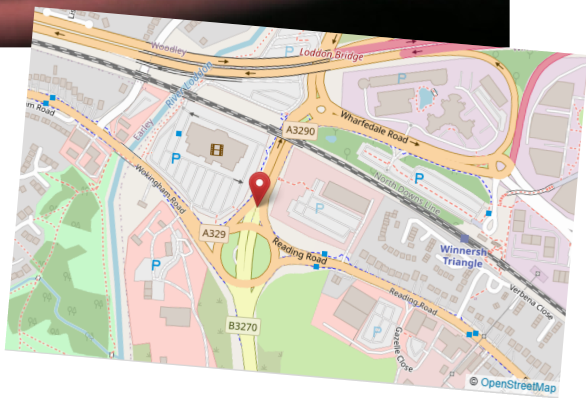
Luminance values				Oncoming vehicle(s)	
X avg. max.	X max.	X min.	X mean	Vehicle details	Most recent MOT
46,760	50,295	0	27	Hybrid electric vehicle Manufactured 2024	n/a (less than 3 years old)

Comment

While the trial vehicle was approaching a left-hand bend (with noticeable camber also causing lean to the left) an oncoming hybrid electric vehicle had just pulled into an on-road parking space with its lights on. The glare button was pressed, and high luminance values were recorded.

3.5.14 Case study #14: Example of high luminance with vehicles and static lighting – urban





Date and time	Glare button	Observer
9 May 2025 22:01:58	Not pressed	Age group 65 or above Wearing glasses

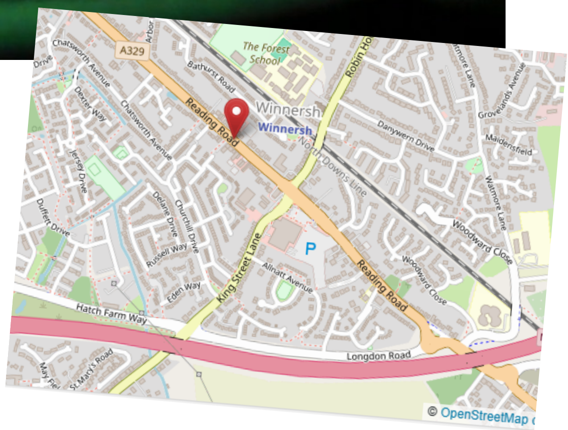
Pitch	Roll	Road layout
		Stationary at traffic lights

Luminance values				Oncoming vehicle(s)	
X avg. max.	X max.	X min.	X mean	Vehicle details	Most recent MOT
58,604	60,680	0	56	No oncoming vehicle	Not applicable

Comment

Example of one of the ten highest average maximum luminance measurements, where multiple stop signals and rear vehicle lights may contribute to high luminance measurements being recorded. Glare button was not pressed, presumably due in part to the position of the observer in the trial vehicle.

3.5.15 Case study #15: Example of high luminance without clearly related vehicles – urban



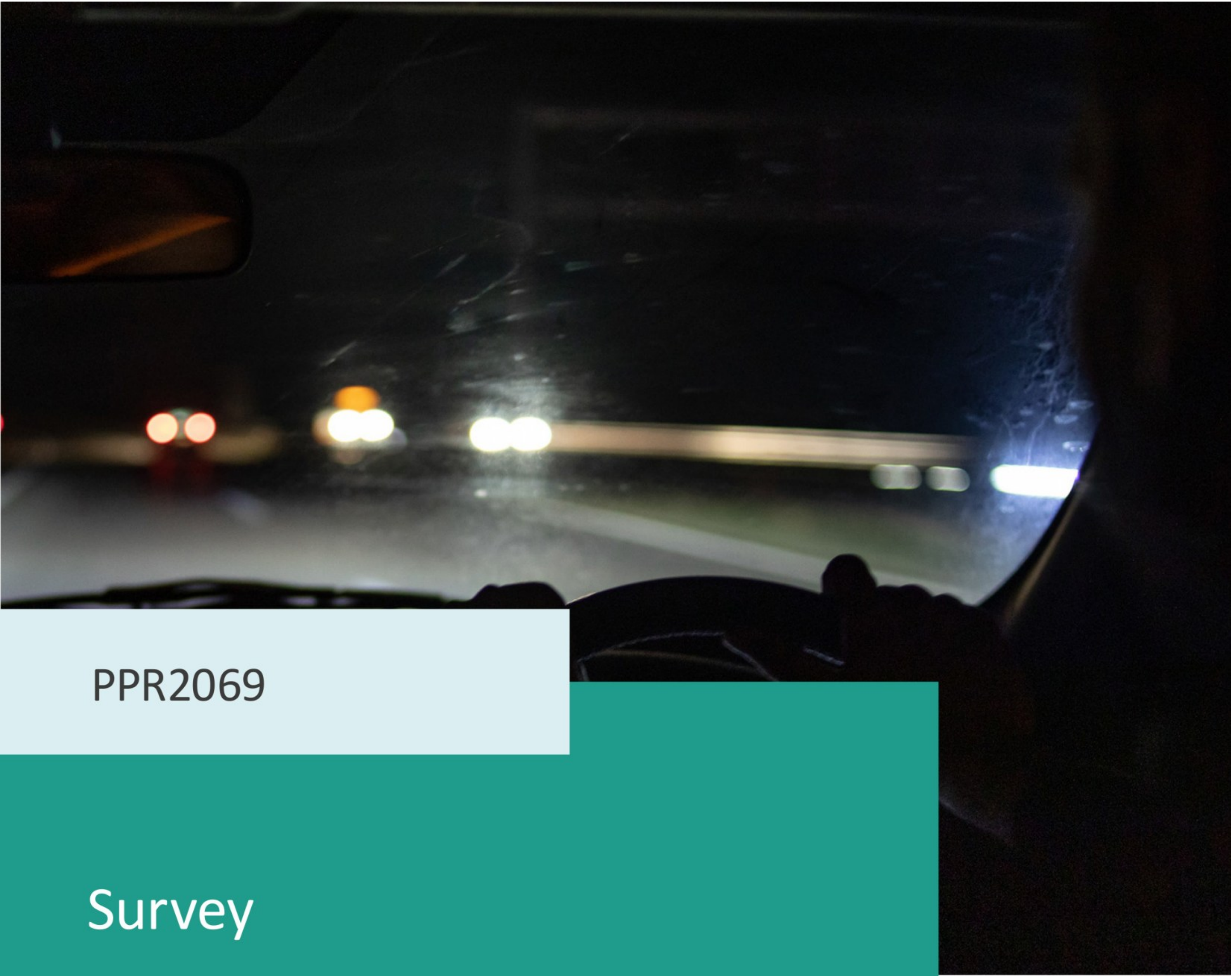
Date and time	Glare button	Observer
8 May 2025 21:56:03	Not pressed	Age group 25–34 Wearing glasses

Pitch	Roll	Road layout
		Straight road

Luminance values				Oncoming vehicle(s)	
X avg. max.	X max.	X min.	X mean	Vehicle details	Most recent MOT
58,160	58,768	0	45	No oncoming vehicle	Not applicable

Comment

Example of one of the ten highest average maximum luminance measurements with no vehicles contributing significantly; rather street scene elements may contribute (i.e. green light and bright streetlight).



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Survey

4 Survey

This section describes the method (Section 4.1) and findings (Sections 4.2 to 4.4) from a survey carried out with members of the public regarding their perceptions and experience of glare; this was suggested by the RAC as a potential source of additional data during stakeholder engagement.

4.1 Method

Thirteen questions (from a wider set) were used in a periodic online survey undertaken by the RAC with its Motorists Opinion Panel. The purpose was to gather data from a sample of UK drivers, representative of UK licence holders in their age and gender distribution, on topics pertinent to the current project.

4.1.1 Materials

The questions listed in Table 11 in Appendix O were presented to the RAC Motorists Opinion Panel in February 2025, using an online survey; panel participants were invited to complete an online survey around once every six weeks, and these questions were asked as one of these waves, to support the project.

This enabled the measurement of public perception of topics related to glare and vehicle headlamps at a time approximately matching when the on-road data collection was being undertaken on the same topics. A wider set of questions were also asked at this survey point, but only the ones relevant to the on-road data collection are reported here.

4.1.2 Participants

1,850 UK motorists (RAC members and other UK motorists who hold a full current UK driving licence and drive at least once a month) were surveyed. The sample was weighted to match DVLA driving licence interlocking age and gender profiles.

4.1.3 Procedure

An online survey methodology was used. For previous reports on the RAC Motorists Opinion Panel surveys see RAC (2025).

4.1.4 Design and analysis

Differences between genders, age groups and those with cars of different ride heights are based on the confidence limits reported in the survey dataset, provided by the RAC. Data collection and analysis were undertaken by the RAC panel administration team.

The complete sample comprised 1,850 UK drivers, as described in Section 4.1.2. All numbers and percentages in this section and in Appendix P (full data tables) are based on the weighted samples.

In Section 4.2 the characteristics of the sample are discussed, focusing on age and gender split and the ride height of the main vehicle respondents reported driving (including the seat height they choose). Data tables are included in this section.

Section 4.3 then focuses on respondents' views on glare ("dazzle" in the survey questions) when driving, covering perceptions of vehicle headlamps, perceptions of driving environments, and changes in behaviour in response to glare. Data tables for these responses are in Appendix P. Key comparisons between gender, age groups and vehicle ride height are discussed. The reason for a focus on these variables is that based on the evidence review (age, gender) and on the geometry involved (ride height) we would expect them to influence the perception of glare.

Section 4.4 summarises the findings from the survey, with reference to the on-road data collection.

4.2 Characteristics of the sample

Table 7 shows the age and gender breakdown of the weighted sample. As noted in Section 4.1.2 the sample matched DVLA licence holder data by age and gender. Age and gender are both of potential interest when considering the findings on perception of glare, as both (especially age) have been shown to have some link to the experience of glare.

Table 7: Gender by age – weighted sample

Gender	17–34	35–44	45–54	55–64	65–74	75+	Total
Male	202	178	181	192	134	95	982
Female	184	159	158	170	115	76	862
Total	386	339	341	364	248	171	1,850*

*Some respondents described their gender as neither male nor female, so some totals do not sum.

Respondents were asked about their usual vehicle. Table 8 shows this data. The ride height variable is of interest when we consider perception of glare, as lower vehicles are more likely to fall within the throw of oncoming vehicle headlamps.

The sample sizes for the van categories are too small for any robust analysis, and consequently later discussions about vehicle type are limited to the three ride height categories of car.

Table 8: What type of vehicle do you drive most often?

Vehicle type	17–34	35–44	45–54	55–64	65–74	75+	Total
Lower ride height car	84 (22%)	19 (6%)	18 (5%)	25 (7%)	8 (3%)	6 (3%)	159 (9%)
Normal ride height car	230 (60%)	238 (70%)	208 (61%)	209 (57%)	157 (63%)	119 (70%)	1,161 (63%)
Higher ride height car	66 (17%)	76 (22%)	100 (29%)	112 (31%)	76 (31%)	45 (26%)	475 (26%)
Small van	3 (1%)	2 (1%)	3 (1%)	7 (2%)	0 (0%)	0 (0%)	16 (1%)
Large van	0 (0%)	2 (1%)	8 (2%)	6 (2%)	4 (1%)	0 (0%)	20 (1%)
Other	3 (1%)	3 (1%)	4 (1%)	5 (1%)	3 (1%)	1 (0%)	19 (1%)
Total	386	339	341	364	248	171	1,850

Table 9 shows data regarding seat height setting. This is not reported further in the perception of glare findings; it is shown here for interest only.

Table 9: In the vehicle you drive most often, at what height is the driver's seat set at?

Seat height	17–34	35–44	45–54	55–64	65–74	75+	Total
Highest setting	63 (16%)	34 (10%)	47 (14%)	59 (16%)	58 (23%)	44 (26%)	304 (16%)
Between high and low	270 (70%)	172 (51%)	187 (55%)	204 (56%)	145 (58%)	94 (55%)	1,073 (58%)
Lowest setting	35 (9%)	57 (17%)	41 (12%)	31 (8%)	14 (6%)	10 (6%)	188 (10%)
Don't know	17 (4%)	76 (22%)	67 (20%)	71 (19%)	32 (13%)	24 (14%)	285 (15%)
Total	386	339	341	364	248	171	1,850

One important point is that the survey only considers the perception of glare findings through comparisons of one or another of the gender, age or vehicle ride height variables. There are, however, some relationships between these variables, which the survey data are not designed to disentangle within the scope of this work. Key examples are:

1. The youngest age group was the most likely to have the "low ride height car" as their main vehicle type (22% of these drivers, compared with 3–7% for other age groups).

2. Regarding gender (not shown in table) males (11%) were more likely than females (6%) to have a "low ride height car", with this pattern reversed for "normal ride height car" (58% and 69% males and females respectively).

3 The 65–74 and 75+ age groups tended to be more likely than others to have their seat on the highest setting (23% and 26% of these drivers respectively, compared with 10–16% for other age groups).

4 The 17–34 age group were more likely than other groups to have a height set in between the extremes (70%, compared with 51–58%).

5 The 35–44 and 45–54 age groups were more likely to have the lowest height (17% and 12% of these drivers respectively).

6 Regarding gender (not shown in table) females were more likely to report setting a seat on its highest setting (21% versus 13% for males) and the opposite was true for the other two settings (males 61%, females 54% for "between" and males 16%, females 4% for "lowest").

In practice, this means that any differences reported below regarding gender, age or vehicle ride height need to be considered as partly due to interrelationships of these variables. For example, any difference in the perception of males and females regarding glare will be contributed to by the fact that males are more likely to be driving a low ride height car, and females are more likely to be setting their seat height higher. It was outside the scope of the current work to examine these interaction effects directly.

4.3 Self-reported experience of glare

Panel respondents were asked about their experiences of glare when driving. Data tables are in Appendix P, with a summary of the main patterns in the below sub-sections.

Section 4.3.1 shows key findings related to vehicle lighting, Section 4.3.2 covers wider driving conditions and Section 4.3.2.1 covers behavioural changes in driving related to glare.

In all these sections, only the most obvious differences between the genders, age groups and ride height of vehicle driven are summarised. The full dataset (available on request from the report authors) can be examined in more detail for all comparisons.

4.3.1 Perception of vehicle lighting and glare

Respondents were asked several questions about their experiences of vehicle lighting and glare. Table 12 to Table 23 in Appendix P contain the detailed data on these questions, by gender, age and vehicle ride height.

4.3.1.1 Perception of vehicle lighting and glare: main findings

The main findings relating to the perception of vehicle lighting and glare are:

- 96% of drivers perceived "most" or "some" headlights to be too bright (36% and 60% respectively).

- 97% of drivers reported they “regularly” or “sometimes” get dazzled by oncoming vehicle headlights (39% and 58% respectively).
- 70% of drivers believed “whiter-coloured” lights are responsible, with only 4% singling out yellower-coloured, and 10% both colours (16% not sure).
- Drivers clearly understand the fact that higher vehicles are likely to be more responsible for glare than lower ones. For example, 47% of drivers believed that higher ride height cars are responsible for dazzling them, while the corresponding figure for lower cars was 8%.

Summary: Headlight glare is perceived as a problem by most drivers. These self-reported data alone are useful to have from a nationally representative sample at the same time as the on-road data collection was being undertaken.

The following breakdown of findings by sub-group adds further detail to our understanding of public perception of headlights and glare.

4.3.1.2 Perception of vehicle lighting and glare: gender differences

There are several reported differences between male and female drivers that warrant further investigation:

- Female drivers are more likely to believe that “most” headlights are too bright (44%, versus 29% of males).
- Female drivers are also more likely to report “regularly” getting dazzled by headlights from oncoming traffic (45% versus 33% of males).

Summary: Female drivers may experience glare from headlights to a greater degree than male drivers. The reasons for this (for example the times they drive, the types of vehicle they drive, physiological differences) is unclear from the data collected.

4.3.1.3 Perception of vehicle lighting and glare: age differences

The findings from the age sub-groups of participants reveal that the issue of glare is not always simple, with a mixture of intuitive and unintuitive results, although the small sample sizes in cases involving the youngest age groups mean caution is needed in interpretation. On age:

- There are no clear differences across the age range regarding perception of headlight brightness.
- Drivers of all ages report being dazzled either “regularly” or “occasionally”.
- The very small number of people reporting not getting dazzled is dominated by the 17–34 age group (11% of this group, 38 of 59 total people who reported no dazzle).
- The 17–34 age group also dominated the very small number of people (61 in total) who reported that yellower-coloured lights were responsible for dazzle (58 of these 61).
- The 17–34 age group also were more likely than other groups to report being dazzled by lower and normal ride height cars.

Summary: Drivers of all ages report glare. The youngest drivers (17–34) were the most likely by far to report not experiencing glare at all. They were also the most likely to report yellow-coloured lights and lower/normal ride height cars as being most to blame for glare.

4.3.1.4 *Perception of vehicle lighting and glare: car ride height differences*

When considering the perceptions of drivers of cars of low, normal and high ride height, again a complex picture emerges:

- There were no major differences in the perception of brightness, with drivers of all vehicle heights reporting "most" or "some" headlights as too bright.
- Drivers of lower cars were more likely than others to report *not* getting dazzled, which is unexpected, but numbers are small (only 16 of 137 such drivers); importantly, most drivers of all car heights reported dazzle regularly or occasionally.
- Drivers of lower cars were also more likely than other groups to report that yellower-coloured lights were to blame (18 of 137 such drivers).
- One expected result was that those driving lower and normal height cars were more likely to perceive that higher height cars were especially to blame.

Summary: Glare is a problem for drivers of all car ride heights. Those in lower cars perceive a specific issue with yellow lights and are more likely to report no glare, but numbers are low. Drivers of lower and normal height cars perceive higher height cars to be particularly to blame for glare.

4.3.2 Perception of driving conditions and glare

Several questions related to the various driving conditions in which drivers believe glare is more of a problem. Table 24 to Table 41 in Appendix P contain the detailed data on these questions, by gender, age and vehicle ride height.

4.3.2.1 *Perception of driving conditions and glare: main findings*

The main findings were:

- Just under half of drivers perceive glare to be an issue on all types of road.
- There was a consistent perception that unlit roads, relative to their lit comparators, were more of an issue for glare (40% versus 9% for unlit and lit rural respectively, 14% versus 3% for motorways, 28% versus 10% for urban or suburban).
- Drivers perceived issues from dazzle from oncoming vehicles in several scenarios, with speed humps (66% of drivers) being the most picked.
- Just under half of drivers perceived that all weather conditions give rise to dazzle; of those conditions offered as particular issues, those involving light rain, heavy rain or wet roads were picked more often than snow and fog.

- All traffic conditions were selected as related to glare, although “single oncoming vehicle” was more commonly selected (69%) than light or heavy traffic (51% and 47% respectively).

Summary: Glare is perceived to be a problem in many driving situations, although there is some insight from drivers as to the specific conditions (unlit conditions, the wet, specific road geometry, isolated traffic) that may be particularly problematic.

4.3.2.2 Perception of driving conditions and glare: gender differences

Gender differences in the perception of specific driving situations and their link to glare were varied but not extensive. Since there is no obvious pattern to the data, we do not discuss them further here.

4.3.2.3 Perception of driving conditions and glare: age differences

Regarding age:

- Around half of drivers of all ages reported that they experienced glare on all types of road, except for the 17–34 age group (24%), who were more likely than other ages to identify lit rural (16% of such drivers, compared with around 5–10% in several other groups) and lit motorway (11% of such drivers, compared with around 1% in all other groups) as being associated with their experience of glare.
- The 17–34 age group were less likely (49%) to single out speed bumps as a particular issue for glare (65–77% for other age groups).
- Around half of drivers of all ages reported that they experienced glare in all types of weather, except for the 17–34 age group (25%), who were more likely to single out specific weather conditions, notably heavy rain (50% of such drivers), snow (21% of such drivers) and fog (18%).
- The 17–34 age group drivers were less likely to report darkness as being a particular issue for glare (79% of these drivers, compared with just under 90% for other ages).
- The 17–34 age group drivers were less likely than all other age groups to report a single oncoming vehicle as being particularly problematic (49% compared with 70–77%).

It should be noted that the absolute numbers of respondents in some response categories (especially in the younger age group) were small. In addition, we know from previous research that younger people are less susceptible to glare overall, so findings related to this group might reflect a tendency for them being more able than older people to attribute their experience to specific situations. Any findings of note, or those that were unexpected related to age, should be considered for clarification in future targeted surveys.

Summary: All age groups reported glare as an issue in a range of situations. There is some variability in how the different age groups perceived driving situations and their contribution to headlight glare, particularly for the 17–34 age group.

4.3.2.4 Perception of driving conditions and glare: car ride height differences

The most salient differences in those groups driving different height cars were:

- Drivers of higher and normal ride height cars were more likely to experience glare as particularly related to a single oncoming vehicle (70% and 71% versus 57%).
- Drivers of higher ride height cars were more likely to say they did not experience glare during the day (75% versus 67–68%).

These findings are not particularly coherent and are not discussed more here.

4.3.3 Changes of behaviour

Respondents were also asked whether they had limited their driving due to glare from vehicle headlights. Table 42 to Table 44 in Appendix P contain the detailed data on this question, by gender, age and vehicle ride height.

4.3.3.1 Changes of behaviour: main findings

The main findings relating to changing driver behaviour were:

- 4% of drivers reported having stopped driving at night completely, and 29% reported driving less, due to headlights being too bright for them.
- A further 22% of drivers reported wishing that they could drive less at night but that they had no choice but to continue.

Summary: The brightness of headlights is reported as a motivating factor in the actual or desired reduction in driving at night for around 55% of UK drivers.

4.3.3.2 Changes of behaviour: gender differences

The findings relating to gender were:

- Females were more likely than males to report having stopped driving at night (6% versus 3%), driving less at night (34% versus 25%) or wishing they could drive less at night (25% versus 19%) due to glare.
- Males were correspondingly more likely than females to report not engaging in any of these behaviours (54% versus 35%).

Summary: Changing driving behaviour (actual or desired) in response to headlight brightness is more commonly reported by females (65%) than males (47%).

4.3.3.3 Changes of behaviour: age differences

The key findings related to age differences were:

- Drivers in the older two age groups, and the 17–34 group, were most likely to have stopped driving completely at night due to headlight brightness (11%, 6%, 8% respectively for 75+, 65–74, 17–34, compared with around 2% for other age groups).
- A similar pattern is seen in the “driving less at night” question (38%, 29%, 53% respectively, compared with around 19% for other groups).
- The older two age groups were less likely than others to report having no choice in the matter (14% and 12% versus around 25% for others).

Summary: Changing actual behaviour in response to the brightness of headlights is especially prevalent in the youngest and oldest drivers. The oldest drivers then – those who would be expected to be most sensitive to glare based on the physiological changes in their eyes related to ageing – are not alone in responding in this way.

4.3.3.4 Changes of behaviour: car ride height differences

The key findings related to car ride height were:

- Drivers of low ride height cars were more likely than other groups to have reported they have stopped driving at night (11% versus 3%–4%).
- Drivers of low and normal ride height cars were more likely than those of higher cars to have reported driving less (37% and 30% versus 24%).
- Drivers of normal and higher ride height cars were more likely than those of lower cars to have reported no change in their behaviour (44% and 52% versus 25%).

Summary: Drivers of higher vehicles were less likely to report changes in behaviour related to glare, which is compatible with the idea that those drivers are less likely to experience glare.

4.4 Summary of findings

The findings from the survey can be considered as a snapshot of the subjective perception of glare from vehicle headlights, the contexts in which it happens and changes in behaviour, at approximately the same time as data were being collected in the on-road part of the research.

In isolation the survey data paint a sobering picture regarding the driving public’s experience of glare from vehicle headlights. Importantly, they suggest that very large numbers of drivers perceive glare to be a problem in a range of driving situations, and from a range of vehicles.

There is some variability in the specific contexts (vehicles, driving situations) perceived as especially important; often these findings demonstrate insight into the causes of glare predicted by our understanding of the visual system, for example the greater likelihood of unlit roads (with their greater potential for high contrast) being identified as particularly problematic. There is a clear perception that whiter lights are more to blame than yellower ones. There is a perception that higher vehicles may be more likely to cause glare than lower ones, for drivers of lower and normal height vehicles.

The findings also suggest that more than half of drivers have changed their behaviour (or would if they could) in terms of stopping or reducing their driving at night due to the brightness of headlights. Female drivers reported more of an issue with glare (and changed behaviour) than male drivers. Older drivers also reported greater change than some age groups, but the very youngest age group (17–34) also reported a heightened perception of glare and greater behaviour change in response to it.

The headline findings are broadly in agreement with some of the main findings from the on-road data collection and machine learning modelling. Drivers reported that headlights are too bright, that higher ride height vehicles is an issue and that road geometry is also important (these all being highly influential in the glare model).

PPR2069

Discussion

5 Discussion

This project was focused on gathering scientific evidence on the extent to which glare induced by vehicle lighting may occur in everyday driving and on trying to understand potential root causes. An earlier report from the project (Beard et al., 2025) reviewed previous evidence on aspects of age and driving behaviour and drivers' experiences of glare. The current report focused on the other two main pieces of work on the project – the on-road data collection and a survey with a nationally representative sample of UK drivers (enabled through access to the RAC panel).

The sections below outline the main findings from the project and, alongside these, potential next steps that could be considered by DfT (Section 5.1). Section 5.2 then discusses limitations.

5.1 Main findings and considerations

The context for the work undertaken in this project is that DfT receives a great number of complaints from members of the public about glare from vehicle lighting. Included within these complaints are several recurring themes, notably about the brightness of headlamps on modern vehicles and the issue of modern headlamps such as LEDs being particularly problematic. The project sought to understand the issue of glare through robust on-road data collection using an instrumented vehicle and through collecting subjective data from a representative survey of UK drivers. Both these methods were designed to equip DfT with current data relevant to the perception of glare on UK roads, so that it could consider taking steps to improve things.

5.1.1 Survey findings

The survey method (specifically the questions asked) was informed by the on-road data collection. It provides a snapshot of driver opinions and perceptions from approximately the same time as the on-road data were being collected; therefore, it provides important information on the context in which the other findings from the work will be used.

In short, the driving public perceive glare from vehicle lighting to be a widespread issue when driving at night. Headlamps on other vehicles are perceived to be too bright, and "whiter" light is perceived to be a greater challenge than "warmer" colours. Larger vehicles are perceived to be problematic. Finally, more than half of drivers have stopped or reduced driving at night due to their perceptions of headlamp brightness (or would if they could). Glare can therefore be said to be an important issue in the minds of the UK driving public, and likely one for which action to improve the situation would be welcomed. A consideration arising from this work relates to the continued use of such data to track progress on this issue over time.

Consideration 1: Improve understanding of road users' experience of glare – for example through conducting annual glare surveys from representative samples of UK drivers to permit tracking of the issue over time.

5.1.2 On-road data collection findings

Some variables that had influence over the perception of glare, and on levels of luminance, were related to the location in which data were collected and to the geometry of the road situation (pitch and roll). For the luminance model these factors were by far the most important influences. This suggests that no matter how well regulated vehicle headlamps are (in terms of their brightness, the types of bulbs used and things like light throw patterns associated with vehicle height), there will always be some situations in which conditions align and make it possible or likely that a driver may experience glare. From the modelling in the current work, such situations seem more likely to be either specific individual locations or scenarios in which the observer vehicle is heading up a hill and/or around a right-hand bend. Therefore, a short-term measure that DfT might consider is:

Consideration 2: Run a public information campaign explaining to UK drivers those situations in which they may be more likely to experience glare, and those situations in which they may be more likely to cause glare to other road users, when driving at night.

Such a campaign would not be expected to reduce the potential for glare in such locations and situations but may assist drivers in planning how they drive, in terms of minimising the impact of glare on both themselves and other drivers. For example, people might choose to change the routes they use or be more prepared to slow their vehicles in particular road situations.

The next consideration relates to further research needed to expand the initial findings from this research. Higher levels of luminance were associated with the experience of glare in observers. Specifically, average maximum levels of luminance over 40,000 cd m^{-2} showed a near exclusive increase in association with glare, and this variable had the greatest influence in the model. This is intuitive – people are more likely to experience glare when lights are brighter. The second most influential variable was vehicle type (make and model). While the vehicle type variable was based on much less robust (and less frequent) data collection, the fact that it is influential in the glare model even with the limitations suggests that it is important. When examining the ten vehicle models with the greatest influence on glare, it was observed that nine of them were larger (mainly SUVs) and that eight of them were identified as likely to have had LED headlamps installed as standard.

Both vehicle height (through its obvious link to the geometric properties of road interactions – higher vehicles being more likely to throw their headlamp pattern into the eyeline of those in lower vehicles) and LED lights have been linked in previous research to the experience of discomfort glare (Beard et al., 2025), and there is some suggestion in the data from the on-road work in the current project that vehicle height and LED lighting may be important factors. Given the preliminary nature of the vehicle type findings in the current research we would not recommend any such action based on this dataset alone. The third consideration therefore concerns further work to examine the effects of vehicle design parameters on glare specifically; such work would involve much larger samples of individual observers and likely more static and controlled testing than was possible in the current research, which was more focused on measuring objective data from on-road driving.

Consideration 3: Conduct further research to understand vehicle design parameters that result in glare focused specifically on identifying those factors that cause discomfort glare in real-world scenarios and ways in which this may be accurately, repeatably and representatively measured in a test scenario. This initial research project has provided some data suggesting that LED lighting and vehicle height may be important factors, but further research is needed to confirm this.

The final core consideration relates to building on the findings from the more targeted research in Consideration 3, and how regulations could be improved in terms of their relevance to drivers' experiences of glare.

Consideration 4: Improve lighting regulations to reduce glare. Lighting regulations are currently based on testing the output of headlamps in relation to luminous intensity at various test points defined in relation to the headlamp itself, not the potential observer. Existing requirements in vehicle lighting regulations may therefore not be sufficient to address issues of glare from vehicle lights. DfT could develop proposals for regulatory amendments building on findings from the research in Consideration 3.

5.2 Limitations

There were several limitations to the current work. Most related to the on-road data collection, which was a new methodology and which would benefit from further development.

1. The first limitation concerns the less-than-desired amount of data collected, particularly from the ANPR camera. This was down to the extremely challenging nature of collecting luminance pictures and ANPR data at night, from a moving vehicle, in such a way that it could be aligned in time with other variables. Another early physical challenge, experienced particularly during collection of the "infinity" focus dataset, was that when using the roof-mounted pan tilt zoom (PTZ) camera, on occasion the lens was found to gradually "droop" from the ideal capture position, requiring periodic intervention by the observer until a permanent solution was implemented to ensure this remained fixed. The final amount of data collected (35 hours of "infinity" focus data and 15 hours of "dialled back" focus data) supported the analysis approach used, but any future work would benefit from collecting more data, especially around vehicle makes and models, so that vehicle characteristics could be studied in more detail. There was very little variation in weather conditions (especially rain) as the winter and spring were particularly dry; again, more data would enable more consideration of these variables.
2. A second limitation concerns aspects of timing associated with the ANPR results. During calibration testing, a variable offset from the known accurate time was seen in some DVR-related data including ANPR, which appeared to fall between zero and a maximum of two

seconds. Further complicating matters, factors such as road geometry and closely bunched vehicles could affect whether a specific vehicle of interest within the scene was captured alongside a glare button press or the nearest luminance measurement. This resulted in some uncertainty around the alignment of timestamps associated with identified vehicles and the other measurements, owing to the inherent real-world context. While this is just noise in the data (and vehicle type was still identified as an influential variable in the dataset) future work should explore other options for refining ANPR data collection.

3 A third limitation concerns the temporal resolution of the data, being limited to the nearest second for matching purposes within the machine learning. This was largely driven by the fact that the luminance camera (by virtue of the filming conditions and processing time) required multiple seconds to capture each image, and this meant that not all lines of data captured at more frequent intervals (pitch, roll etc.) were matched to a luminance value. Future work could try to increase the temporal resolution at which luminance data are collected.

4 A fourth limitation concerns more general noise in the data collection and potential errors of measurement. In such a large dataset it is not feasible to check every possible data point for accuracy and precision, and this was indeed the reason why a machine learning approach was used. During the process of selecting the case studies, however, a small number of data points (for example pitch) were found that seemed to be at odds with the contextual information provided by the dashcam. While not a major issue if random noise in the data (the modelling was still able to identify variables that were associated with the outcomes), nonetheless in future work more could be done to quantify the amount of noise in the data for each variable.

5 The fifth limitation around data collection concerns the fact that only one driver eye height was used for the luminance camera. This was done for pragmatic reasons. First, the way the luminance data collection was undertaken meant that it focused on physical features of the driving environment, which would not vary greatly with eye heights mere centimetres apart, and for the analysis planned (machine learning picking up broad patterns) did not need to be measured in absolute terms. Second, in the data collection the experience of glare was measured by the subjective observer, whose eye height was not fixed throughout the drive. It was also reasoned that seat height is largely a personal choice, even for drivers of greater and lesser physical stature. Supporting this, in the RAC survey data one additional question concerned driver seat height, and responses showed that female drivers (who are shorter) were more likely (21%) than male drivers (13%) to report setting their seat on its highest height. Nonetheless, in future improvements to this work we would recommend setting up the mounting to be moveable in terms of height, so that this variable can be studied in more detail.

6 A sixth limitation mentioned here also concerns variability in data collection. Only male observers were available during the on-road elements of the work, and no one with any visual conditions such as cataracts was available. Again, this was not an issue for the analysis planned, which was focused on objective measurements of luminance and did not rely on

comparing individual differences in perceptions of glare; nonetheless, we would recommend a more diverse set of observers, if possible, in future work.

7 A seventh limitation concerns the specific light sources in the scene that were the brightest. It is possible vehicle lighting sources other than headlamps were the brightest things in some scenes, but this would require further analysis to quantify.

8 Finally, there are other approaches that could have been taken to calculating variables for analysis. For example, contrast between brightest and lowest luminance values in scenes could have been calculated, as could the position in the scene of the highest luminance sources. The final approach taken in this work was limited, as is the case for any research, by the time and resource available.

5.3 Further work

A final consideration concerns specific research (further to that suggested in Considerations 1 to 3) that would assist in more fully understanding the problem of glare in driving. Several suggestions are given for research to address these specific issues:

Consideration 5: Conduct additional further research to support further understanding of glare in driving.

- In combination with the research suggested in Consideration 3 (measuring discomfort glare associated with different vehicle design parameters such as height and lighting technology) user research could be undertaken. This research would use detailed visual and other measurements in controlled off-road settings (using equipment developed in the current work where possible) to segment road users for their susceptibility to such glare, focusing on how factors such as age, gender and visual diseases interact with vehicle design factors to affect glare perception.

- Further analysis of the survey data in the current project, and any future work undertaken, could seek to understand how real-world driving experience (for example road types typically driven on, times of day) is related to experience of glare. Currently this work relies on the interpretation of single effects (rather than looking at interactions) meaning that real-world experiences may not be fully understood; for example, the extent to which someone in each age group may report glare on specific road types will be related to their exposure as well as their susceptibility. Such work would increase the extent to which such data can inform policy.

- Work could begin to scope a practical assessment of luminance that would support the revised lighting regulations examined as part of Consideration 4.

- One thing not covered in the current work is the extent to which real-world lighting is properly aligned. Work to sample and test a range of vehicle and lighting types at varied times in the MOT cycle (and in the pre-MOT phase) would indicate the extent to which misalignment may be contributing to issues outside of any ideal regulation. Again, existing equipment could be repurposed to assess this.
- Finally, ways of testing luminance and vehicle information from existing infrastructure could be scoped to understand whether such an approach could build the very large datasets needed to detect subtle patterns. Designing and piloting such an approach could be done within a living lab environment (for example the SMLL in London) and, if successful, could be exported to other contexts in which roadside infrastructure would permit it. The machine learning approaches in the current work could be incorporated into this.

PPR2069

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PPR2069

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Appendix A. Stakeholders

The following stakeholders were involved in initial meetings in the autumn of 2024, when the project began, and were then involved in both ad hoc communication throughout the project and monthly updates between December 2024 and July 2025. Most of these updates were through email, with the one in February being communicated through a presentation at a virtual workshop.

While all stakeholders were given the opportunity to steer the direction of the work, their involvement should not be taken as any endorsement of its methods, findings, interpretation or recommendations.

Name	Organisation
Baroness Dianne Hayter	House of Lords
Rod Dennis	RAC
Allan Howard	WSP and UK Lighting Liaison Group
Mark Grainger	SMMT
Carl Harrison	RING AUTOMOTIVE and OSRAM
Anonymous stakeholder 6	The AA
John Lincoln	LightAware
Burkhard Boettcher	FIA and ADAC
Steve Gooding	The RAC Foundation
Nick Lyes	IAM Roadsmart
Anonymous stakeholder 11	Fédération Internationale de l'Automobile (FIA)
Anonymous stakeholder 12	The College of Optometrists
Anonymous stakeholder 13	The College of Optometrists
Anonymous stakeholder 14	The College of Optometrists
Anonymous stakeholder 15	UK Health Security Agency
Anonymous stakeholder 16	UK Health Security Agency
Anonymous stakeholder 17	Jaguar Land Rover
Anonymous stakeholder 18	OSRAM Germany
Gareth Enstone	Bee Lighting, UK headlamp manufacturer, SMMT working group
Colin Fulford	Bee Lighting, UK headlamp manufacturer
Anonymous stakeholder 21	Vehicle lighting manufacturer
Harm Zeven	ANWB

Appendix B. Trials car equipment

Both on-road and off-road data collection sessions were undertaken using an instrumented, left-hand-drive vehicle. The data collection system used standard components combined into a bespoke system. This appendix provides further details of the equipment installed within the trial car.

B.1 Equipment details

B.1.1 Luminance camera and software

The luminance camera used was a Westboro Photonics P501U with a Kowa 25mm lens. The device was calibrated new on 24th January 2025, with lens focal distances (cm) of 100, 500 and 1,000 and infinity and apertures of f/1.8 and f/16.

The P501U was supplied with a Westboro Photonics software licence. This software was used to configure the device and collect and export the luminance data.

For the data collection activities, an infinite focus and aperture setting of f/1.8 were used for the initial ≈35 hours of footage; for the final ≈15 hours of footage, and after some discussion with the supplier regarding the need for greater confidence in absolute values of luminance, the focus was "dialled back" slightly from infinity to improve depth of field in the scene, with the aperture remaining at f/1.8.

The camera was operated by a trial observer with a standalone laptop on the seat behind the sensor. To ensure consistent settings, a template was created on the Westboro software.

Operators opened this template and set the sensor to record continuously for a survey. This achieved a sampling rate of ~0.5–0.4Hz. On completion of a survey run, the recording was stopped and the file saved directly to a data folder on the laptop's C: drive.

B.1.2 Illuminance meter

A potential divider circuit board with a light-dependent resistor was mounted beside the luminance camera on its frame in the passenger seat. This board was connected to a Raspberry Pi Pico on the 3.3V, GND and GPIO 26/ADC0 terminals.

The Pi Pico was programmed to read the analogue value of the ADC input and print the value to the serial (USB) port.

The Pi Pico USB port was connected directly to a USB port on the data gatherer.

B.1.3 PTZ/ANPR camera

Registrations of oncoming vehicles were gathered by a PTZ (pan tilt zoom) camera mounted to roof bars on the car, for the purposes of ANPR.

The camera used was a Dahua DH-PTZ1A225-HNR-XA. The position and camera settings such as exposure, aperture and focus were preset for the survey conditions and this preset was used for all surveys. This ensured the best likelihood of registration capture for all oncoming vehicles on single-carriageway roads. The key parameters are identified in Table 10.

Table 10: Settings for PTZ/ANPR camera

Parameter	Value (units identified only where given by camera software)
Shutter	1/10,000
Gain	50~100
Iris	10~50
Focus	20m
Illuminator (near light)	40
Illuminator (far light)	60

Power and data were carried power over ethernet (PoE) between the PTZ and network switch within the vehicle boot.

Footage from this camera was saved to a removable hard disk drive on the DVR.

B.1.4 Forward-facing imaging (FFI) camera

Contextual video footage was gathered by an analogue camera mounted to the windscreen in a central position showing a “dashcam” view. The camera was connected directly to the analogue input of the DVR.

B.1.5 DVR (digital video recorder)

As mentioned above, video streams from the PTZ and FFI were collected and stored by a Streamax X3N-H0404 DVR. The DVR gathered the time via an NTP server through a Wi-Fi connection to the internet on a 4G Wi-Fi router.

This time was stamped to the two input video streams and coupled with GPS position data (using a magnetic GPS antenna on the vehicle’s roof) before being saved to a removable hard disk drive.

B.1.6 Inclinometer

The vehicle pitch and roll were determined using an Adafruit BNO055 board to record the absolute orientation to the data gatherer through I2C protocol. The angles were printed in degrees.

B.1.7 User input push button

A push button was connected between GPIO26 and GND on the data gatherer’s header. This was used to gather the subjective glare data from trial participants.

B.1.8 Data gatherer (Raspberry Pi 4B)

A Raspberry Pi 4B was used as the base for the main data gatherer, which generated a .CSV file, collating all data into a new line at a rate of 5Hz.

Each line was formatted as follows:

> *Year, Month, Day, Hour, Minute, Second, Millisecond, Pitch, Roll, User Input, Ambient Light*

Time was gathered from an NTP server as the Pi was also connected to the internet by the in-car 4G router.

Pitch and roll were gathered by interrogating the I2C inclinometer.

User input was a printed “True” or “False”, based on button pressed or not pressed, respectively.

Ambient light was calculated based on the raw input from the Pi Pico, a gain value and an offset value.

B.1.9 Controller for equipment

At the start of a survey, the PTZ camera was set to a preset position using a joystick. This ensured that it would collect the registration of oncoming cars at a consistent distance from the survey vehicle. The correct position was also labelled on the joints of the camera to provide visual assurance that the setup was completed.

B.1.10 Storage media

Luminance data were saved in a proprietary file format manually to the laptop’s C: drive. Each file contained all of the measurements from a single run and was named by the operator in the format “YYYYMMDD_Run[Run Number]”.

Video footage was saved automatically to a removable hard disk drive on the DVR, with embedded date, time and GPS information, in a proprietary file format for review in CEIBA II software.

Data gatherer data were automatically saved in .CSV format to a removable USB memory stick while surveying, so no additional file management was required. The file name was given by date and time of survey start.

B.1.11 Data management and software

A centralised spreadsheet record was maintained to track all on-road data collection undertaken, together with information about vehicle routes, participating observers, weather conditions, etc. These records were also updated as the various collected data were converted or processed ready for their use in the analysis phase. Date and time information was converted into Unix Epoch time format for consistency, also taking into account the move into British Summer Time, which occurred during the project.

Following guidance provided by the supplier, all luminance measurements were exported as individually timestamped files in .CSV format. Metrics such as maximum luminance were calculated from these for use in the machine learning and other analyses. The size of the raw measurement files totalled approximately 2.8 terabytes (TB).

The .CSV files from the data gatherer were principally processed using Excel PowerQuery, ensuring consistent formatting, time and date information, and the addition of survey-specific information (i.e. anonymised observer characteristics and road conditions).

The relevant GPS data from each survey were exported from CEIBA II software in Excel format ready for combining with the other collected data.

The video streams from the PTZ and FFI were accessible through CEIBA II software, and the relevant footage from each survey was exported as follows.

The FFI footage was exported in .MP4 format and could be viewed natively by team members when manually reviewing surveys and in the preparation of case studies.

The PTZ footage was also exported in .MP4 format and was imported into ANPR software, namely Plate Recognizer Stream (Direct) v1.55. This software was set up using proprietary guidance, to best match the project's usage scenarios. The software identified registration plates in the PTZ footage and assigned its own "confidence" rating for each plate read. After a manual review and sampling of a set of approximately 100 plates, the 0.95 confidence rating was considered suitably reliable at returning correctly interpreted results. Plates falling below this threshold were discarded, as were plates where the software identified it likely that the vehicle was not "oncoming", to exclude, for example, vehicles travelling in the same direction as the trial vehicle.

Python was then utilised to automate querying the UK government's MOT history API using these registration plates. The library dvsa-mot-history v1.0.4 was used to establish a connection to the API. The library is open source and verified by the reputable website PyPi. The source code of the library can be found on Github. Information including manufacture year, make, model and most recent MOT date were obtained and matched with the ANPR dataset. For GDPR purposes, the original registration plates information was then removed. Timings then had to be calculated based on their timestamp (at the point of successful read) within each .MP4 video file and the known start time of each survey. The resulting dataset was then saved in .CSV format for combining with the other data.

The above data were then combined, ordered by date and time, into complete chronological datasets, one for each focus type – "infinity" focus initially, and then from 30th April onwards "dialled back".

B.1.12 Power

There were three voltage levels required for all systems.

240V AC and 5V DC power were distributed by an RS Pro Sine Wave Inverter. This has a built-in USB port for the 5V power.

The inverter and all 12V DC equipment were powered via a distribution and, if required, fuse block. The 12V supply was transferred to the boot via a $16mm^2$ fused lead from the vehicle's battery.

B.1.13 Physical mountings

To secure the PTZ camera, a vehicle-appropriate Thule roof bar kit was secured to the vehicle transversely. Two aluminium extrusion profiles were secured to the roof bars and an aluminium base plate secured between those. The camera was bolted directly to this plate.

The FFI camera was secured to the windscreen using a supplied 3M sticky pad. It was positioned at a height of 1,280mm from the ground and 160mm from the centre on the passenger side.

The luminance and ambient light sensors, along with the Pi Pico, were secured to a custom bracket. This bracket was originally 3D printed in PLA but this was superseded by a folded steel alternative as the ambient temperature increased with the season change.

On the passenger seat was a polycarbonate plastic board, with a DIN rail bolted vertically. This board was secured to the seat with M8 threaded bar and saddle clamps on the headrest bars. The bracket was clipped to the DIN rail to allow for height adjustment and final position locking. The bracket was locked in a position such that the luminance sensor measured at a height of 1,220mm from the ground, and the ambient light sensor was 15mm lower at 180mm from the ceiling.

The height of 1,220mm from the ground was based on a requirement for the project to measure light at the B50L test point. The B50L test point is specified as an angular coordinate and thus depends on the mounting height of the headlamps being tested. Average mounting height of headlamps in the vehicle fleet was not available, and the height used was also constrained by the need for the camera to sit outside of the view of the observer in the rear of the vehicle. Therefore, a pragmatic approach to the mounting height was taken. The 1,220mm height corresponds to what would be used as the B50L test point for a headlamp approximately 750mm off the ground at approximately 50m from the test vehicle. It was chosen based on advice from a lighting manufacturer.

All other equipment was screwed directly to an 18mm plywood board in the boot. This allowed flexibility in positioning while avoiding any permanent changes to the vehicle.

B.2 Project information and privacy information

To provide information for members of the public who might encounter the trial vehicle while it was parked in public places, two stickers were fitted. These provided website URLs for project information and data privacy. See Figure 24.

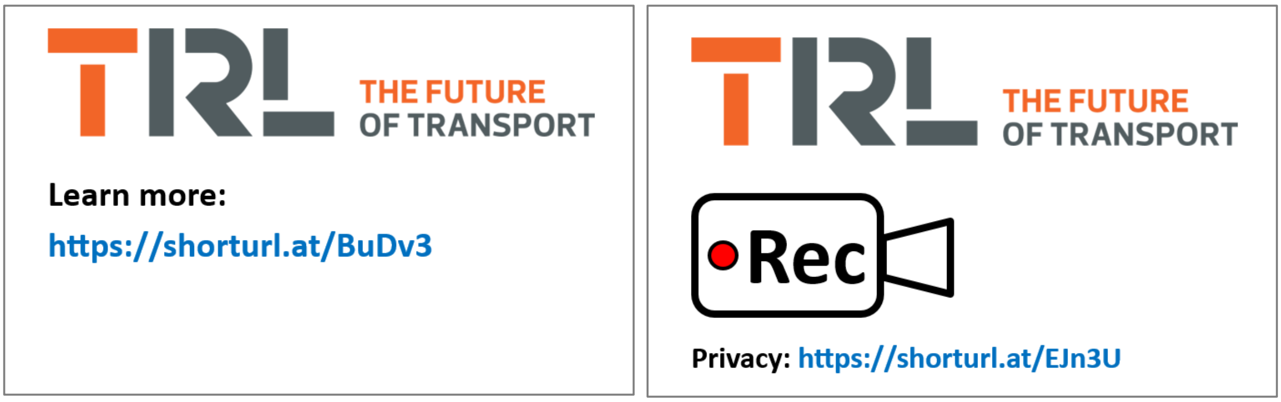
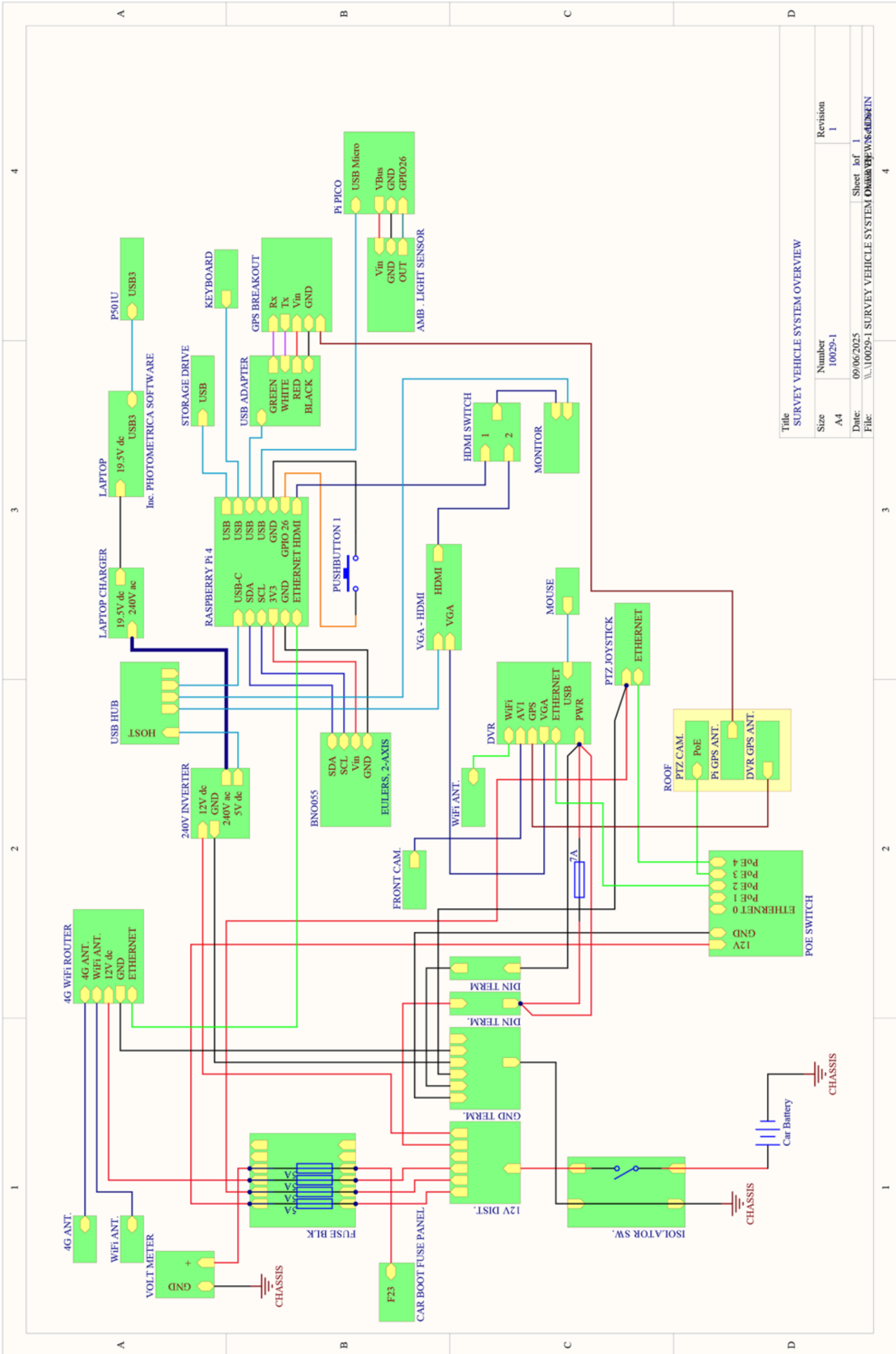


Figure 24: Project information stickers

Appendix C. System diagram

The diagram below shows full connectivity of the data gathering and storage system installed in the GLARE project trials car.



Appendix D. Luminance dataset

The maximum luminance, average maximum luminance (the mean of the five highest luminance points), mean luminance and minimum luminance were computed in R (version 4.4.2) for 22,845 luminance matrices captured over seven discrete data acquisition sessions. The Westboro P501U uses a 7th order polynomial with unconstrained intercept to model luminance, so any negative numbers in the matrices were set to zero.

The maximum luminance frequency distribution (see Figure 12 in Section 3.3) had local maxima around 1,000 cd m^{-2} and 42,000 cd m^{-2}. The mean maximum luminance was 15,860.2 cd m^{-2} (standard deviation = 17,747.29). The maximum luminance ranged from 152.7 cd m^{-2} to 63,566.4 cd m^{-2}. The mean average maximum luminance was 14,626.6 cd m^{-2} (standard deviation =16,728.9). The average maximum luminance ranged from 147.8 cd m^{-2} to 62,180.9 cd m^{-2}.

Inspection of the relationship between maximum luminance and average maximum luminance (Figure 25) did not reveal any cause for concern with respect to outliers ($r = 0.9956$, $t = 1{,}615$, $df = 22{,}843$, p-value < 2.2e-16).

The temporal resolution of data acquisition ranged from milliseconds to seconds for different variables and were typically asynchronous at ms resolution. All timestamps were therefore rounded to the nearest integer using the round() function in Base R.

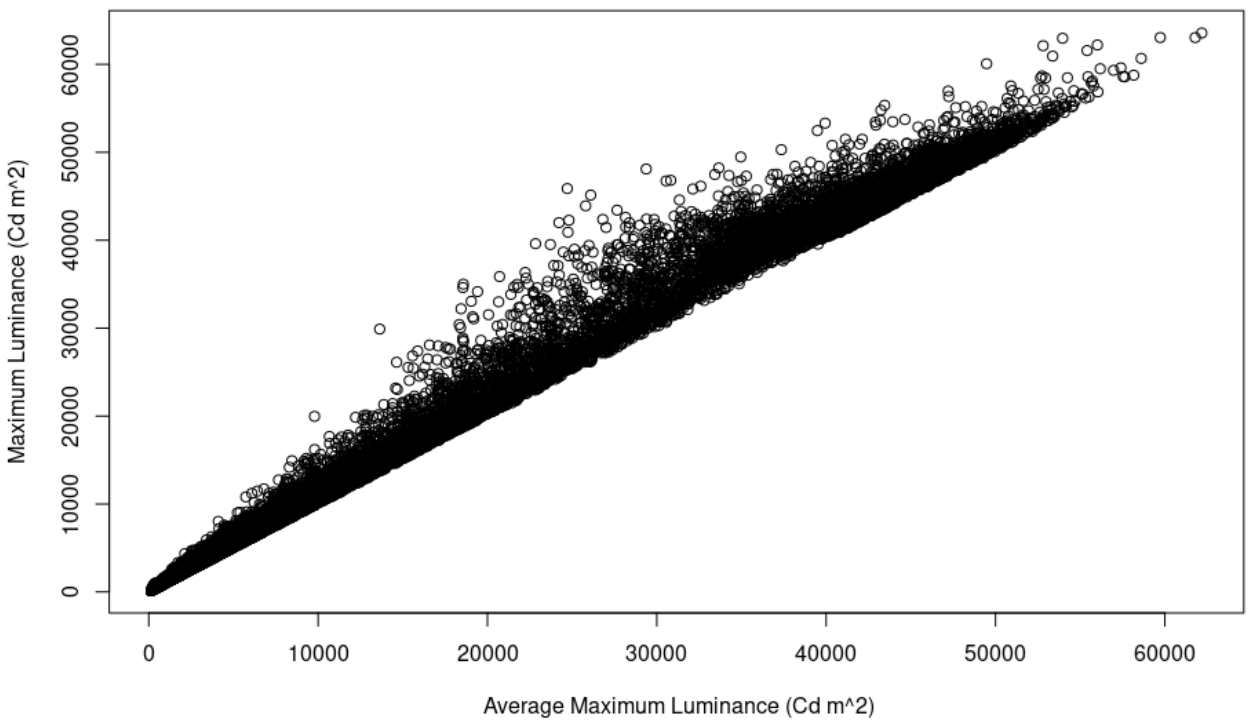


Figure 25: Average maximum luminance (x axis) as a function of maximum luminance (y axis)

Appendix E. Hyper-parameter grid search results for the glare model

shrinkage	interaction.depth	n.trees	n.minobsinnode	bag.fraction	optimal_trees	min_RMSE
0.01	6	1000	20	0.5	281	0.0869825456653791
0.1	6	1000	20	0.5	26	0.0870877752322234
0.01	10	1000	20	0.5	482	0.0865330845718979
0.1	10	1000	20	0.5	26	0.0867327749907445
0.01	12	1000	20	0.5	482	0.0863270779331768
0.1	12	1000	20	0.5	26	0.0867098416899217
0.01	6	2000	20	0.5	281	0.0869825456653791
0.1	6	2000	20	0.5	26	0.0870877752322234
0.01	10	2000	20	0.5	482	0.0865330845718979
0.1	10	2000	20	0.5	26	0.0867327749907445
0.01	12	2000	20	0.5	482	0.0863270779331768
0.1	12	2000	20	0.5	26	0.0867098416899217
0.01	6	3000	20	0.5	281	0.0869825456653791
0.1	6	3000	20	0.5	26	0.0870877752322234
0.01	10	3000	20	0.5	482	0.0865330845718979
0.1	10	3000	20	0.5	26	0.0867327749907445
0.01	12	3000	20	0.5	482	0.0863270779331768
0.1	12	3000	20	0.5	26	0.0867098416899217
0.01	6	1000	30	0.5	321	0.0868295656237394
0.1	6	1000	30	0.5	30	0.0869746103981664
0.01	10	1000	30	0.5	593	0.0864040024835407
0.1	10	1000	30	0.5	30	0.0865659022687999
0.01	12	1000	30	0.5	708	0.0862670831917275
0.1	12	1000	30	0.5	26	0.0863733530427273
0.01	6	2000	30	0.5	321	0.0868295656237394
0.1	6	2000	30	0.5	30	0.0869746103981664
0.01	10	2000	30	0.5	593	0.0864040024835407
0.1	10	2000	30	0.5	30	0.0865659022687999
0.01	12	2000	30	0.5	708	0.0862670831917275
0.1	12	2000	30	0.5	26	0.0863733530427273
0.01	6	3000	30	0.5	321	0.0868295656237394
0.1	6	3000	30	0.5	30	0.0869746103981664
0.01	10	3000	30	0.5	593	0.0864040024835407
0.1	10	3000	30	0.5	30	0.0865659022687999
0.01	12	3000	30	0.5	708	0.0862670831917275
0.1	12	3000	30	0.5	26	0.0863733530427273
0.01	6	1000	40	0.5	593	0.0867316908200584
0.1	6	1000	40	0.5	37	0.0868314551319841
0.01	10	1000	40	0.5	593	0.0863423915464703
0.1	10	1000	40	0.5	34	0.0865933830461891
0.01	12	1000	40	0.5	704	0.0862066421977922
0.1	12	1000	40	0.5	27	0.0864038998639617
0.01	6	2000	40	0.5	593	0.0867316908200584
0.1	6	2000	40	0.5	37	0.0868314551319841

shrinkage	interaction.depth	n.trees	n.minobsinnode	bag.fraction	optimal_trees	min_RMSE
0.01	10	2000	40	0.5	593	0.0863423915464703
0.1	10	2000	40	0.5	34	0.0865933830461891
0.01	12	2000	40	0.5	704	0.0862066421977922
0.1	12	2000	40	0.5	27	0.0864038998639617
0.01	6	3000	40	0.5	593	0.0867316908200584
0.1	6	3000	40	0.5	37	0.0868314551319841
0.01	10	3000	40	0.5	593	0.0863423915464703
0.1	10	3000	40	0.5	34	0.0865933830461891
0.01	12	3000	40	0.5	704	0.0862066421977922
0.1	12	3000	40	0.5	27	0.0864038998639617
0.01	6	1000	50	0.5	766	0.0866473939553636
0.1	6	1000	50	0.5	37	0.0867566408820108
0.01	10	1000	50	0.5	774	0.0862911105361782
0.1	10	1000	50	0.5	30	0.0864484667052973
0.01	12	1000	50	0.5	752	0.0861698757364293
0.1	12	1000	50	0.5	37	0.0862921641039717
0.01	6	2000	50	0.5	766	0.0866473939553636
0.1	6	2000	50	0.5	37	0.0867566408820108
0.01	10	2000	50	0.5	774	0.0862911105361782
0.1	10	2000	50	0.5	30	0.0864484667052973
0.01	12	2000	50	0.5	752	0.0861698757364293
0.1	12	2000	50	0.5	37	0.0862921641039717

Appendix F. Hyper-parameter grid search results for the luminance model

shrinkage	interaction.depth	n.trees	n.minobsinnode	bag.fraction	optimal_trees	min_RMSE
0.01	6	1000	20	0.5	1000	16327.3933078732
0.1	6	1000	20	0.5	1000	14528.6816214554
0.01	10	1000	20	0.5	1000	15969.8229526653
0.1	10	1000	20	0.5	1000	13754.9885834311
0.01	12	1000	20	0.5	1000	15820.3464521154
0.1	12	1000	20	0.5	1000	13476.2923626947
0.01	6	2000	20	0.5	2000	15900.5246657652
0.1	6	2000	20	0.5	2000	13734.4882648742
0.01	10	2000	20	0.5	2000	15427.9417992972
0.1	10	2000	20	0.5	2000	12775.1027235081
0.01	12	2000	20	0.5	2000	15235.3376721059
0.1	12	2000	20	0.5	1999	12453.8737357313
0.01	6	3000	20	0.5	3000	15601.3236304804
0.1	6	3000	20	0.5	3000	13211.5053384366
0.01	10	3000	20	0.5	3000	15052.8162594796
0.1	10	3000	20	0.5	3000	12138.3568052749
0.01	12	3000	20	0.5	3000	14833.4732064079
0.1	12	3000	20	0.5	3000	11807.7992217842
0.01	6	1000	30	0.5	1000	16330.1780062446
0.1	6	1000	30	0.5	1000	14615.5529750954
0.01	10	1000	30	0.5	1000	15971.8469755822
0.1	10	1000	30	0.5	999	13854.0173005694
0.01	12	1000	30	0.5	1000	15817.4353133526
0.1	12	1000	30	0.5	1000	13591.868219602
0.01	6	2000	30	0.5	2000	15901.5422522117
0.1	6	2000	30	0.5	2000	13889.5918182507
0.01	10	2000	30	0.5	2000	15438.1323875085
0.1	10	2000	30	0.5	2000	12953.1762392468
0.01	12	2000	30	0.5	2000	15251.9559823368
0.1	12	2000	30	0.5	2000	12645.1839857473
0.01	6	3000	30	0.5	3000	15613.5859675908
0.1	6	3000	30	0.5	3000	13392.6586751613
0.01	10	3000	30	0.5	3000	15087.6486785699
0.1	10	3000	30	0.5	3000	12373.74803352
0.01	12	3000	30	0.5	3000	14876.9838471534
0.1	12	3000	30	0.5	3000	12075.4970806508
0.01	6	1000	40	0.5	1000	16319.0230400133
0.1	6	1000	40	0.5	1000	14690.6896871733
0.01	10	1000	40	0.5	1000	15973.7963797904
0.1	10	1000	40	0.5	999	13966.20167025
0.01	12	1000	40	0.5	1000	15822.5176444989
0.1	12	1000	40	0.5	1000	13694.817596127

shrinkage	interaction.depth	n.trees	n.minobsinnode	bag.fraction	optimal_trees	min_RMSE
0.01	6	2000	40	0.5	2000	15902.7515099318
0.1	6	2000	40	0.5	2000	13991.4370188803
0.01	10	2000	40	0.5	2000	15457.5316930514
0.1	10	2000	40	0.5	2000	13119.1782632006
0.01	12	2000	40	0.5	2000	15277.0021115284
0.1	12	2000	40	0.5	2000	12810.5922647199
0.01	6	3000	40	0.5	3000	15618.2762618358
0.1	6	3000	40	0.5	3000	13530.3208006299
0.01	10	3000	40	0.5	3000	15113.5929688108
0.1	10	3000	40	0.5	3000	12570.7291557566
0.01	12	3000	40	0.5	3000	14907.038970684
0.1	12	3000	40	0.5	3000	12266.2625930353
0.01	6	1000	50	0.5	1000	16317.1087190626
0.1	6	1000	50	0.5	1000	14739.6659141694
0.01	10	1000	50	0.5	1000	15974.4974107365
0.1	10	1000	50	0.5	999	14034.5915887983
0.01	12	1000	50	0.5	1000	15824.1109226265
0.1	12	1000	50	0.5	1000	13795.7372360154
0.01	6	2000	50	0.5	2000	15906.6356639604
0.1	6	2000	50	0.5	2000	14075.4268024221
0.01	10	2000	50	0.5	2000	15467.10922257
0.1	10	2000	50	0.5	2000	13231.9927688766
0.01	12	2000	50	0.5	2000	15285.2109863035
0.1	12	2000	50	0.5	2000	12938.1301002264
0.01	6	3000	50	0.5	3000	15627.3141347822
0.1	6	3000	50	0.5	3000	13636.1156805667
0.01	10	3000	50	0.5	3000	15129.7768545429
0.1	10	3000	50	0.5	3000	12716.5468358389
0.01	12	3000	50	0.5	3000	14930.2638368871
0.1	12	3000	50	0.5	3000	12412.1939501743

Appendix G. The grid search values for balanced accuracy of the glare model

Threshold	Balanced accuracy
0.001	0.509060576691585
0.005	0.781494907467943
0.01	0.771775772578276
0.015	0.775036295058765
0.02	0.768376916398745
0.025	0.742826359500382
0.03	0.734522689813196
0.06	0.689807794725137
0.08	0.669184218397765
0.1	0.635946180053796

Appendix H. Relative influence of variables in the glare model

Variable	Relative influence
avg_max_lum	23.1123162192306
vehicle	20.1824544216982
Latitude	14.9500483775592
mean_lum	11.0060736027918
Longitude	9.85471976139745
Pitch	9.6299420040843
Roll	7.91729003048539
AmbientLight	2.3609918021114
ObserverEyesight	0.984246660754705
last_mot_unix	0.00191711988703551
VehicleManufactureYear	0

Appendix I. The glare model partial dependencies for average maximum and mean luminance

avg_max_lum	y	mean_lum	y.1
147.78686	-0.0244111791467282	24.6847629850899	-0.0226080124061853
774.384128282828	-0.0244111791467282	25.8877792065228	-0.0226080124061853
1400.98139656566	-0.0244111791467282	27.0907954279557	-0.0225506634541672
2027.57866484848	-0.0244111791467282	28.2938116493886	-0.022569862567866
2654.17593313131	-0.0244111791467282	29.4968278708215	-0.0225246157654962
3280.77320141414	-0.0244111791467282	30.6998440922545	-0.0216336203191291
3907.37046969697	-0.0244111791467282	31.9028603136874	-0.0216336203191291
4533.9677379798	-0.0244111791467282	33.1058765351203	-0.0216336203191291
5160.56500626263	-0.0244111791467282	34.3088927565532	-0.0216336203191291
5787.16227454546	-0.0244111791467282	35.5119089779861	-0.0216336203191291
6413.75954282828	-0.0244111791467282	36.714925199419	-0.0216336203191291
7040.35681111111	-0.0244111791467282	37.9179414208519	-0.0216336203191291
7666.95407939394	-0.0244111791467282	39.1209576422848	-0.0216336203191291
8293.55134767677	-0.0244111791467282	40.3239738637177	-0.0216336203191291
8920.1486159596	-0.0244111791467282	41.5269900851506	-0.0216336203191291
9546.74588424242	-0.0244111791467282	42.7300063065835	-0.0216336203191291
10173.3431525253	-0.0244111791467282	43.9330225280165	-0.0216336203191291
10799.9404208081	-0.0244111791467282	45.1360387494494	-0.0216336203191291
11426.5376890909	-0.0244111791467282	46.3390549708823	-0.0216336203191291
12053.1349573737	-0.0244111791467282	47.5420711923152	-0.0216336203191291
12679.7322256566	-0.0244111791467282	48.7450874137481	-0.0216336203191291
13306.3294939394	-0.0244111791467282	49.948103635181	-0.0216336203191291
13932.9267622222	-0.0244111791467282	51.1511198566139	-0.0216336203191291
14559.5240305051	-0.0244111791467282	52.3541360780468	-0.0216336203191291
15186.1212987879	-0.0244111791467282	53.5571522994797	-0.0216336203191291
15812.7185670707	-0.0244111791467282	54.7601685209127	-0.0216336203191291
16439.3158353535	-0.0244111791467282	55.9631847423456	-0.0216336203191291
17065.9131036364	-0.0244111791467282	57.1662009637785	-0.0216336203191291
17692.5103719192	-0.0244111791467282	58.3692171852114	-0.0216336203191291
18319.107640202	-0.0244111791467282	59.5722334066443	-0.0216336203191291
18945.7049084848	-0.0244111791467282	60.7752496280772	-0.0216336203191291
19572.3021767677	-0.0244111791467282	61.9782658495101	-0.0216336203191291
20198.8994450505	-0.0244111791467282	63.181282070943	-0.0216336203191291
20825.4967133333	-0.0244111791467282	64.3842982923759	-0.0216336203191291
21452.0939816162	-0.0244111791467282	65.5873145138088	-0.0216336203191291
22078.691249899	-0.0244111791467282	66.7903307352418	-0.0216336203191291
22705.2885181818	-0.0244111791467282	67.9933469566747	-0.0216336203191291
23331.8857864646	-0.0244111791467282	69.1963631781076	-0.0216336203191291
23958.4830547475	-0.0244111791467282	70.3993793995405	-0.0216336203191291
24585.0803230303	-0.0244111791467282	71.6023956209734	-0.0216336203191291
25211.6775913131	-0.0244111791467282	72.8054118424063	-0.0216336203191291
25838.274859596	-0.0244111791467282	74.0084280638392	-0.0216336203191291

avg_max_lum	y	mean_lum	y.1
26464.8721278788	-0.0244111791467282	75.2114442852721	-0.0216336203191291
27091.4693961616	-0.0244111791467282	76.414460506705	-0.0216336203191291
27718.0666644444	-0.0244111791467282	77.6174767281379	-0.0216336203191291
28344.6639327273	-0.0244111791467282	78.8204929495708	-0.0216336203191291
28971.2612010101	-0.0244111791467282	80.0235091710038	-0.0216336203191291
29597.8584692929	-0.0244111791467282	81.2265253924367	-0.0216336203191291
30224.4557375758	-0.0244111791467282	82.4295416138696	-0.0216336203191291
30851.0530058586	-0.0244111791467282	83.6325578353025	-0.0216336203191291
31477.6502741414	-0.0244111791467282	84.8355740567354	-0.0216336203191291
32104.2475424242	-0.0244111791467282	86.0385902781683	-0.0216336203191291
32730.8448107071	-0.0244111791467282	87.2416064996012	-0.0216336203191291
33357.4420789899	-0.0244111791467282	88.4446227210341	-0.0216336203191291
33984.0393472727	-0.0243308998467406	89.6476389424671	-0.0216336203191291
34610.6366155556	-0.0243308998467406	90.8506551639	-0.0216336203191291
35237.2338838384	-0.0243308998467406	92.0536713853329	-0.0216336203191291
35863.8311521212	-0.0243308998467406	93.2566876067658	-0.0216336203191291
36490.428420404	-0.0243308998467406	94.4597038281987	-0.0216336203191291
37117.0256886869	-0.0243308998467406	95.6627200496316	-0.0216336203191291
37743.6229569697	-0.0243308998467406	96.8657362710645	-0.0216336203191291
38370.2202252525	-0.0243308998467406	98.0687524924974	-0.0216336203191291
38996.8174935354	-0.0243308998467406	99.2717687139303	-0.0216336203191291
39623.4147618182	-0.0243308998467406	100.474784935363	-0.0216336203191291
40250.012030101	-0.0243308998467406	101.677801156796	-0.0216336203191291
40876.6092983838	-0.0227923074928891	102.880817378229	-0.0216336203191291
41503.2065666667	-0.017597741282664	104.083833599662	-0.0216336203191291
42129.8038349495	-0.013571272874452	105.286849821095	-0.0216336203191291
42756.4011032323	-0.013571272874452	106.489866042528	-0.0216336203191291
43382.9983715152	-0.0133369557713941	107.692882263961	-0.0216336203191291
44009.595639798	-0.0133369557713941	108.895898485394	-0.0216336203191291
44636.1929080808	-0.0126178231091559	110.098914706827	-0.0216336203191291
45262.7901763636	-0.0130681436827528	111.301930928259	-0.0216336203191291
45889.3874446465	-0.0130681436827528	112.504947149692	-0.0216336203191291
46515.9847129293	-0.0130681436827528	113.707963371125	-0.0216336203191291
47142.5819812121	-0.0128160251229883	114.910979592558	-0.0216336203191291
47769.1792494949	-0.012698722848972	116.113995813991	-0.0216336203191291
48395.7765177778	-0.00808926575315288	117.317012035424	-0.0216336203191291
49022.3737860606	-0.00799986223015508	118.520028256857	-0.0216336203191291
49648.9710543434	-0.00812774631457357	119.72304447829	-0.0216336203191291
50275.5683226263	-0.00812774631457357	120.926060699723	-0.0216336203191291
50902.1655909091	-0.00812774631457357	122.129076921156	-0.0216336203191291
51528.7628591919	-0.00812774631457357	123.332093142589	-0.0216336203191291
52155.3601274747	-0.00812774631457357	124.535109364021	-0.0216336203191291
52781.9573957576	-0.00812774631457357	125.738125585454	-0.0216336203191291
53408.5546640404	-0.00812774631457357	126.941141806887	-0.0216336203191291
54035.1519323232	-0.00812774631457357	128.14415802832	-0.0216336203191291
54661.7492006061	-0.00812774631457357	129.347174249753	-0.0216336203191291

avg_max_lum	y	mean_lum	y.1
55288.3464688889	-0.00812774631457357	130.550190471186	-0.0216336203191291
55914.9437371717	-0.00812774631457357	131.753206692619	-0.0216336203191291
56541.5410054545	-0.00812774631457357	132.956222914052	-0.0216336203191291
57168.1382737374	-0.00812774631457357	134.159239135485	-0.0216336203191291
57794.7355420202	-0.00812774631457357	135.362255356918	-0.0216336203191291
58421.332810303	-0.00812774631457357	136.565271578351	-0.0216336203191291
59047.9300785859	-0.00812774631457357	137.768287799783	-0.0216336203191291
59674.5273468687	-0.00812774631457357	138.971304021216	-0.0216336203191291
60301.1246151515	-0.00812774631457357	140.174320242649	-0.0216336203191291
60927.7218834343	-0.00812774631457357	141.377336464082	-0.0216336203191291
61554.3191517172	-0.00812774631457357	142.580352685515	-0.0216336203191291
62180.91642	-0.00812774631457357	143.783368906948	-0.0216336203191291

Appendix J. The glare model partial dependencies for pitch and roll

Pitch	y	Roll	y.1
-2043.8125	-0.0204674921767325	-2044	-0.0225558191752157
-2002.52272727273	-0.0204674921767325	-2002.71464646465	-0.0225558191752157
-1961.23295454545	-0.0204674921767325	-1961.42929292929	-0.0225558191752157
-1919.94318181818	-0.0204674921767325	-1920.14393939394	-0.0225558191752157
-1878.65340909091	-0.0204674921767325	-1878.85858585859	-0.0225558191752157
-1837.36363636364	-0.0204674921767325	-1837.57323232323	-0.0225558191752157
-1796.07386363636	-0.0204674921767325	-1796.28787878788	-0.0225558191752157
-1754.78409090909	-0.0204674921767325	-1755.00252525253	-0.0225558191752157
-1713.49431818182	-0.0204674921767325	-1713.71717171717	-0.0225558191752157
-1672.20454545455	-0.0204674921767325	-1672.43181818182	-0.0225558191752157
-1630.91477272727	-0.0204674921767325	-1631.14646464646	-0.0225558191752157
-1589.625	-0.0204674921767325	-1589.86111111111	-0.0225558191752157
-1548.33522727273	-0.0204674921767325	-1548.57575757576	-0.0225558191752157
-1507.04545454545	-0.0204674921767325	-1507.2904040404	-0.0225558191752157
-1465.75568181818	-0.0204674921767325	-1466.00505050505	-0.0225558191752157
-1424.46590909091	-0.0204674921767325	-1424.7196969697	-0.0225558191752157
-1383.17613636364	-0.0204674921767325	-1383.43434343434	-0.0225558191752157
-1341.88636363636	-0.0204674921767325	-1342.14898989899	-0.0225558191752157
-1300.59659090909	-0.0204674921767325	-1300.86363636364	-0.0225558191752157
-1259.30681818182	-0.0204674921767325	-1259.57828282828	-0.0225558191752157
-1218.01704545455	-0.0204674921767325	-1218.29292929293	-0.0225558191752157
-1176.72727272727	-0.0204674921767325	-1177.00757575758	-0.0225558191752157
-1135.4375	-0.0204674921767325	-1135.72222222222	-0.0225558191752157
-1094.14772727273	-0.0204674921767325	-1094.43686868687	-0.0225558191752157
-1052.85795454545	-0.0204674921767325	-1053.15151515152	-0.0225558191752157
-1011.56818181818	-0.0204674921767325	-1011.86616161616	-0.0225558191752157
-970.278409090909	-0.0204674921767325	-970.580808080808	-0.0225558191752157
-928.988636363636	-0.0204674921767325	-929.295454545455	-0.0225558191752157
-887.698863636364	-0.0204674921767325	-888.010101010101	-0.0225558191752157
-846.409090909091	-0.0204674921767325	-846.724747474747	-0.0225558191752157
-805.119318181818	-0.0204674921767325	-805.439393939394	-0.0225558191752157
-763.829545454545	-0.0204674921767325	-764.15404040404	-0.0225558191752157
-722.539772727273	-0.0204674921767325	-722.868686868687	-0.0225558191752157
-681.25	-0.0204674921767325	-681.583333333333	-0.0225558191752157
-639.960227272727	-0.0204674921767325	-640.29797979798	-0.0225558191752157
-598.670454545455	-0.0204674921767325	-599.012626262626	-0.0225558191752157
-557.380681818182	-0.0204674921767325	-557.727272727273	-0.0225558191752157
-516.090909090909	-0.0204674921767325	-516.441919191919	-0.0225558191752157
-474.801136363636	-0.0204674921767325	-475.156565656566	-0.0225558191752157
-433.511363636364	-0.0204674921767325	-433.871212121212	-0.0225558191752157
-392.221590909091	-0.0204674921767325	-392.585858585859	-0.0225558191752157
-350.931818181818	-0.0204674921767325	-351.300505050505	-0.0225558191752157
-309.642045454545	-0.0204674921767325	-310.015151515152	-0.0225558191752157
-268.352272727273	-0.0204674921767325	-268.729797979798	-0.0225558191752157

Pitch	y	Roll	y.1
-227.0625	-0.0204674921767325	-227.444444444444	-0.0225558191752157
-185.772727272727	-0.0204674921767325	-186.159090909091	-0.0225558191752157
-144.482954545455	-0.0204674921767325	-144.873737373737	-0.0225558191752157
-103.193181818182	-0.0204674921767325	-103.588383838384	-0.0225558191752157
-61.903409090909	-0.0204674921767325	-62.3030303030303	-0.0225558191752157
-20.6136363636365	-0.0204674921767325	-21.0176767676767	-0.0225558191752157
20.6761363636365	-0.0226357919434914	20.2676767676767	-0.01908286350525
61.965909090909	-0.0226357919434914	61.5530303030305	-0.01908286350525
103.255681818182	-0.0226357919434914	102.838383838384	-0.01908286350525
144.545454545455	-0.0226357919434914	144.123737373738	-0.01908286350525
185.835227272727	-0.0226357919434914	185.409090909091	-0.01908286350525
227.125	-0.0226357919434914	226.694444444444	-0.01908286350525
268.414772727273	-0.0226357919434914	267.979797979798	-0.01908286350525
309.704545454545	-0.0226357919434914	309.265151515152	-0.01908286350525
350.994318181818	-0.0226357919434914	350.550505050505	-0.01908286350525
392.284090909091	-0.0226357919434914	391.835858585859	-0.01908286350525
433.573863636364	-0.0226357919434914	433.121212121212	-0.01908286350525
474.863636363636	-0.0226357919434914	474.406565656566	-0.01908286350525
516.153409090909	-0.0226357919434914	515.691919191919	-0.01908286350525
557.443181818182	-0.0226357919434914	556.977272727273	-0.01908286350525
598.732954545455	-0.0226357919434914	598.262626262626	-0.01908286350525
640.022727272727	-0.0226357919434914	639.54797979798	-0.01908286350525
681.3125	-0.0226357919434914	680.833333333333	-0.01908286350525
722.602272727273	-0.0226357919434914	722.118686868687	-0.01908286350525
763.892045454545	-0.0226357919434914	763.404040404041	-0.01908286350525
805.181818181818	-0.0226357919434914	804.689393939394	-0.01908286350525
846.471590909091	-0.0226357919434914	845.974747474747	-0.01908286350525
887.761363636364	-0.0226357919434914	887.260101010101	-0.01908286350525
929.051136363636	-0.0226357919434914	928.545454545455	-0.01908286350525
970.340909090909	-0.0226357919434914	969.830808080808	-0.01908286350525
1011.63068181818	-0.0226357919434914	1011.11616161616	-0.01908286350525
1052.92045454545	-0.0226357919434914	1052.40151515152	-0.01908286350525
1094.21022727273	-0.0226357919434914	1093.68686868687	-0.01908286350525
1135.5	-0.0226357919434914	1134.97222222222	-0.01908286350525
1176.78977272727	-0.0226357919434914	1176.25757575758	-0.01908286350525
1218.07954545455	-0.0226357919434914	1217.54292929293	-0.01908286350525
1259.36931818182	-0.0226357919434914	1258.82828282828	-0.01908286350525
1300.65909090909	-0.0226357919434914	1300.11363636364	-0.01908286350525
1341.94886363636	-0.0226357919434914	1341.39898989899	-0.01908286350525
1383.23863636364	-0.0226357919434914	1382.68434343434	-0.01908286350525
1424.52840909091	-0.0226357919434914	1423.9696969697	-0.01908286350525
1465.81818181818	-0.0226357919434914	1465.25505050505	-0.01908286350525
1507.10795454545	-0.0226357919434914	1506.5404040404	-0.01908286350525
1548.39772727273	-0.0226357919434914	1547.82575757576	-0.01908286350525
1589.6875	-0.0226357919434914	1589.11111111111	-0.01908286350525
1630.97727272727	-0.0226357919434914	1630.39646464646	-0.01908286350525

Pitch	**y**	**Roll**	**y.1**
1672.26704545455	-0.0226357919434914	1671.68181818182	-0.01908286350525
1713.55681818182	-0.0226357919434914	1712.96717171717	-0.01908286350525
1754.84659090909	-0.0226357919434914	1754.25252525253	-0.01908286350525
1796.13636363636	-0.0226357919434914	1795.53787878788	-0.01908286350525
1837.42613636364	-0.0226357919434914	1836.82323232323	-0.01908286350525
1878.71590909091	-0.0226357919434914	1878.10858585859	-0.01908286350525
1920.00568181818	-0.0226357919434914	1919.39393939394	-0.01908286350525
1961.29545454545	-0.0226357919434914	1960.67929292929	-0.01908286350525
2002.58522727273	-0.0226357919434914	2001.96464646465	-0.01908286350525
2043.875	-0.0226357919434914	2043.25	-0.01908286350525

Appendix K. The glare model partial dependency values for the vehicles variable

Vehicle information is redacted.

y	y	y
0.86561626784249	0.0167701220931241	0.0144448817820938
0.86561626784249	0.0167696361778223	0.0143870794545581
0.439732779878188	0.0167198208364632	0.0143376498195172
0.376940046325069	0.0166989033894478	0.0140145534398667
0.315747106523512	0.0166506936446107	0.0138985411405864
0.299730448604275	0.0166473098728019	0.0136573284517876
0.295871742671983	0.0165388243236962	0.0135890217763256
0.293584574288119	0.0165345881275319	0.0135673911285358
0.287551451147524	0.0165241735635054	0.0135563069001471
0.284886546943125	0.0165222615526774	0.01344704870564
0.264590930573901	0.0165051557892435	0.0132196082090917
0.212657793101134	0.0164806800875567	0.0129198712984664
0.199067255878162	0.0164396473670909	0.0127549904400919
0.182524225063539	0.0164054548302136	0.0126859549340472
0.160171587084858	0.0163978834725418	0.0123913554745415
0.134297929168616	0.0163537520159017	0.0123715371208702
0.13380712000693	0.0163296471132193	0.0123134175360401
0.128976543142522	0.0162272380819281	0.0121928038091165
0.124980058599677	0.0162268793134493	0.0116864329356964
0.124769155588829	0.0161875486775846	0.0116532625902948
0.0997224518764545	0.0158367303396064	0.0113310970387317
0.0982676206307697	0.0157471067733021	0.0112637435947264
0.0890411019133767	0.0157456841385691	0.0111735877117005
0.0774208790462096	0.0157422872945067	0.0111145806503394
0.037433726241668	0.0156357088445186	0.0110311900955748
0.0173918644344517	0.0155616031258844	0.00638701672430404
0.0172967410455371	0.0155289390540646	0.00617220872157486
0.0172744308908442	0.0154775300904125	0.00374453861731132
0.0171396761968816	0.0154089247560234	0.00328114587801629
0.0171205334007981	0.0153635270114876	0.00299419351092557
0.0169716804861359	0.0153584867339097	0.00216663707303729
0.0169570726573539	0.0153335524629582	0.00208319017247701
0.0169261527448621	0.0151900409833317	0.00207790900342457
0.0168910874651534	0.0149245854512943	0.00205598345244793
0.0168639617448192	0.0149183177560344	0.0020222645435435
0.016855521980821	0.0148760799625609	0.00174505540668581
0.0168250604670422	0.0147852127688422	0.00168521014535661
0.016812012359177	0.0147257815926184	0.00160958122230027
0.0168023737726456	0.0146490275478999	0.00156657559456733
0.0167954388947095	0.0145023864457225	0.0015605652634271

y	y	y
0.00149845528222613	-0.0020760070871691	-0.00560881879115994
0.00140882755684961	-0.00211738841981244	-0.00571758310453971
0.000861146075359145	-0.00214570301217693	-0.00606564629353074
0.000708919488274113	-0.00214708390291218	-0.00625141143574956
0.000632296412784241	-0.00268743879235983	-0.00626813109328887
0.000625752565799042	-0.00274361131073308	-0.00627388027672728
0.00051916811350591	-0.00275589749322665	-0.00628202183901031
0.000473339337226473	-0.0028339902042175	-0.0063644067219669
0.000404432880928712	-0.00311873937841512	-0.00644293912728652
0.000356447373842193	-0.00313933090124357	-0.0064964114380263
0.00034302940848039	-0.00317162284680279	-0.00718674973611185
0.000178989881084358	-0.00320670921460713	-0.00719849964553157
0.000102183377921136	-0.00330328809723135	-0.00803728392747417
7.73708716935283E-05	-0.00343291217658427	-0.0082664429970874
-5.4961888332857E-05	-0.0034828018545157	-0.00833998151721374
-0.000118714988313403	-0.0036115977903718	-0.00855546939716808
-0.00020026923723659	-0.00373089331744445	-0.00868807599519695
-0.000293071993575608	-0.00388685917444994	-0.00877041551419757
-0.000389682583334471	-0.00418618013767843	-0.00896326283508896
-0.000389982708689438	-0.00432469271113192	-0.00937997799895894
-0.000494205609385472	-0.00434894787941124	-0.00941438093172376
-0.000520943450383786	-0.00450893401778904	-0.00953839744631429
-0.000557536417804297	-0.00460338325858533	-0.0096685719476114
-0.000557597339954158	-0.00472816066782008	-0.00987520002545931
-0.000645656833619666	-0.00480568881442132	-0.00997846624939137
-0.00104112652845428	-0.00500684718072541	-0.0104439413905046
-0.00110163194398183	-0.00506758902242942	-0.0107417593242777
-0.00119309574130965	-0.00523989846427084	-0.0111444329697838
-0.00123757006245276	-0.00526379068037155	-0.0125450701035852
-0.00145042892336184	-0.00535482997861174	-0.0134324540438177
-0.00166069764187173	-0.00546068605608163	-0.01401475068796
-0.0017191122669497	-0.00549061733258656	-0.0148782196203412
-0.00181035722475125	-0.00549469585569302	-0.015487372664962
-0.00197845591069819	-0.00553062680271566	-0.0159917864271633
-0.00201520066927517	-0.00556261357137417	-0.0169942880423314

Appendix L. Relative influence of variables in the luminance model

Variable	Relative influence
Longitude	33.6849346223366
Latitude	31.4085941988353
Pitch	15.0925648929702
Roll	14.3627077392892
vehicle	4.42052330461886
UserInput	0.977369054117736
last_mot_unix	0.0347373644862232
VehicleManufactureYear	0.0185688233459151

Appendix M. The luminance model partial dependency values for pitch and roll

Pitch	y	Roll	y.1
-2043.8125	26100.4608631443	-2044	27663.1893188902
-2002.5220959596	26100.4608631443	-2002.72411616162	22565.8802694909
-1961.23169191919	26100.4608631443	-1961.44823232323	22565.8802694909
-1919.94128787879	26100.4608631443	-1920.17234848485	22565.8802694909
-1878.65088383838	26100.4608631443	-1878.89646464646	22565.8802694909
-1837.36047979798	26100.4608631443	-1837.62058080808	22565.8802694909
-1796.07007575758	26100.4608631443	-1796.3446969697	22565.8802694909
-1754.77967171717	26100.4608631443	-1755.06881313131	22565.8802694909
-1713.48926767677	26100.4608631443	-1713.79292929293	22565.8802694909
-1672.19886363636	26100.4608631443	-1672.51704545455	22565.8802694909
-1630.90845959596	26100.4608631443	-1631.24116161616	22565.8802694909
-1589.61805555556	26100.4608631443	-1589.96527777778	22565.8802694909
-1548.32765151515	26100.4608631443	-1548.68939393939	22565.8802694909
-1507.03724747475	26100.4608631443	-1507.41351010101	22565.8802694909
-1465.74684343434	26100.4608631443	-1466.13762626263	22565.8802694909
-1424.45643939394	26100.4608631443	-1424.86174242424	22565.8802694909
-1383.16603535354	26100.4608631443	-1383.58585858586	22565.8802694909
-1341.87563131313	26100.4608631443	-1342.30997474747	22565.8802694909
-1300.58522727273	26100.4608631443	-1301.03409090909	22565.8802694909
-1259.29482323232	26100.4608631443	-1259.75820707071	22565.8802694909
-1218.00441919192	26100.4608631443	-1218.48232323232	22565.8802694909
-1176.71401515152	26100.4608631443	-1177.20643939394	22565.8802694909
-1135.42361111111	26100.4608631443	-1135.93055555556	22565.8802694909
-1094.13320707071	26100.4608631443	-1094.65467171717	22565.8802694909
-1052.8428030303	26100.4608631443	-1053.37878787879	22565.8802694909
-1011.5523989899	26100.4608631443	-1012.1029040404	24333.0053601719
-970.261994949495	26100.4608631443	-970.82702020202	24333.0053601719
-928.971590909091	26100.4608631443	-929.551136363636	24333.0053601719
-887.681186868687	26100.4608631443	-888.275252525252	24333.0053601719
-846.390782828283	26100.4608631443	-846.999368686869	24333.0053601719
-805.100378787879	26100.4608631443	-805.723484848485	24333.0053601719
-763.809974747475	26100.4608631443	-764.447601010101	24333.0053601719
-722.519570707071	26100.4608631443	-723.171717171717	24333.0053601719
-681.229166666667	26100.4608631443	-681.895833333333	24333.0053601719
-639.938762626263	26100.4608631443	-640.619949494949	24333.0053601719
-598.648358585859	26100.4608631443	-599.344065656566	24333.0053601719
-557.357954545455	26100.4608631443	-558.068181818182	24333.0053601719
-516.06755050505	26100.4608631443	-516.792297979798	24333.0053601719
-474.777146464646	26100.4608631443	-475.516414141414	24333.0053601719
-433.486742424242	26100.4608631443	-434.24053030303	24333.0053601719
-392.196338383838	26100.4608631443	-392.964646464646	24333.0053601719
-350.905934343434	26100.4608631443	-351.688762626263	24333.0053601719

Pitch	y	Roll	y.1
-309.61553030303	26100.4608631443	-310.412878787879	24333.0053601719
-268.325126262626	26100.4608631443	-269.136994949495	24333.0053601719
-227.034722222222	26100.4608631443	-227.861111111111	24333.0053601719
-185.744318181818	26100.4608631443	-186.585227272727	24333.0053601719
-144.453914141414	26100.4608631443	-145.309343434343	24333.0053601719
-103.16351010101	26100.4608631443	-104.03345959596	24333.0053601719
-61.873106060606	26100.4608631443	-62.7575757575755	24333.0053601719
-20.5827020202019	26139.9076451502	-21.4816919191917	26815.8241185123
20.7077020202023	21164.4413229276	19.7941919191921	25535.873107388
61.998106060606	21164.4413229276	61.070075757576	28079.7237456168
103.28851010101	21164.4413229276	102.34595959596	28079.7237456168
144.578914141414	21164.4413229276	143.621843434344	28079.7237456168
185.869318181818	21164.4413229276	184.897727272727	28079.7237456168
227.159722222222	21164.4413229276	226.173611111111	28079.7237456168
268.450126262626	21164.4413229276	267.449494949495	28079.7237456168
309.74053030303	21164.4413229276	308.725378787879	28079.7237456168
351.030934343435	21164.4413229276	350.001262626263	28079.7237456168
392.321338383838	21164.4413229276	391.277146464647	28079.7237456168
433.611742424242	21164.4413229276	432.55303030303	28079.7237456168
474.902146464647	21164.4413229276	473.828914141414	28079.7237456168
516.19255050505	21164.4413229276	515.104797979798	28079.7237456168
557.482954545455	21164.4413229276	556.380681818182	28079.7237456168
598.773358585859	21164.4413229276	597.656565656566	28079.7237456168
640.063762626263	21164.4413229276	638.93244949495	28079.7237456168
681.354166666667	21164.4413229276	680.208333333333	28079.7237456168
722.644570707071	21164.4413229276	721.484217171717	28079.7237456168
763.934974747475	21164.4413229276	762.760101010101	28079.7237456168
805.225378787879	21164.4413229276	804.035984848485	28079.7237456168
846.515782828283	21164.4413229276	845.311868686869	28079.7237456168
887.806186868687	21164.4413229276	886.587752525253	28079.7237456168
929.096590909091	21164.4413229276	927.863636363636	28079.7237456168
970.386994949495	21164.4413229276	969.13952020202	28079.7237456168
1011.6773989899	21164.4413229276	1010.4154040404	28079.7237456168
1052.9678030303	23024.1700309378	1051.69128787879	28079.7237456168
1094.25820707071	23024.1700309378	1092.96717171717	28079.7237456168
1135.54861111111	23024.1700309378	1134.24305555556	28079.7237456168
1176.83901515152	23024.1700309378	1175.51893939394	28079.7237456168
1218.12941919192	23024.1700309378	1216.79482323232	28079.7237456168
1259.41982323232	23024.1700309378	1258.07070707071	28079.7237456168
1300.71022727273	23024.1700309378	1299.34659090909	28079.7237456168
1342.00063131313	23024.1700309378	1340.62247474747	28079.7237456168
1383.29103535354	23024.1700309378	1381.89835858586	28079.7237456168
1424.58143939394	23024.1700309378	1423.17424242424	28079.7237456168
1465.87184343434	23024.1700309378	1464.45012626263	28079.7237456168
1507.16224747475	23024.1700309378	1505.72601010101	28079.7237456168
1548.45265151515	23024.1700309378	1547.00189393939	28079.7237456168

Pitch	y	Roll	y.1
1589.74305555556	23024.1700309378	1588.27777777778	28079.7237456168
1631.03345959596	23024.1700309378	1629.55366161616	28079.7237456168
1672.32386363636	23024.1700309378	1670.82954545455	28079.7237456168
1713.61426767677	23024.1700309378	1712.10542929293	28079.7237456168
1754.90467171717	23024.1700309378	1753.38131313131	28079.7237456168
1796.19507575758	23024.1700309378	1794.6571969697	28079.7237456168
1837.48547979798	23024.1700309378	1835.93308080808	28079.7237456168
1878.77588383838	23024.1700309378	1877.20896464646	28079.7237456168
1920.06628787879	23024.1700309378	1918.48484848485	28079.7237456168
1961.35669191919	23024.1700309378	1959.76073232323	28079.7237456168
2002.6470959596	23024.1700309378	2001.03661616162	28079.7237456168
2043.9375	25661.3174910267	2042.3125	28079.7237456168

Appendix N. The luminance model partial dependency values for the vehicles variable

Vehicle information is redacted.

y	y	y
79727.3820664292	56060.1464579063	50963.4254452328
79152.5526748229	56005.5780189119	50917.9678540747
73420.9688430299	55673.8160988712	50581.8610380279
71195.1609179669	55667.247099177	50546.6672571577
66249.9025137285	55443.4428367403	50523.0167916592
65048.7677073496	55311.9676147751	50507.1849141592
64479.1729378164	55272.9707362156	50313.72101019
63256.064853839	55076.7078729666	50105.1492457076
62981.0693033874	54713.8463304411	49927.4453756157
62370.4083278335	54321.4699866138	49869.1972924209
62157.2950114273	54297.6301372564	49846.0672656813
62007.3090487638	54084.2760396002	49827.4682186672
61592.6928907131	53953.4860670515	49755.5455407905
61572.6304424803	53842.8583663916	49593.8678723108
61443.7198026959	53719.1802147529	49273.353952207
61317.4849362506	53587.8837825196	48993.3179053952
61217.0066912874	53352.002885527	48938.713193474
61082.2546220146	53051.1528841522	48861.8577905937
60889.1808817852	52996.7634211495	48778.2120233822
59927.9862409035	52876.0876515182	48354.5683064211
59474.1474451789	52757.1810039305	48347.0028428251
59461.7522921424	52684.3918899637	48310.7655473257
59334.2197464203	52479.8700373148	48197.1722516054
59316.3655307818	52394.2000229973	47829.507913007
58995.5165629831	52229.2650834788	47620.5338526196
58939.5258943785	52160.1215316824	47518.1075974436
58679.1305710113	51973.6692863196	47470.2950689043
58466.9919408546	51884.8213415645	47417.2910428348
58344.920179558	51748.377656978	47051.1742676377
58340.0681677079	51636.7200756597	47004.5009064719
57635.7769227553	51629.3238465008	46673.8901180685
57586.3625217139	51573.5297217725	46510.0078829537
57491.4571851077	51571.4170061813	46195.0431441891
57385.4149084558	51380.3637743904	46136.0406139989
57375.202825699	51344.9043888498	46078.930496549
56721.0976987222	51259.9324985844	46051.7278267695
56683.0964117972	51238.2013295777	45979.4471045828
56477.8859811638	51121.2309125968	45833.8212074549
56459.0989569977	51083.7504793186	45641.3463825331
56384.2861467248	51017.271152094	45575.8206845313

y	y	y
45541.7041335555	36697.3735504992	23608.7429515315
45382.8316940301	35466.0106236869	22621.7078380356
45191.5584016775	35351.3498912576	22621.656309127
44897.816316605	35305.5363101148	21619.1126665166
44715.8664208051	35275.886518188	21557.4456874919
44586.8439806095	35258.200077236	21356.288612663
44531.8254137325	35176.8986140694	21074.3174050436
44140.5243043403	34707.8736415976	20682.6324603669
43967.35794367	34470.233388621	20499.7059715154
43917.8238797119	34261.2727507239	20391.8982138029
43793.1711792804	33180.8488125056	20189.4444350034
43499.3492313325	32667.3160368599	19701.1918206042
43495.2432833524	32238.915937887	19476.8791489298
43025.3456862119	31844.0004845653	18699.3688696818
42796.4507026979	31812.6940273356	18672.1395421933
42710.9923443349	31736.4965245975	18364.4674353399
42683.3840517151	31647.8052316887	18320.6396323275
42343.446060251	31037.3054642044	17943.5757557177
42251.8803259938	30647.9965824682	17863.4408433328
42008.2349882533	30166.2858624099	17533.4938696911
41807.026775776	29456.0106550384	17518.5995265734
41727.7018133541	29389.2907357485	17407.795352292
40649.7430157439	28582.8428511507	14356.1434278841
40047.1459973309	28149.992485535	13311.3541229858
40025.6049603823	27365.2762524089	12481.8960414228
39255.15565899	27056.6377252075	12429.6875680069
38499.0553236848	26167.5123999005	12047.5182726918
38007.5797686856	25543.3253418289	11638.7706905284
37995.9759134316	25530.101490222	11064.8538093433
37426.7941675614	25366.704400478	11052.7942524006
37405.8612509582	25022.8391131055	9691.8995340783
37194.6968486218	25014.1600548989	8449.16582785499
37151.6540442715	24295.6405617906	7486.74778187233
37118.6159097935	24233.43332139	4747.52874101978
36984.3083334199	24103.2322422413	-

Appendix O. Survey questions in the RAC Motorists Panel survey

Table 11: Questions asked as part of the RAC Motorists Opinion Panel

Question (includes number in RAC survey	Options
Q1. What type of vehicle do you drive most often?	• Car with a lower ride height, such as a sports car (e.g. Mazda MX-5, BMW Z4) • Car with a normal ride height such as a hatchback, estate or saloon (e.g. Ford Fiesta, VW Golf, Audi A4) • Car with a higher ride height such as an SUV or 4x4 (e.g. Nissan Qashqai, Audi Q7, Range Rover, VW Tiguan) • Small van (e.g. a VW Caddy, Citroen Berlingo) • Large van (e.g. a Ford Transit, VW Transporter) • Other
Q2. In the vehicle you drive most often, at what height is the driver's seat set at?	• On the highest setting (seat at its highest) • Between the highest and lowest setting • On the lowest setting (seat at its lowest) • Don't know
Q3. Thinking about the brightness of vehicle headlights that you see on the roads today, which of the following best describes your thoughts?	• Most are too bright • Some are too bright • None are too bright
Q4. Which of the following would you say is true in relation to the headlights of oncoming vehicles you see while driving?	• I regularly get dazzled by these lights while driving • I occasionally get dazzled by these lights while driving • I do not get dazzled by these lights while driving
Q7. Do you believe a certain colour of headlight is responsible for the dazzling you experience?	• Yes – those with a yellower-coloured light • Yes – those with a whiter-coloured light • No – both • Not sure
Q8. Do you believe certain type/s of vehicle are responsible for the dazzling you experience?	• Cars with a lower ride height, such as a sports car (e.g. Mazda MX-5, BMW Z4) • Cars with a normal ride height such as a hatchback, estate or saloon (e.g. Ford Fiesta, VW Golf, Audi A4) • Cars with a higher ride height such as an SUV or 4x4 (e.g. Nissan Qashqai, Audi Q7, Range Rover, VW Tiguan) • Small vans (e.g. a VW Caddy, Citroen Berlingo) • Large vans (e.g. a Ford Transit, VW Transporter) • Motorbikes • Lorries (HGVs) • No, there is no particular type of vehicle
Q9. Do you mostly suffer from dazzle on any particular type/s of roads?	• Unlit rural roads • Lit rural roads • Unlit motorways • Lit motorways • Unlit urban and suburban roads • Lit urban and suburban roads • No, it's a problem on all types of road

Question (includes number in RAC survey	Options
Q10. Do you particularly suffer from dazzle in any of the following scenarios?	• When oncoming vehicles drive over speed humps (“sleeping policemen”) • When oncoming vehicles are driving over potholes / poor quality roads • When driving up a hill and oncoming vehicles dazzle me • When driving down a hill and oncoming vehicles dazzle me • When it’s raining and/or the road is wet • None of the above
Q11. Do you particularly experience dazzle from vehicle headlights in any of the following weather conditions?	• When it’s raining lightly • When it’s raining heavily • When the road is wet but it’s not raining • When it’s snowing • When it’s foggy • None of the above – I experience headlight dazzle in all weather conditions
Q12. Do you particularly experience dazzle from vehicle headlights during any of the following times of day?	• During dawn – soon after the sun has risen • During hours of darkness • During dusk – soon after the sun has set • None of the above
Q13. Have you experienced dazzle from vehicle headlights during daylight hours (but outside the hours of dawn and dusk)?	• Yes • No
Q14. Do you particularly experience dazzle from vehicle headlights in any of the following traffic conditions?	• When it’s a single vehicle coming towards me • In light traffic when there are several vehicles coming towards me • In heavy traffic when there are several vehicles coming towards me • None of the above
Q43. Are you driving less, or have you stopped driving, at night, as a result of headlights being too bright for you?	• I’ve stopped driving at night completely due to other vehicles’ headlights being too bright • I’m driving less at night as a result of other vehicles’ lights being too bright • I’d like to drive less at night because other vehicles’ lights are too bright, but I have no option other than driving at night (e.g. for work purposes) • None of the above

Appendix P. Findings from survey with drivers – tables

These tables contain detailed (weighted) numbers and column percentages for the key questions about vehicles, driving environments and glare perception (including behaviour). These are split down by gender, age and the ride height of the car people usually drive (these being the most relevant individual difference variables focused on in the work). Because weighted samples are used, and due to rounding, numbers do not always add to totals.

For "by gender" tables, 6 people in the base number are missing from the gender columns as they either identified as a different gender or preferred not to give their gender. For the "by car ride height" tables, 35 people who responded that they normally drive a van or light van were excluded in the same manner due to small sample size in these categories (15 and 20 respectively). All questions are "select one answer" except when noted.

Lists under tables note some of the more obvious differences between sub-groups (these being based on the non-overlapping of confidence intervals). No distinction is made between 95% and 99% confidence intervals.

Table 12: Thinking about the brightness of vehicle headlights that you see on the roads today, which of the following best describes your thoughts? By gender

Brightness	Male	Female	Total
Most are too bright	283 (29%)	383 (44%)	667 (36%)
Some are too bright	651 (66%)	456 (53%)	1,112 (60%)
None are too bright	48 (5%)	23 (3%)	70 (4%)
Total	982	682	1,850

Females more likely than males to report "most are too bright". Males more likely than females to report "Some" or "None".

Table 13: Thinking about the brightness of vehicle headlights that you see on the roads today, which of the following best describes your thoughts? By age

Brightness	17–34	35–44	45–54	55–64	65–74	75+	Total
Most are too bright	150 (39%)	141 (42%)	118 (35%)	116 (32%)	89 (36%)	53 (31%)	667 (36%)
Some are too bright	219 (57%)	188 (56%)	214 (63%)	229 (63%)	152 (61%)	110 (64%)	1,112 (60%)
None are too bright	17 (4%)	10 (3%)	9 (3%)	19 (5%)	7 (3%)	8 (5%)	70 (4%)
Total	386	339	341	364	248	171	1,850

35–44 age group more likely to report "Most".

Table 14: Thinking about the brightness of vehicle headlights that you see on the roads today, which of the following best describes your thoughts? By car ride height

Brightness	Lower ride height car	Normal ride height car	Higher ride height car	Total
Most are too bright	67 (42%)	435 (37%)	151 (32%)	653 (36%)
Some are too bright	88 (55%)	686 (59%)	304 (64%)	1,078 (60%)
None are too bright	5 (3%)	41 (4%)	19 (4%)	65 (4%)
Total	159	1,161	475	1,795

Table 15: Which of the following would you say is true in relation to the headlights of oncoming vehicles you see while driving? By gender

Dazzle	Male	Female	Total
Regularly get dazzled	295 (33%)	357 (45%)	695 (39%)
Occasionally get dazzled	577 (64%)	407 (52%)	987 (58%)
Do not get dazzled	34 (4%)	25 (3%)	59 (3%)
Total	906	789	1,701

Females more likely than males to report “Regularly”. Males more likely than females to report “Occasionally”.

Table 16: Which of the following would you say is true in relation to the headlights of oncoming vehicles you see while driving? By age

Dazzle	17–34	35–44	45–54	55–64	65–74	75+	Total
Regularly get dazzled	109 (32%)	122 (38%)	148 (45%)	135 (40%)	91 (40%)	50 (34%)	655 (39%)
Occasionally get dazzled	194 (57%)	191 (59%)	182 (55%)	196 (58%)	133 (59%)	91 (63%)	987 (58%)
Do not get dazzled	38 (11%)	9 (3%)	2 (0%)	4 (1%)	3 (1%)	4 (3%)	59 (3%)
Total	340	323	331	336	227	145	1,701

17–34 age group more likely than all other groups to report “I do not get dazzled”.

Table 17: Which of the following would you say is true in relation to the headlights of oncoming vehicles you see while driving? By car ride height

Dazzle	Lower ride height car	Normal ride height car	Higher ride height car	Total
Regularly get dazzled	51 (37%)	425 (40%)	159 (36%)	636 (38%)
Occasionally get dazzled	70 (51%)	621 (58%)	270 (61%)	961 (58%)
Do not get dazzled	16 (12%)	28 (3%)	11 (2%)	55 (3%)
Total	137	1,075	440	1,652

Lower ride height car drivers more likely than other groups to report "I do not get dazzled".

Table 18: Do you believe a certain colour of headlight is responsible for the dazzling you experience? By gender

Light colour	Male	Female	Total
Yellower-coloured light	41 (5%)	20 (3%)	61 (4%)
Whiter-coloured light	629 (71%)	532 (69%)	1,165 (70%)
Both	95 (11%)	78 (11%)	175 (10%)
Not sure	118 (13%)	140 (18%)	259 (16%)
Total	883	771	1,660

Females more likely than males to report "Not sure".

Table 19: Do you believe a certain colour of headlight is responsible for the dazzling you experience? By age

Light colour	17–34	35–44	45–54	55–64	65–74	75+	Total
Yellower-coloured light	58 (19%)	0 (0%)	2 (0%)	0 (0%)	0 (0%)	1 (1%)	61 (4%)
Whiter-coloured light	199 (64%)	240 (75%)	237 (72%)	238 (71%)	159 (71%)	92 (65%)	1,165 (70%)
Both	26 (8%)	35 (11%)	36 (11%)	32 (10%)	25 (11%)	20 (14%)	175 (11%)
Not sure	28 (9%)	44 (14%)	55 (17%)	63 (19%)	40 (18%)	29 (14%)	259 (16%)
Total	311	319	330	334	225	141	1,660

17–34 age group more likely than all other age groups to report "Yellower-coloured".

Table 20: Do you believe a certain colour of headlight is responsible for the dazzling you experience? By car ride height

Light colour	Lower ride height car	Normal ride height car	Higher ride height car	Total
Yellower-coloured light	18 (14%)	31 (3%)	12 (3%)	61 (4%)
Whiter-coloured light	85 (67%)	742 (70%)	310 (72%)	1,138 (71%)
Both	13 (10%)	115 (11%)	39 (9%)	167 (10%)
Not sure	12 (9%)	165 (16%)	72 (17%)	248 (15%)
Total	128	1,053	433	1,614

Lower ride height car drivers more likely to report “Yellower-coloured”.

Table 21: Do you believe certain type/s of vehicle are responsible for the dazzling you experience? By gender (select multiple)

Vehicle type	Male	Female	Total
Lower ride height cars	77 (9%)	60 (8%)	139 (8%)
Normal ride height cars	164 (19%)	105 (14%)	269 (16%)
Higher ride height cars	448 (51%)	325 (42%)	775 (47%)
Small vans	95 (11%)	58 (8%)	154 (9%)
Large vans	219 (25%)	133 (17%)	354 (21%)
Motorbikes	44 (5%)	38 (5%)	83 (5%)
Lorries	107 (12%)	81 (10%)	189 (11%)
No particular type	367 (42%)	382 (49%)	751 (45%)
Total	883	771	1,660

Males more likely than females to report “Normal ride height cars”, “Higher ride height cars” and “Large vans”.

Table 22: Do you believe certain type/s of vehicle are responsible for the dazzling you experience? By age (select multiple)

Vehicle type	17–34	35–44	45–54	55–64	65–74	75+	Total
Lower ride height cars	69 (22%)	21 (7%)	7 (2%)	23 (7%)	11 (5%)	8 (5%)	139 (8%)
Normal ride height cars	87 (28%)	36 (11%)	42 (13%)	45 (14%)	32 (14%)	26 (18%)	269 (16%)
Higher ride height cars	130 (42%)	169 (53%)	161 (49%)	154 (46%)	98 (43%)	63 (45%)	775 (47%)
Small vans	26 (8%)	33 (10%)	27 (8%)	33 (10%)	21 (9%)	13 (10%)	154 (9%)
Large vans	55 (18%)	79 (25%)	66 (20%)	71 (21%)	51 (23%)	33 (23%)	354 (21%)
Motorbikes	9 (3%)	12 (4%)	20 (6%)	19 (6%)	14 (6%)	9 (7%)	83 (5%)
Lorries	29 (9%)	39 (12%)	36 (11%)	39 (12%)	26 (11%)	20 (14%)	189 (11%)
No particular type	98 (31%)	135 (42%)	159 (48%)	167 (50%)	123 (55%)	70 (50%)	751 (45%)
Total	311	319	330	334	225	141	1,660

17–34 age group more likely than all other groups to report “Lower ride height cars” and “Normal ride height cars”.

Table 23: Do you believe certain type/s of vehicle are responsible for the dazzling you experience? By car ride height (select multiple)

Vehicle type	Lower ride height car	Normal ride height car	Higher ride height car	Total
Lower ride height cars	18 (14%)	75 (7%)	40 (9%)	133 (8%)
Normal ride height cars	26 (20%)	177 (17%)	51 (12%)	253 (15%)
Higher ride height cars	80 (62%)	561 (53%)	116 (27%)	757 (46%)
Small vans	16 (13%)	105 (10%)	31 (7%)	153 (9%)
Large vans	26 (20%)	261 (25%)	64 (15%)	351 (21%)
Motorbikes	7 (5%)	53 (5%)	21 (5%)	81 (5%)
Lorries	15 (12%)	122 (12%)	45 (10%)	183 (11%)
No particular type	37 (29%)	414 (39%)	279 (64%)	731 (44%)
Total	128	1,053	433	1,614

Lower ride height car drivers and normal ride height car drivers more likely than higher ride height car drivers to report “Higher ride height cars” and “Large vans”.

Table 24: Do you mostly suffer from dazzle on any particular type/s of roads? By gender (select multiple)

Road type	Male	Female	Total
Unlit rural	362 (41%)	302 (29%)	667 (40%)
Lit rural	92 (10%)	61 (8%)	154 (9%)
Unlit motorways	107 (12%)	118 (15%)	227 (14%)
Lit motorways	40 (5%)	11 (1%)	52 (3%)
Unlit urban/suburban	229 (26%)	228 (30%)	459 (28%)
Lit urban/suburban	87 (10%)	72 (9%)	159 (10%)
All types of road	365 (41%)	355 (46%)	721 (43%)
Don't know	28 (3%)	29 (4%)	58 (3%)
Total	883	771	1,660

Males more likely than females to report "Lit motorway".

Table 25: Do you mostly suffer from dazzle on any particular type/s of roads? By age (select multiple)

Road type	17–34	35–44	45–54	55–64	65–74	75+	Total
Unlit rural	118 (38%)	121 (38%)	127 (39%)	146 (44%)	90 (40%)	63 (45%)	667 (40%)
Lit rural	50 (16%)	15 (5%)	23 (7%)	24 (7%)	30 (13%)	14 (10%)	154 (9%)
Unlit motorways	63 (20%)	43 (13%)	44 (13%)	38 (11%)	25 (11%)	14 (10%)	227 (14%)
Lit motorways	35 (11%)	5 (2%)	1 (0%)	4 (1%)	4 (2%)	1 (1%)	52 (3%)
Unlit urban/suburban	83 (27%)	76 (24%)	88 (27%)	93 (28%)	72 (32%)	47 (33%)	459 (28%)
Lit urban/suburban	43 (14%)	19 (6%)	32 (10%)	26 (8%)	23 (10%)	16 (11%)	159 (10%)
All types of road	75 (%)	164 (%)	157 (%)	155 (%)	111 (%)	59 (%)	721 (43%)
Don't know	17 (5%)	8 (3%)	12 (4%)	10 (3%)	4 (2%)	6 (4%)	58 (3%)
Total	311	319	330	334	225	141	1,660

17–34 age group more likely than all other groups to report "Lit motorways".
17–34 age group more likely than 35–44, 45–54 and 55–64 age groups to report "Lit rural".
65–74 age group more likely than 35–44, 45–54 and 55–64 age groups to report "Lit rural".

Table 26: Do you mostly suffer from dazzle on any particular type/s of roads? By car ride height (select multiple)

Road type	Lower ride height car	Normal ride height car	Higher ride height car	Total
Unlit rural	52 (41%)	419 (40%)	179 (41%)	651 (40%)
Lit rural	21 (17%)	94 (9%)	37 (9%)	152 (9%)
Unlit motorways	23 (18%)	138 (13%)	64 (15%)	225 (14%)
Lit motorways	9 (7%)	34 (3%)	9 (2%)	52 (3%)
Unlit urban/suburban	42 (33%)	264 (25%)	140 (32%)	447 (28%)
Lit urban/suburban	13 (10%)	98 (9%)	45 (10%)	156 (10%)
All types of road	47 (37%)	470 (45%)	177 (41%)	694 (43%)
Don't know	3 (2%)	37 (4%)	17 (4%)	57 (4%)
Total	128	1,053	433	1,614

Lower ride height car drivers more likely than other groups to report "Lit rural".
Higher ride height car drivers more likely than normal ride height car drivers to report "Unlit urban and suburban".

Table 27: Do you particularly suffer from dazzle in any of the following scenarios? By gender (select multiple)

Scenario	Male	Female	Total
Oncoming vehicle drives over speed hump	582 (66%)	513 (67%)	1,101 (66%)
Oncoming vehicle drives over pothole	374 (42%)	349 (45%)	727 (44%)
When I am driving up a hill	481 (54%)	438 (57%)	922 (56%)
When I am driving down a hill	270 (31%)	329 (43%)	602 (36%)
When it is raining/road is wet	388 (44%)	401 (52%)	793 (48%)
None of the above	88 (10%)	73 (9%)	162 (10%)
Total	883	771	1,660

Females more likely than males to report "Driving down a hill" and "Raining/wet".

Table 28: Do you particularly suffer from dazzle in any of the following scenarios? By age (select multiple)

Scenario	17–34	35–44	45–54	55–64	65–74	75+	Total
Oncoming vehicle drives over speed hump	153 (49%)	207 (65%)	224 (68%)	243 (73%)	173 (77%)	101 (72%)	1,101 (66%)
Oncoming vehicle drives over pothole	138 (44%)	137 (43%)	134 (41%)	150 (45%)	107 (48%)	60 (43%)	727 (44%)
When I am driving up a hill	162 (52%)	184 (58%)	178 (54%)	182 (55%)	134 (60%)	83 (59%)	922 (56%)
When I am driving down a hill	86 (28%)	127 (40%)	112 (34%)	134 (40%)	89 (40%)	53 (37%)	602 (36%)
When it is raining/road is wet	100 (32%)	155 (49%)	135 (41%)	189 (57%)	127 (57%)	88 (62%)	793 (48%)
None of the above	12 (4%)	42 (13%)	50 (15%)	28 (8%)	18 (8%)	13 (9%)	162 (10%)
Total	311	319	330	334	225	141	1,660

All other age groups more likely than 17–34 group to report "Speed humps".
35–44, 55–64, 65–74 and 75+ groups more likely than 17–34 to report "Raining/wet".
55–64, 65–74 and 75+ groups more likely than 45–54 to report "Raining/wet".

Table 29: Do you particularly suffer from dazzle in any of the following scenarios? By car ride height (select multiple)

Scenario	Lower ride height car	Normal ride height car	Higher ride height car	Total
Oncoming vehicle drives over speed hump	81 (64%)	694 (66%)	298 (69%)	1,074 (65%)
Oncoming vehicle drives over pothole	52 (41%)	471 (45%)	178 (41%)	701 (42%)
When I am driving up a hill	61 (48%)	596 (57%)	240 (55%)	897 (54%)
When I am driving down a hill	42 (33%)	386 (37%)	157 (36%)	585 (35%)
When it is raining/road is wet	44 (35%)	502 (48%)	222 (51%)	769 (46%)
None of the above	9 (7%)	107 (10%)	41 (9%)	157 (9%)
Total	128	1,053	433	1,614

Normal and high car ride height car drivers more likely than low ride height car drivers to report "Raining/wet".

Table 30: Do you particularly experience dazzle from vehicle headlights in any of the following weather conditions? By gender (select multiple)

Weather	Male	Female	Total
Light rain	237 (27%)	153 (20%)	391 (24%)
Heavy rain	369 (42%)	263 (34%)	635 (38%)
Wet road but not raining	287 (33%)	184 (24%)	473 (29%)
Snow	83 (9%)	78 (10%)	161 (10%)
Fog	77 (9%)	100 (13%)	177 (11%)
All weather	370 (42%)	393 (51%)	766 (46%)
Total	883	771	1,660

Males more likely than females to report “Light rain”, “Heavy rain” and “Wet road”.
Females more likely than males to report “Fog” and “All weather”.

Table 31: Do you particularly experience dazzle from vehicle headlights in any of the following weather conditions? By age (select multiple)

Weather	17–34	35–44	45–54	55–64	65–74	75+	Total
Light rain	67 (21%)	75 (24%)	70 (21%)	78 (23%)	61 (27%)	40 (29%)	391 (24%)
Heavy rain	156 (50%)	103 (32%)	98 (30%)	121 (36%)	92 (41%)	66 (46%)	635 (38%)
Wet road but not raining	90 (29%)	101 (32%)	85 (26%)	83 (25%)	64 (28%)	50 (36%)	473 (28%)
Snow	66 (21%)	29 (9%)	14 (4%)	25 (7%)	17 (8%)	10 (7%)	161 (10%)
Fog	57 (18%)	38 (12%)	20 (6%)	29 (9%)	20 (9%)	14 (10%)	177 (11%)
All weather	78 (25%)	155 (48%)	194 (59%)	174 (52%)	109 (49%)	57 (41%)	766 (5%)
Total	311	319	330	334	225	141	1,660

17–34 age group more likely than all other groups to report “Snow”.
17–34 age group more likely than 35–44, 45–54, 55–64 to report “Heavy rain”.
17–34 age group more likely than 45–54, 55–64, 65–74 and 75+ to report “Fog”.
All other age groups more likely than 17–34 age group to report “All weather”.
75+ age group more likely than 35–44, 45–54 and 55–64 age groups to report “Heavy rain”.
75+ age group more likely than 45–54, 55–64 and 65–74 age groups to report “Wet road”.

Table 32: Do you particularly experience dazzle from vehicle headlights in any of the following weather conditions? By car ride height (select multiple)

Weather	Lower ride height car	Normal ride height car	Higher ride height car	Total
Light rain	29 (23%)	255 (24%)	100 (23%)	384 (24%)
Heavy rain	56 (43%)	373 (35%)	186 (43%)	615 (38%)
Wet road but not raining	44 (34%)	307 (29%)	111 (26%)	462 (29%)
Snow	20 (16%)	94 (9%)	45 (10%)	159 (10%)
Fog	18 (14%)	97 (9%)	58 (13%)	173 (11%)
All weather	42 (33%)	504 (48%)	197 (45%)	743 (46%)
Total	128	1,053	433	1,614

Table 33: Do you particularly experience dazzle from vehicle headlights during any of the following times of day? By gender (select multiple)

Time of day	Male	Female	Total
Dawn	112 (13%)	86 (11%)	199 (12%)
Darkness	754 (85%)	671 (87%)	1,430 (86%)
Dusk	258 (29%)	274 (36%)	532 (32%)
None of the above	75 (9%)	50 (6%)	126 (8%)
Total	883	771	1,660

Females more likely than males to report “Dusk”.

Table 34: Do you particularly experience dazzle from vehicle headlights during any of the following times of day? By age (select multiple)

Time of day	17–34	35–44	45–54	55–64	65–74	75+	Total
Dawn	52 (17%)	43 (13%)	36 (11%)	36 (11%)	20 (9%)	12 (9%)	199 (12%)
Darkness	245 (79%)	276 (86%)	290 (88%)	296 (89%)	197 (88%)	125 (89%)	1,430 (86%)
Dusk	81 (26%)	100 (31%)	99 (30%)	120 (36%)	85 (38%)	47 (33%)	532 (32%)
None of the above	26 (8%)	30 (9%)	28 (9%)	19 (6%)	14 (6%)	9 (6%)	126 (8%)
Total	311	319	330	334	225	141	1,660

17–34 age group more likely than 65–74 and 75+ age groups to report "Dawn".
All age groups except 35–44 more likely than 17–34 age group to report "Darkness".
65–74 age group more likely than 17–34 and 45–54 age groups to report "Dusk".

Table 35: Do you particularly experience dazzle from vehicle headlights during any of the following times of day? By car ride height (select multiple)

Time of day	Lower ride height car	Normal ride height car	Higher ride height car	Total
Dawn	24 (19%)	115 (11%)	56 (13%)	196 (12%)
Darkness	106 (83%)	911 (87%)	374 (86%)	1,391 (86%)
Dusk	36 (28%)	345 (33%)	133 (31%)	514 (33%)
None of the above	3 3(%)	78 (7%)	40 (9%)	122 (7%)
Total	128	1,053	433	1,614

Table 36: Have you experienced dazzle from vehicle headlights during daylight hours (but outside the hours of dawn and dusk)? By gender

Daylight hours	Male	Female	Total
Yes	277 (31%)	236 (31%)	514 (31%)
No	605 (69%)	535 (69%)	1,146 (69%)
Total	883	771	1,660

Table 37: Have you experienced dazzle from vehicle headlights during daylight hours (but outside the hours of dawn and dusk)? By age

Daylight hours	17–34	35–44	45–54	55–64	65–74	75+	Total
Yes	116 (37%)	84 (26%)	82 (25%)	115 (35%)	76 (24%)	41 (29%)	514 (31%)
No	196 (63%)	235 (74%)	247 (75%)	218 (65%)	149 (66%)	100 (71%)	1,146 (69%)
Total	311	319	330	334	225	141	1,660

17–34, 55–64 and 65–74 age groups more likely than 45–54 age group to report “Yes”.

Table 38: Have you experienced dazzle from vehicle headlights during daylight hours (but outside the hours of dawn and dusk)? By car ride height

Daylight hours	Lower ride height car	Normal ride height car	Higher ride height car	Total
Yes	41 (32%)	348 (33%)	106 (25%)	496 (31%)
No	86 (68%)	705 (67%)	327 (75%)	1,119 (69%)
Total	128	1,053	433	1,614

High ride height car drivers more likely than Normal ride height car drivers to report “No”.

Table 39: Do you particularly experience dazzle from vehicle headlights in any of the following traffic conditions? By gender (select multiple)

Traffic	Male	Female	Total
Single oncoming vehicle	589 (67%)	556 (72%)	1,150 (69%)
Light traffic – several oncoming vehicles	429 (49%)	402 (52%)	835 (50%)
Heavy traffic – several oncoming vehicles	394 (45%)	384 (50%)	780 (47%)
None of the above	102 (12%)	77 (10%)	179 (11%)
Total	883	771	1,660

Table 40: Do you particularly experience dazzle from vehicle headlights in any of the following traffic conditions? By age (select multiple)

Traffic	17–34	35–44	45–54	55–64	65–74	75+	Total
Single oncoming vehicle	152 (49%)	236 (74%)	252 (77%)	248 (74%)	163 (72%)	99 (70%)	1,150 (69%)
Light traffic – several oncoming vehicles	142 (45%)	165 (52%)	159 (48%)	177 (53%)	121 (54%)	71 (50%)	835 (51%)
Heavy traffic – several oncoming vehicles	124 (40%)	146 (46%)	149 (45%)	166 (50%)	119 (53%)	75 (53%)	780 (47%)
None of the above	29 (9%)	42 (13%)	36 (11%)	39 (12%)	20 (9%)	13 (10%)	179 (11%)
Total	311	319	330	334	225	141	1,660

All age groups more likely than 17–34 age group to report "Single oncoming vehicle".
65–74 and 75+ age groups more likely than 17–34 age group to report "Heavy traffic".

Table 41: Do you particularly experience dazzle from vehicle headlights in any of the following traffic conditions? By car ride height (select multiple)

Traffic	Lower ride height car	Normal ride height car	Higher ride height car	Total
Single oncoming vehicle	72 (57%)	740 (70%)	306 (71%)	1,118 (69%)
Light traffic – several oncoming vehicles	63 (49%)	533 (51%)	209 (48%)	805 (50%)
Heavy traffic – several oncoming vehicles	59 (46%)	500 (47%)	191 (44%)	749 (46%)
None of the above	11 (9%)	117 (11%)	49 (11%)	178 (11%)
Total	128	1,053	433	1,614

Normal ride height and high ride height car drivers more likely than low ride height car drivers to report "Single oncoming vehicle".

Table 42: Are you driving less, or have you stopped driving, at night, as a result of headlights being too bright for you? By gender

Limitation	Male	Female	Total
Stopped driving at night completely	28 (3%)	50 (6%)	78 (4%)
Driving less at night	230 (25%)	285 (34%)	515 (29%)
Like to drive less but have no choice	174 (19%)	208 (25%)	385 (22%)
None of the above	502 (54%)	296 (35%)	801 (45%)
Total	934	839	1,779

Females more likely than males to report "Stopped", "Driving less" or "Like to drive less".
Males more likely than females to report "none".

Table 43: Are you driving less, or have you stopped driving, at night, as a result of headlights being too bright for you? By age

Limitation	17–34	35–44	45–54	55–64	65–74	75+	Total
Stopped driving at night completely	29 (8%)	6 (2%)	1 (0%)	9 (3%)	14 (6%)	18 (11%)	78 (4%)
Driving less at night	196 (53%)	54 (16%)	53 (16%)	79 (23%)	71 (29%)	62 (38%)	515 (29%)
Like to drive less but have no choice	83 (23%)	92 (28%)	88 (27%)	67 (20%)	34 (14%)	20 (12%)	385 (22%)
None of the above	61 (17%)	177 (54%)	191 (57%)	189 (55%)	122 (51%)	62 (38%)	801 (45%)
Total	369	329	332	345	241	163	1,779

17–34, 65–74 and 75+ age groups more likely than others to report “Stopped” or “Driving less”.
35–44, 45–54 and 55–64 tend to be more likely to report “Like to drive less”.

Table 44: Are you driving less, or have you stopped driving, at night, as a result of headlights being too bright for you? By car ride height

Limitation	Lower ride height car	Normal ride height car	Higher ride height car	Total
Stopped driving at night completely	17 (11%)	45 (4%)	15 (3%)	78 (5%)
Driving less at night	57 (37%)	340 (30%)	110 (24%)	507 (29%)
Like to drive less but have no choice	42 (27%)	238 (21%)	94 (21%)	374 (22%)
None of the above	38 (25%)	497 (44%)	236 (52%)	771 (45%)
Total	154	1,120	455	1,730

Low ride height car drivers more likely than other groups to report “Stopped”.
Low and normal ride height car drivers more likely than high ride height car drivers to report “Less”.
Normal and high ride height car drivers more likely than low ride height car drivers to report “None”.

Glare from vehicle lighting

Vehicle lighting can cause glare to other drivers. Regulations exist to limit the luminous intensity of headlamps, and their aim, but drivers still report problems with glare, especially when driving at night. Drivers have also reported problems with specific headlamp technologies such as LEDs, and in particular situations such as when facing larger vehicles. In this project, two pieces of work were undertaken to further understand the root causes of glare in night driving on UK roads, and to propose solutions.

First, a survey was undertaken with 1,850 UK drivers matched to the age and gender split of the licence-holding population. These drivers answered questions about their own experiences of glare when driving. Second, an instrumented trial car (left-hand drive) was used to collect data from the usual driver eye position while driving at night. Variables measured included levels of luminance, location, other vehicles in the scene (through number plate recognition), the pitch and roll of the trial car and subjective reports of glare from an observer present in the trial car. Data were analysed using a machine learning algorithm to uncover patterns and establish which variables were associated with high levels of maximum luminance in the scene and reported glare from the observer.

The survey findings indicated that the driving public perceive glare from vehicle headlamps to be an important and widespread issue when driving at night. More than half of drivers reported either having stopped or reduced driving at night (or would if they could) due to headlamp glare.

Analysis of the data from the instrumented car revealed that reported glare was associated with high levels of luminance in the scene, with particular locations and with particular positions (pitch and roll) of the trial vehicle. Specific vehicle types in the scene were also associated with the observer reporting glare, although these findings can only be treated as indicative due to limitations in the vehicle information collected. High levels of luminance in the scene were associated with location and pitch and roll; vehicles in the scene had a much smaller association with luminance than they did with reported glare.

The study demonstrates that glare from vehicle lighting can be studied using an instrumented car, and several considerations for further activities are made. These include public awareness campaigns on glare, further research to understand the problem in more detail and potential changes to regulations.

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