Synthesis title:

# Vehicle Lighting

## Category: Vehicles

**Other Relevant Topics:**

- Crash Mitigation and Collision Avoidance
- Advanced Vehicle Systems

**Keywords:**

**Headlight, Glare, Daytime running lights, Halogen, High-intensity discharge, Light-emitting diode, Advanced front-lighting systems, Conspicuity**

# About the Road Safety Observatory

**The Road Safety Observatory aims to provide free and easy access to independent road safety research and information for anyone working in road safety and for members of the public. It provides summaries and reviews of research on a wide range of road safety issues, along with links to original road safety research reports.**

The Road Safety Observatory was created as consultations with relevant parties uncovered a strong demand for easier access to road safety research and information in a format that can be understood by both the public and professionals. This is important for identifying the casualty reduction benefits of different interventions, covering engineering programmes on infrastructure and vehicles, educational material, enforcement and the development of new policy measures.

The Road Safety Observatory was designed and developed by an Independent Programme Board consisting of key road safety organisations, including:

- Department for Transport
- The Royal Society for the Prevention of Accidents (RoSPA)
- Road Safety GB
- Parliamentary Advisory Council for Transport Safety (PACTS)
- RoadSafe
- RAC Foundation

By bringing together many of the key road safety governmental and non-governmental organisations, the Observatory hopes to provide one coherent view of key road safety evidence.

The Observatory originally existed as a standalone website, but is now an information hub on the RoSPA website which we hope makes it easy for anyone to access comprehensive reviews of road safety topics.

All of the research reviews produced for the original Road Safety Observatory were submitted to an Evidence Review Panel (which was independent of the programme Board), which reviewed and approved all the research material before it was published to ensure that the Key Facts, Summaries and Research Findings truly reflected the messages in underlying research, including where there may have been contradictions. The Panel also ensured that the papers were free from bias and independent of Government policies or the policies of the individual organisations on the Programme Board.

The Programme Board is not liable for the content of these reviews. The reviews are intended to be free from bias and independent of Government policies and the policies of the individual organisations on the Programme Board. Therefore, they may not always represent the views of all the individual organisations that comprise the Programme Board.

Please be aware that the Road Safety Observatory is not currently being updated; the research and information you will read throughout this paper has not been updated since 2017. If you have any enquiries about the Road Safety Observatory or road safety in general, please contact **help@rospa.com** or call **0121 248 2000**.

## How do I use this paper?

This paper consists of an extensive evidence review of key research and information around a key road safety topic. The paper is split into sections to make it easy to find the level of detail you require. The sections are as follows:

| | |
|---|---|
| **Key Facts** | A small number of bullet points providing the key facts about the topic, extracted from the findings of the full research review. |
| **Summary** | A short discussion of the key aspects of the topic to be aware of, research findings from the review, and how any pertinent issues can be tackled. |
| **Methodology** | A description of how the review was put together, including the dates during which the research was compiled, the search terms used to find relevant research papers, and the selection criteria used. |
| **Key Statistics** | A range of the most important figures surrounding the topic. |
| **Research Findings** | A large number of summaries of key research findings, split into relevant subtopics. |
| **References** | A list of all the research reports on which the review has been based. It includes the title, author(s), date, methodology, objectives and key findings of each report, plus a hyperlink to the report itself on its external website. |

**The programme board would like to extend its warm thanks and appreciation to the many people who contributed to the development of the project, including the individuals and organisations who participated in the initial consultations in 2010.**

## Key facts

- The three major objectives of automobile lighting are to improve driver visual performance in darkness, to improve vehicle conspicuity in specific conditions, and to facilitate communication between road users. Of these, improving visual conditions in the darkness is the primary purpose (Rumar, 2001).
- High intensity discharge (HID) headlights provide improved forward road illumination, are more energy efficient, and are longer lasting than conventional incandescent headlights. Depending on their design and use, light-emitting diode LED headlights may offer even greater benefits in these areas.
- Despite early papers reporting their effectiveness, recent studies looking at the benefit of daytime running lights (DRLs) have not reported significant effects for passenger vehicles due to the increase in daytime conspicuity that they produce. However, the estimated trend is often for a substantial benefit, rather than a disbenefit.
- Under controlled conditions, motorcycles with DRLs can be detected faster than motorcycles without DRLs. Furthermore, changes to the geometry of motorcycle lighting in the future could provide motorcyclists with greater gap allowances than for single headlamp arrangements, because it allows other road users to judge their distance and rate of approach better.
- Headlight glare resistance declines with human age and therefore is an important consideration for older drivers on the roads at night.
- The light source for brake lights and their design has an influence on other road users' reaction times. LED light sources can improve recognition response times associated with vehicle braking compared with incandescent bulb lights.

## Summary

Forward lighting is extremely important to enable drivers to guide the vehicle safely at night along varying road geometries and to identify obstacles and pedestrians. Vehicle signal lighting enhances conspicuity enabling drivers and other road users to be able to see each other and understand their respective intentions and directions of travel, indicating, braking etc.

Brake lights and dipped beam headlamps for cars have been available since the 1910s but the technology did not develop significantly until the 1960s. In the last 20 years, lighting technology has advanced rapidly with the transition from halogen bulbs to high intensity gas discharge, to LEDs, and to laser technology. Alongside the advances in light source technology, there have been interesting developments for avoiding glare, illuminating the forward road scene even around corners, utilising infrared or ultraviolet light to pick out obstacles and providing signal lighting that adapts to varying ambient conditions or responding to emergency braking conditions. All of these developments result from the desire to make driving during the day or night as comfortable and safe as possible.

The Statutory Instrument which comprises the GB Road Vehicle Lighting Regulation is the Road Vehicles Lighting Regulations 1989 (Statutory Instrument 1989, No. 1796), as amended.

Relevant UN Regulations concerning vehicle lighting are:

- No. 6 Direction indicators
- No. 7 Front and rear position lamps, stop-lamps and end-outline marker lamps
- No. 8 Headlamps equipped with halogen filament lamps ($H_1$, $H_2$, $H_3$, $HB_3$, $HB_4$, $H_7$, $H_8$, $H_9$, $HIR_1$, $HIR_2$ and/or $H_{11}$)
- No. 19 Front fog lamps
- No. 20 Headlamps equipped with halogen filament lamps (H4lamps)
- No. 23 Reversing and manoeuvring lamps
- No. 31 Sealed-beam headlamps (SB), (incl. a halogen sealed-beam headlamp unit)
- No. 37 Filament lamps in approved lamp units
- No. 38 Rear fog lamps
- No. 48 Installation of lighting and light-signalling devices
- No. 50 Position, stop, direction indicator lamps for mopeds and motorcycles
- No. 53 Installation of lighting and light-signalling devices for L3 vehicles
- No. 56 Headlamps (mopeds)
- No. 57 Headlamps (motorcycles)
- No. 72 Headlamps ($HS_1$ lamps) (motorcycles)
- No. 74 Installation of lighting and light-signalling devices (mopeds)
- No. 76 Headlamps for mopeds
- No. 77 Parking lamps
- No. 82 Headlamps ($HS_2$) (mopeds)

- No. 86 Installation of lighting and light-signalling devices for agricultural tractors
- No. 87 Daytime running lamps
- No. 91 Side-marker lamps
- No. 98 Headlamps with gas-discharge light sources
- No. 99 Gas-discharge light sources
- No. 112 Headlamps equipped with filament lamps and/or light-emitting diode (LED) modules
- No. 113 Headlamps equipped with filament, gas-discharge light sources or LED modules
- No. 123 Adaptive front-lighting systems (AFS)
- No. 128 Light Emitting Diode (LED) sources

Equivalent EU Directives exist and can be found at http://ec.europa.eu/enterprise/sectors/automotive/documents/directives/index_en.htm. As an example, Council Directive 76/756/EEC, as amended, relates to lighting and light-signalling devices on motor vehicles and their trailers. This has now been amended to allow dedicated daytime running lights, adaptive front lighting systems and emergency stop signals as they are all “expected to have a positive influence on road safety” (Commission Directive 2008/89/EC).

Following the CARS 21 High Level Group recommendation, there is an initiative for European Directives to be replaced by the corresponding UN Regulations. Commission Regulation EU 523/2012 (and preceding EU Regulations) already sets out the inclusion of certain UN Regulations in the European vehicle type-approval legislation.

Higher intensity headlights have the potential to offer better illumination during night time driving. This could be associated with the potential for casualty reductions. However, increased light intensity will also be associated in an increase in the ratio of head light luminance to ambient light levels and as has been suggested, a possible increase in the likelihood of glare. Glare can detract from optimal observation and hence vulnerable road users and other obstacles could be detected later or not even observed at all. Also, glare resistance declines with age and therefore is an important consideration for older drivers on the roads at night.

Also, in certain circumstances, it may be expected that the use of vehicle headlights in the presence of road lighting will not necessarily improve the luminance contrast of a target located on the road (Ekrias et al., 2008).

The latest advanced frontal lighting system technologies, including concepts such as automatically adjustable beam dipping and vulnerable road user detection, seem able to maximise the benefits from increased output headlights whilst minimising the potential negative aspects for other road users.

Reaction times to brake lights with neon and LED light sources are shorter than to incandescent bulb lights. Also, neon and LEDs are generally more efficient at generating light of the appropriate saturated red colour than filtered

incandescent lamps. It may be that 2014 sees the sale of the first car which will not have a single light bulb (Mueller, 2013). Instead this vehicle may rely solely on LEDs to provide all lighting.

Under controlled conditions, it is expected that benefits of daytime running lights can be demonstrated, as for motorcyclists (Smither and Torrez, 2010). However, due to confounding factors the importance of these benefits in real-world data analyses for passenger-vehicles and motorcycles seems difficult to determine with statistical certainty, although general trends are encouraging. The magnitude of the effect of DRLs for bicyclists is reported as being substantial, even when analysing all accidents with personal injury (Madsen et al., 2013).

## Methodology

A detailed description of the methodology used to produce this review is provided in the Methodology section of the Observatory website at http://www.roadsafetyobservatory.com/Introduction/Methods .

This synthesis was compiled during November 2013. Searches were carried out on the pre-defined sources identified in the methodology section. Search terms used to identify relevant papers included: Vehicle light*, Brake, Forward vision, Night vision assistance, Weather, Colour, Glare, Distraction, Adaptive, LED, High-intensity discharge OR "HID", Xenon, Halogen, Projector lamps, Evaluat*, Effect*, Accident OR collisions, Assess*.

At the start of the review process it was intended that research articles would be scored on their relevance and quality. A rating of 'High', 'Medium' and 'Low' would have been given to each article under the following criteria.

For relevance:

- 'High' = refers to data on a metric clearly relevant to the topic under investigation
- 'Medium' = refers to data on a metric that is probably relevant to the UK (e.g. effects of lighting on very specific types of vehicles that are not used in the UK)
- 'Low' = does not refer to data relevant to the topic under investigation

For quality:

- High' = from a high-quality peer-reviewed publication, and clearly methodologically appropriate
- 'Medium' = from an academic source (e.g. book chapter, conference) but without peer-review, and/or possessing some methodological weakness (e.g. some possible confounding factors)
- 'Low' = from a more 'general' source (e.g. conference, trade paper) and/or clearly being methodologically weak or inappropriate (e.g. failing to address random variability by use of appropriate statistical techniques)

However, the balance of the relevant material obtained on the topic was predominantly given Low quality ratings. With the exception of papers related to Daytime Running Lights, no High relevance and High quality sources were found on vehicle lighting. Due to the rapidly evolving and highly technical nature of the subject matter it became evident that even Low quality sources could provide useful information about emerging concepts. Therefore the rating was relaxed to include information from all available sources.

The potential issue with removing filters to exclude Low quality sources is that the information presented could be biased to promote a particular product. Unfortunately, biased articles could not be excluded from this review as they often contained the most detailed information about a particular technology. Instead, the reference section has been used to try and highlight where a source is essentially publicity material for a particular company or product, or where the funding source and product under assessment seem particularly closely linked.

About 60 items of research, statistical reports or policy documents have been included in this review. The information documented here is based on the top 52 of those (including regulatory texts) following the review of each.

## Key statistics

It is the intention of safety interventions to reduce the number of fatal and other injuries that would otherwise have occurred. In some cases, the analyses reviewed offered some estimation of casualty saving potential for a technology. However, in other cases, the research is at a more fundamental stage where the results can only be expressed perhaps in terms of detection distances or times, or gap allowance. For quick reference, some of the key findings, based on such statistics, are presented under the headings below.

### HID headlights; fatalities; driving at night

- “Xenon can reduce road fatalities by 18 %.” This is the theoretical potential change if all vehicles on German roads were equipped with High Intensity Discharge (HID) car lights, instead of conventional incandescent alternatives (Independent study proves life-saving potential Xenon car lighting from Philips: Philips; 2007)

### LED headlights; fatalities; driving at night

- Since LED sources contain more relative energy in the short-wavelength region of the visible spectrum, it has been shown through calculation that they may provide a benefit to off-axis visual performance over halogen and HID lamps. An LED forward lighting system can result in at least a 150 ms decrease in reaction time over tungsten-halogen systems, though the amount of this visual benefit will depend on the spectral density of the LED. (Spectral effects of LED forward lighting: Van Derlofske et al.; 2005)

### Glare sensitivity; night driving ability; driving at night

- 40 per cent of drivers over the age of 60 have reduced night driving ability. The majority of persons over the age of 60 were not able to fulfil the criteria for night driving ability according to the recommendations of the German Ophthalmological Society (DOG). (Nachtfahreignung augen-gesunder personen verschiedener altersstufen: Scharwey et al.; 1998;)

### Auxiliary ultra-violet headlights; Pedestrians and pedal-cyclists; night time motor vehicle crashes

- This technology has not been exploited in production vehicles yet
- Percentage improvements in pedestrian detection distances varied from 34 to 117 per cent. This result is based on the measured detection distances for pedestrian ‘cut-outs’ when compared for conventional U.S. headlight illumination and the trial ultraviolet alternative. (Benefits and costs of ultraviolet fluorescent lighting: Lestina et al.; 1999; Page 50)

## Daytime running lights; multiparty accidents during daytime

- The best estimate of the intrinsic effect of DRL on cars is a 10-15% reduction in the number of multi-party daytime accidents. (A meta-analysis of studies concerning the safety effects of daytime running lights on cars: Elvik; 1996; page 693)
- The expected effect of daytime headlights as a motor vehicle standard for motorcycles in the European Union was predicted at about 7% fewer fatalities and injured motorcyclists in the EU (Effectiveness of daytime motorcycle headlights in the European Union: Bijleveld; 1997; Page 3)
- It has been assumed for cost-benefit purposes that the accident benefits for DRL would be considerably greater for fatal accidents (15%) than for serious (10%) or slight (5%) accidents. This assumption was only weakly supported by the available data. Changing it to a mean effect of 5.9% for all accident types may be more technically defensible (Daytime Running Lights (DRL): a review of the reports from the European Commission: Knight et al.; 2006; Page ii)
- The incidence rate, including all recorded bicycle accidents with personal injury to the participating cyclist, is 19% lower for cyclists with permanent running lights mounted. For multiparty accidents with personal injury to the participating cyclist, the incidence rate ratio is estimated to be 0.53; thus suggesting that the accident rate is 47% lower for the users of the bicycle running lights than those without. (Safety effects of permanent running lights for bicycles: A controlled experiment: Madsen et al.; 2013; Page 829.)

## Advanced Frontal lighting Systems; pedestrians; driving at night

- The safety benefit with an Advanced Frontal lighting System (AFS) is approximately 1.8m, when considering the earlier detection of a pedestrian with the swivelling low beam light distribution. With AFS drivers were capable of recognising the pedestrian earlier than with a standard system, thus leading to a benefit of approximately half the length of a passenger car (Advanced Frontal lighting System – Safety improvements at night: Neumann; 2003; Figure 4 / Page 4).
- On curves towards the offside, (but not the near-side) an increase in disability glare for oncoming traffic was predicted. However, no major discomfort glare problems are expected with AFS (Benefits of applying adaptive lighting to the U.S. and European low-beam patterns: Sivak et al.; 2001; Pages 15-17).

## Research findings

Summaries of key findings are given below. Further details of the studies reviewed, including methodology and findings, and links to the reports are given in the References section.

### HID headlights

Conventional headlights use light bulbs which consist of a tungsten filament which is powered by an electrical current to glow. The tungsten filament is mounted in a sealed glass bulb to prevent oxidation and subsequent failure. By filling the bulb with a halogen gas, a tungsten-halogen ('halogen') bulb is able to operate at higher filament temperatures without reducing the life of the bulb because the tendency towards oxidation of the filament is reduced.

High intensity discharge (HID) lamps offer a slightly different method to produce light where the electrical current is applied via two electrodes surrounded by a gas in a container. An arc between the electrodes ionises the gas and allows plasma to form. Radiation is emitted as the excited atoms drop back to a lower energy state, generating specific colours of emitted light.

> "High intensity discharge (HID) headlights are brighter, more energy efficient, and longer lasting than conventional incandescent headlights." (Mainster & Timberlake, 2003)

Those authors suggest that for a given installation, HID headlights may allow owners to detect road hazards, signage, and pedestrians at greater distances than an equivalent incandescent headlight.

The remarkable (18%) figure of potential fatality reductions due to HID lights claimed by Philips is based on the fact that xenon lights give twice the light of standard halogen lamps. According to this source, the extra whitish-blue light can offer a driver an additional 30 to 50 m of stopping distance as dangerous situations can be detected sooner (Philips, 2007). The allowable whitish light (or selected yellow) for light sources is controlled by UN Regulation 99 and its equivalents (e.g. SAE J578).

Bullough and Skinner (2012) found that pedestrian identification times in a roundabout scenario were significantly shorter with HID illumination than with halogen headlamps. Similar studies have shown equivalent performance with different road layouts (e.g. Bullough & Van Derlofske, 2005).

However, Flannagan et al. (2007) judged that because of changes in the sharpness of the vertical gradient in U.S. low beams, brought about with the introduction of HID beam patterns, the importance of headlamp levelling systems had increased. This view supports the requirements that vehicles with HID headlamps have a headlamp washing system (a wiper is not required) and be self-levelling. These additional features associated with the use of HID headlamps contribute to the economic cost of changing from incandescent bulbs to HID lights.

> "The uptake of xenon has remained low despite twice the flux of halogen, owing to its forbidding option price." (Mueller, 2013; quoting Fleury)

Sivak et al. (2006) indicated that HID projection patterns with less illumination to the sides of the road may mean that roadside lighting levels would have to be increased to offer equivalent conspicuity compared with halogen bulbs. However, this observation was based on a sample of U.S. vehicles and it is not clear whether this finding would also be true for the projection patterns of current and new vehicles compliant with European lighting regulations.

Also;

> "Although HID lamps offer an enormous increase in visibility, they can also result in a comparable increase in glare." (Mace et al., 2001)

Although, Bullough et al. (2002)[a] determined that it was the luminance of a light source, rather than the type of source, which was most important in the levels of glare disability experienced by an observer. Those authors demonstrated that HID glare source resulted in consistently lower (more glaring) De Boer ratings[1] than a halogen source at all illuminances. However, in terms of disability, whilst illuminance and viewing angle are important, the effect of lamp type was not significant ($p>0.05$) in their study. It was explained that, "even if one might experience greater discomfort in the presence of HID headlamp glare, it is possible that no deterioration of driving performance would be experienced, as long as the glare illuminance is controlled."

## Glare

Glare can cause discomfort or disability. Discomfort glare is described as not impairing to vision; however, it can be startling or distracting to a driver. It can also lead to blinking and squinting, etc. and also fatigue. On the other hand, disability glare does impair visual performance. It can be divided into aspects that might either dazzle or veil an object from being detected by a driver.

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[1] The De Boer rating is a nine point scale with five verbal descriptors associated with it. Though some of the words seem interchangeable between revisions, depending on the precise application (e.g. acceptable and admissible); a basic example would be:

1. Unbearable,
2.
3. Disturbing
4.
5. Just admissible
6.
7. Satisfactory
8.
9. Unnoticeable (or perhaps, Just noticeable)

> “Glare is the blinding experience that results from a bright light source in the visual field of view. Car drivers may frequently experience blinding because of glare from oncoming cars when driving at night on a dark road.” (Theeuwes et al., 2002)
>
> “Older individuals have increased intraocular stray light, glare sensitivity, and photostress recovery time.” (Mainster & Timberlake, 2003)

This means that the use of brighter light sources is likely to present greater potential problems associated with glare sensitivity and photostress recovery time for older than for younger drivers.”

Glare has been associated with slowed detection of pedestrians and, to a lesser extent, slowed detection of targets appearing in mirrors, increased lane position variability, reduced speed on curves, and, most consistently, increased steering variability (Ranney et al., 2000).

Countermeasures to reduce glare include:

- Infrastructure
    - Wide separation of opposing traffic flows, with independent alignment (where possible)
    - Glare screens to reduce glare from oncoming traffic
    - Fixed roadway lighting, where rural roads might otherwise be unlit, to decrease the light differential between the ambient light levels and vehicle lights
- Vehicle industry
    - Adaptive headlights, responding to curves and oncoming traffic
    - Lowering headlamp height (limited to mirror glare issues and subject to styling constraints)
    - Anti-glare mirrors
    - Ultraviolet headlights
    - Organic Light-Emitting Diodes (OLEDs)
        - “By being far more homogeneous than LED-based rear lights, OLEDs will reduce discomfort glare in applications such as bright stop lamps.” (Mueller, 2013; quoting Fleury).

- Drivers
    - Night-driving glasses – concomitant loss in visibility
    - Maintenance of headlight aim
        - Appropriate use of dipped/passing beam
        - Maintenance of vehicle (e.g. periodic inspection requirements, condition of lenses, correct functioning of supporting brackets and mechanisms)
        - Removal of dirt from light clusters
- Policy
    - Changing photometric distribution – uncertain safety improvement
        - By changing the colour and distribution of light, it might be possible to reduce the potential glare with the consequential risk of adversely affecting other functions of vehicle lighting
    - Polarized headlights / screens
        - An idealised, perhaps impractical concept

## Ultraviolet headlights

A U.S. Department of Transportation field study (1999) demonstrated that in certain circumstances ultraviolet headlights can significantly improve early detection of road markings and objects or obstructions. Significant improvements in detection and recognition distances for pedestrian scenarios were shown to be in the range from 34% to 117% by Lestina et al. (1999). Noting that UVA headlights have great potential to reduce pedestrian and bicycle crashes, they concluded that a reduction of 19% of all pedestrian crashes would result in a cost-benefit ratio of one. It is not clear that this would be a reasonable expectation of benefit; therefore one might conclude that some technological development is needed before the widespread use of ultraviolet headlights becomes cost-beneficial. Indeed, this is a technology that has not yet been exploited commercially.

## Infrared headlights

Infrared headlights or infrared LEDs have been used on the road for a number of years. Infrared light sources have been incorporated into headlamp systems to augment the conventional headlamp performance. Rather than replacing the conventional headlamps; they offer an additional function intended to be part of a driver assistance system. As such, these systems offer infrared light to the front of the vehicle which is recorded by camera and offered to the driver via a black and white image. Due to the properties of the infrared light (including that being in the non-visible part of the spectrum it presents no risk of glare) it is particularly effective at picking out people or animals at night.

As part of its Integrated Safety Concept, Mercedes-Benz offers the option of Night View Assist on models such as the CLS-Class.

> "This infrared camera system captures the entire area that would be illuminated on main beam and shows a black-and-white image in the instrument panel. In situations where switching to main beam is not appropriate, Night View Assist gives you a clearer picture of what's ahead and enables you to react faster to potential dangers such as pedestrians or animals in the road."
> (Mercedes-Benz, 2013)

## Advanced Front lighting Systems

Advanced Front lighting Systems (AFS) offer the ability to direct light from headlights depending on the forthcoming road. Initially these systems were based on vehicle steering angle and speed. However, development continues and can now include integration with GPS data. As noted in the Summary, Commission Directive 2008/89/EC now includes AFS and UN Regulation 123 specifically concerns AFS.

For some systems, the low beam function of halogen headlamps could swivel horizontally in order to optimise visibility in bends when driving at night without increasing glare light for the oncoming vehicles. This involves swivelling of the halogen projector unit by up to about 20 degrees. With High intensity discharge (HID) light sources, headlamp cleaning and dynamic levelling functions can also be added. The experimental study reported by Neumann (2003) demonstrated that an AFS system can increase the range for pedestrian detection, and perhaps therefore safety at night, significantly; especially with curved road sections.

Since demonstrations with halogen and xenon headlight sources, AFS with LED headlamps have been developed (e.g. Hsu & Wang, 2006). LED vehicle forward lighting systems may offer some general improvements over conventional and HID lights, for instance, styling freedom, total light output per headlamp device, and illumination to the side of the vehicle for peripheral vision of the driver (Van Derlofske et al., 2005).

In a U.S. study, Sullivan and Flannagan (2011) identified that in a set of either dark or light condition pedestrian-vehicle collisions, there was a suggestion that during left-turn (towards the offside) events in the dark, the visibility of pedestrians is poorer on that side of the roadway, consistent with low-beam light distribution. A similar, although not statistically significant, pattern was also observed for pedestrians crossing in front of vehicles traveling straight. In this case, there was a trend for more collisions than expected (~17 % in all non-intersection crashes), to occur when the pedestrian crossed from the offside in the dark. The authors of this study comment that the results provide examples of how asymmetries in headlamp photometry may affect real-world pedestrian-vehicle collision outcomes. They may therefore provide an important opportunity for validation of headlamp countermeasure performance (such as cornering lamps and AFS).

Again, based on the U.S. driving situation where the near-side is to the right and the off-side to the left, there will be an increase in glare illuminance for oncoming traffic with AFS in left curves and a decrease in right curves. For European beams, the increased glare illuminance never reaches the levels needed for a rating of 4 on the DeBoer discomfort-glare scale, and was therefore not considered to be a problem with shifted beams (Sival et al., 2001). The compromise between providing adequate forward illumination while minimising the effects of glare to the other road users remains a constraint in the design of headlamp beam patterns. This balance together with the research on pedestrian detection led to the Society of Automotive Engineers, Inc. releasing the Standard J2829; ‘Pedestrian visibility – low beam optimization to reduce night-time fatalities.’

## Automatic dipped / Adaptive main beam

A technological innovation possible through the advent of forward facing cameras in cars is the ability to automatically dip the headlights. This function controls the vehicle lighting with the goal of maximising the possible range of the lights and hence providing the optimum driver sight. This optimisation is achieved with the adaptation of the low beam to oncoming and preceding road users. The result is that, whereas the low beam might end at approximately 65 meters in a conventional lamp, the visible range can be increased up to a couple of hundred meters in best cases. Dazzle for other road users should be negligible because the headlight beam always ends at their vehicles (Könning, n.d.).This feature has now penetrated the market to the C-Segment level already being available as an option on certain vehicles.

> “High Beam Assist dips your high beam automatically to improve driver control and safety for both the driver and other road users… Using a camera built into the rear-view mirror, the system automatically dips the headlights when it detects either oncoming traffic or vehicles ahead. It is easier than constantly switching from high to dipped beam and safer too, giving you the best view of the road ahead without dazzling other road users.” (Volkswagen, 2013)

This implementation of the technology uses a dynamic ‘shadow’ in the vehicle lighting field to avoid illuminating the identified road user(s) whilst keeping full illumination of the rest of the lighting field.

LEDs present the opportunity to illuminate people and points of danger within the forward vision field (Könning, n.d.). This highlights key regions for attention by the driver. In theory, the driver is able not only to discern hazards considerably earlier but also consciously detects them and can adapt his or her driving behaviour accordingly in time.

As an example of such a system, the BMW Night Vision with Dynamic Light Spot is already on the market. A thermal image camera in the radiator grille with a range of up to 300 metres relays images of people and animals directly onto the Control Display.

> “When the road ahead is in darkness, a remote infrared system detects pedestrians or larger animals in front of the car, and directs two separately controlled Dynamic Light Spots at them without creating unpleasant glare. This gives both the driver and the person or animal in front a highly effective warning of a potential risk situation. Additional warnings are provided when the thermal image is activated in the multifunctional instrument display or in the full-colour BMW Head-up Display.” (BMW, 2013)

## Daytime running lights

> “Dedicated daytime running lights (DRL) are a set of high luminance, additional forward-facing vehicle lights that operate independently of the vehicle’s other external lighting, and are lit only during daylight hours. As a road safety countermeasure they are intended to increase a vehicle’s conspicuity. This in turn should reduce the number of crashes and/or reduce the severity of crashes by enabling drivers (and riders and pedestrians and bicyclists) to see an oncoming vehicle sooner (or at all) and begin to react earlier to attempt to avoid a crash, or begin braking sooner and thus reduce the crash’s severity.” (Symmons, 2009)

Sweden has mandated the use of daytime running lights since 1977. Early research proposed that this had resulted in a reduction of 11% of multiple accidents during daytime. However, the reanalysis by Theeuwes and Riemersma (1995) indicated that this was sensitive to concurrent changes in baseline accident rates and hence could not support such a clear effect of DRL. Non-significant overall effects were also predicted by the NHTSA analysis for the U.S. (2008).

The European Union has acceded to UN Regulation 87; therefore, (according to Directive 2008/89/EC) new types of M and N category vehicles are to be fitted with dedicated daytime running lights. However, the use of these lights is still controlled under national law.

To compensate for a perceived difficulty of other road users to spot motorcycles, for years the "Convention on Road Traffic" from 1968 has recommended the signatory countries to implement the obligation for motorcyclists to drive with the headlamp on during the daytime. Out of the 25 European Member States, 21 have introduced legislation according to this recommendation.

During a simulated turn across traffic scenario, based on participants' responses to videos, Smither and Torrez (2010) revealed a significant difference between reaction time for motorcycles with daytime running lights and those without. These results seem to support previous research on this topic.

> "A motorcycle with DRLs is detected faster than a motorcycle without DRLs." (Smither & Torrez, 2010)

However, the NHTSA study from 2011 found inconclusive results for the effectiveness of motorcycle DRLs when investigating gap acceptance turning across oncoming traffic, based on Canadian and U.S. on-road field trials (Pierowicz et al., 2011).

Convinced of the importance of powered two wheeler conspicuity and to avoid users becoming more vulnerable when they forget to switch their headlights on, the manufacturers' members of ACEM (Association des Constructeurs Européens de Motocycles) committed themselves to equip all their models including mopeds with Automatic Headlamp-On (AHO) since 2003.

In contrast to the increased conspicuity given to motorcycles through AHO, concerns have been expressed that widespread use of daytime running lights by other road users may reduce the effective conspicuity for motorcycles (Knight et al., 2006). Jenness et al. (2011[a]) reported tentative analysis of fatal crashes in the U.S. and Canada which may support this concern.

Daytime running lights for cyclists are also likely to offer a substantial benefit. In multiparty accidents with personal injury this effect could be as great as a 47% reduction in the accident rate (Madsen et al., 2013).

## Motorcycle lighting

Gould et al. (2012)[a] used a desk-based visual study to demonstrate that individuals were extremely poor at judging the speed of an approaching motorcycle with a solo headlight in night-time conditions. Further to this, the study demonstrated a substantial effect in terms of fitting a tri-headlight configuration to a standard motorcycle frame. This feature dramatically increased the accuracy of speed judgments.

The same authors (Gould et al., 2012[b]) used further simulator experiments to demonstrate that the estimation of an approaching car's speed stayed relatively constant across various ambient light levels. Whereas participant estimations of the solo headlight motorcycle speed became significantly less accurate in the degraded lighting levels of the early night and night-time conditions.

To some extent, the findings of Gould et al. have been further validated through the efforts of Cavallo et al. (2013). The findings of their driving simulator trial indicated that innovative motorcycle headlight ergonomics can improve motorcyclist safety by increasing the gaps accepted by automobile drivers when they turn left in front of a motorcycle (towards the offside in the European scenario). Cavallo tested a variety of headlight configurations for the motorcycle targets in their trial and found that only light arrangements that accentuated the vertical dimension of the motorcycle/motorcyclist outline provided substantial improvements as compared to motorcycles equipped with only standard headlights. It was noted as being of interest by the authors that the time gaps accepted in front of these configurations, were equivalent to the time gaps accepted in front of cars. A similar U.S. study by Jenness et al (2011[b]) suggested that such modifications to motorcycle lighting may also be of benefit in the daytime, as well as in lower light levels.

## Reaction to brake lights

Common light sources in brake lights are incandescent (or on a few vehicle models, neon lamps) and light-emitting diodes (LEDs). Reaction times to high-mounted brake lights with either neon or LED light sources are shorter than to incandescent brake lights. Furthermore, reaction times for a 615-nm LED central high-mounted brake light were significantly shorter than for a neon equivalent ($p<0.05$), which also had a dominant wavelength near 615 nm (Bullough et al., 2002[b]).

The use of LED brake lights allows them to change the area being lit or intensity during a braking event. For instance, they could flash during an emergency braking event, as used by Mercedes. Flashing LED lights have been shown to be better at grabbing attention compared with steady light from either an LED or incandescent source (NHTSA, 2009)

It is in reaction to potential braking events that laser lighting technology may first be used in a production car. Holographic warnings are being proposed to alert following drivers if they are too close (Mueller, 2013). In this application a warning could be displayed permanently behind a vehicle but would only become visible to another road user if they are in the position of a driver very close behind the vehicle.

## Retroreflective materials

In the review of vehicle lighting with a focus on the developing world, and after considering many headlight based countermeasures to improve twilight safety, Rumar noted that,

> *"Most of the recommended actions concern automobile headlights, while some specific situations would require special designs of automobile signal lights. However, most of the visibility improvements in traffic in darkness could probably be solved in a more cost-effective way by more extensive and systematic use of retroreflective materials. The question is how realistic it is to expect that a majority of pedestrians will wear retroreflective materials. Other potential improvements involve lower speed limits during night traffic, as well as driver training, education, and information." (Rumar, 2001)*

## How effective?

In Canada, the introduction of daytime running lights in 1989 led to a reduction of collisions in 1991 of 5.3 %, considering those collisions in which the DRL were expected to be effective and comparing 1989 and 1990 collision involvement rates (Tofflemire & Whitehead, 1997).

In Austria, a new law was introduced in 1982 mandating the use of DRL for motorcycles. It was found by Bijleved (1997) that this law reduced the number of victimised motorcyclists in daytime multiple vehicle accidents by about 16%.

Research using the Minnesota Department of Transportation crash database found that the overall crash rate among vehicles without DRL was 1.73 times higher than the rate for vehicles with standard DRL (Minnesota Departments of Public Health and Transportation, 2011).

The incidence rate, including all recorded bicycle accidents with personal injury to the participating cyclist, is 19% lower for cyclists with permanent running lights mounted; indicating that the permanent bicycle running light significantly improves traffic safety for cyclists (Madsen et al., 2013).

By the mid-1980s all automobiles in the U.S. were required to be fitted with central high-mounted brake lights. Vans, sport utility vehicles, and pick-up trucks followed after cars, in 1993. Some early estimates of effectiveness predicted that these high-mounted brake lights would reduce rear-end crashes by as much as 35%, but according to Lee et al. (2002), analysis of crash data indicate that the effectiveness is closer to 4%. This effectiveness offers support for the requirement of vehicles to have a high-mounted stop lamp, as defined in UN Regulation 48.

NHTSA investigated the crash-reduction benefits of light-emitting diode (LED) brake lights and central high-mounted brake lights (Greenwell, 2013). They compared crash rates for models of car which changed to LEDs from incandescent bulbs before and after the change. The main analysis showed a significant overall 3.6% reduction in rear-impact crashes with LED. However, the switch was not beneficial for all models of car investigated and the author also notes that all changes to LED brake lights were accompanied with other changes to the vehicles. This therefore means that the analysis is unable to support a firm conclusion regarding the crash-reduction benefit of LED brake lights.

## References

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| **Title:** | **A worldwide perspective on future automobile lighting** |
| **Published:** | Rumar K (2001)<br>The University of Michigan Transportation Research Institute |
| **Link:**<br><br>**Free/priced:** | http://deepblue.lib.umich.edu/bitstream/handle/2027.42/49452/UMTRI-2001-35.pdf?sequence=1<br><br>Free |
| **Objectives:** | To analyse how our understanding of lighting needs might be affected if the perspective was widened to the entire world, including the developing countries |
| **Methodology:** | Analyses based on the limited information that is available were made of the crash and traffic situations in which automobile lighting plays a critical role and where an improvement in automobile lighting would increase safety. |
| **Key Findings:** | The large number of pedestrians killed in developing countries in night traffic is the major safety difference. This study suggests and evaluates improvements in automobile lighting that would reduce this safety problem in darkness for the world in general and for the developing countries in particular. |
| **Keywords:** | Night traffic, headlights, signal lights, visibility, development, fatalities, pedestrians, developing countries |
| **Comments:** | Impressive list of contributors via the University of Michigan Industry Affiliation Program for Human Factors in Transportation Safety |

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| **Title:** | **16930 Motor lighting systems** |
| **Published:** | Home Office (2010) |
| **Link:**<br><br>**Free/priced:** | https://www.gov.uk/government/publications/16930-motor-lighting-systems<br><br>Free |
| **Objectives:** | - |
| **Methodology:** | In response to a request under the Freedom of Information Act 2000 for information on motor lighting systems. |
| **Key Findings:** | All headlights must comply with European regulations, which are intended to minimise dazzle while maximising visibility. |
| **Keywords:** | Motor lighting systems |
| **Comments:** | The regulations are subject to development and the Department for Transport continues to take an active part in this work, together with experts from other European member states. They seek to ensure that any changes that are made do not have a negative effect on glare. |

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| **Title:** | **Information Sheet – Aftermarket HID Headlamps** |
| **Published:** | Department for Transport (2010) |
| **Link:**<br><br>**Free/priced:** | http://webarchive.nationalarchives.gov.uk/20120606172804/http://assets.dft.gov.uk/publications/dft-information-sheets/aftermarket-hid-headlamps.pdf<br>Free |
| **Objectives:** | To provide general guidance and advice on the legislative requirements in Great Britain relating to aftermarket HID headlamps. |
| **Methodology:** | The information in this document is a summary of DfT's understanding of what the law requires. |
| **Key findings:** | It is not permitted to convert an existing halogen headlamp unit for use with HID bulbs. The entire headlamp unit must be replaced with one designed and approved for use with HID bulbs. |
| **Keywords:** | Aftermarket, HID, Xenon, bulb |
| **Comments:** | As well as its intended purpose, this document is a useful reference source for the GB road vehicle lighting regulations. |

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| **Title:** | **The Road Vehicles Lighting Regulations 1989: Statutory Instrument (S.I.) 1989 No. 1796** |
| **Published:** | (1989)<br>The Office of Public Sector Information (OPSI) |
| **Link:**<br>**Free/priced:** | http://www.legislation.gov.uk/uksi/1989/1796/contents/made<br>Free (electronic), paper copies of Statutory Instruments are available for purchase from The Stationery Office |
| **Objectives:** | |
| **Methodology:** | |
| **Key Findings:** | |
| **Keywords:** | Road traffic regulation |
| **Comments:** | |

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|---|---|
| **Title:** | **The contribution of vehicle headlights to visibility of targets in road lighting environments** |
| **Published:** | Ekrias A, Eloholma M and Halonen L (2008)<br>International Review of Electrical Engineering (IREE), 3 (1) 208-217 |
| **Link:**<br>**Free/priced:** | http://lib.tkk.fi/Diss/2010/isbn9789526030838/article5.pdf<br>Free |
| **Objectives:** | To study the impacts of vehicle headlights on luminance contrasts of targets located on the road. |
| **Methodology:** | Experimental measurements were made on a highway to investigate the contribution of halogen and high-intensity discharge headlights to road lighting. |
| **Key Findings:** | The measurement results indicate that in general, the use of vehicle headlights, in the presence of road lighting, does not improve the luminance contrasts of targets located on the road. |
| **Keywords:** | Road lighting, vehicle headlights, luminance measurement, luminance contrast, target visibility |
| **Comments:** | Demonstration of an assumed feature of vehicle lighting. |

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| **Title:** | **Festival of lights** |
| **Published:** | Max Mueller (2013)<br>Vision zero international, June 2013 |
| **Link:**<br>**Free/priced:** | http://viewer.zmags.com/publication/783832a6#/783832a6/16<br>Free |
| **Objectives:** | A review of recent developments in lighting design. |
| **Methodology:** | Press article written with regard to automotive lighting, sources seem to be conversations with vehicle lighting experts and reviews of forthcoming vehicle releases. |
| **Key Findings:** | Organic and infrared LEDs and holographic laser technology could offer safety benefits in the future. |
| **Keywords:** | Automotive lighting, lights, LED (light-emitting diode), laser technology, safety. |
| **Comments:** | A nice collation of prospective technological ideas. Some may be closer to market than others. |

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| **Title:** | **Motorcycle conspicuity: effects of age and daytime running lights** |
| **Published:** | Smither J A-A and Torrez L I (2010)<br>Human factors: The journal of the human factors and ergonomics society, 2010 (52) 355 |
| **Link:**<br><br>**Free/priced:** | http://hfs.sagepub.com/content/52/3/355<br><br>Priced |
| **Objectives:** | This study investigated variables that may contribute to motorcycle conspicuity within a high-fidelity simulated environment. The variables included motorcycle lighting, vehicular daytime running lights (DRLs), and age of the driver of the other vehicle. |
| **Methodology:** | The 75 participants who took part in this study watched a series of video clips of roadway traffic and were asked to indicate when they saw a hazardous situation, such as the presence of pedestrians, motorcycles, or traffic cones. Both motorcycle and following vehicle lights were manipulated, and participant reaction times were collected and analysed. |
| **Key Findings:** | Overall, findings showed a link between DRLs and the effective detection of motorcycles and suggested that age-related changes affect the ability to detect and respond to a motorcycle effectively. |
| **Keywords:** | Motorcycle conspicuity, vehicular daytime running lights, headlight modulators, motorcycle lighting, following-vehicle lights, aging motorists |
| **Comments:** | |

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| **Title:** | **Safety effects of permanent running lights for bicycles: a controlled experiment** |
| **Published:** | Madsen J C O, Andersen T and Lahrmann H S (2013)<br>Accident analysis and prevention, 50 (2013) 820-829: Elsevier |
| **Link:**<br>**Free/priced:** | http://www.ncbi.nlm.nih.gov/pubmed/22884376<br>Priced |
| **Objectives:** | To examine, if permanent running lights mounted to bicycles would improve traffic safety for cyclists. |
| **Methodology:** | The permanent running lights were mounted to 1845 bicycles and the accident rate was recorded through 12 months for this treatment group and 2000 other bicyclists, the latter serving as a control group without bicycle running lights. The safety effect of the running lights is analysed by comparing incidence rates – number of bicycle accidents recorded per man-month – for the treatment group and the control group. |
| **Key Findings:** | The incidence rate, including all recorded bicycle accidents with personal injury to the participating cyclist, is 19% lower for cyclists with permanent running lights mounted, indicating that the permanent bicycle running light significantly improves traffic safety for cyclists. |
| **Keywords:** | Bicycle running lights, cyclists, safety evaluation, controlled experiment |
| **Comments:** | It is likely that the members of the treatment group were biased in favour of the bicycle running lights, which could have resulted in a likely under-reporting of bicycle accidents from the treatment group. A control for this likely underreporting was performed by using the difference in the reporting of bicycle solo accidents by the treatment group and the control group as a proxy for the likely underreporting. |

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| **Title:** | **Independent study proves life saving potential Xenon car lighting from Philips** |
| **Published:** | Philips (2007)<br>Philips.com |
| **Link:**<br>**Free/priced:** | http://www.newscenter.philips.com/main/standard/about/news/news/20070926_xenon_saves_lives.wpd<br>Free |
| **Objectives:** | Press release following positive study |
| **Methodology:** | Summary of independent study performed by TÜV Rheinland |
| **Key Findings:** | Xenon can reduce road fatalities by 18%, which equals more than 1200 lives a year in Germany alone |
| **Keywords:** | Xenon |

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| **Comments:** | Only press release style summary of the original material |

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| **Title:** | **Spectral effects of LED forward lighting** |
| **Published:** | Van Derlofske J, Bullough J D and Watkinson J (2005)<br>Lighting Research Center, Rensselaer Polytechnic Institute: Troy, N.Y., U.S.A.; Report number TLA2005-02 |
| **Link:**<br><br>**Free/priced:** | http://www.lrc.rpi.edu/programs/transportation/TLA/pdf/TLA-2005-02.pdf<br><br>Free |
| **Objectives:** | To determine the potential advantage on visual performance of light emitting diodes (LEDs) through their spectral power distribution and off-axis target detection. |
| **Methodology:** | Calculations were performed comparing the outputs from LED forward lighting systems and those from high intensity discharge (HID) and tungsten halogen equivalent systems. |
| **Key Findings:** | Most of the LED sources analysed were judged to offer, theoretically, increased off-axis visual performance over current headlamp technology. |
| **Keywords:** | Automotive, LED, headlamp, lamp, peripheral, illumination, visibility |
| **Comments:** | Transportation lighting alliance members: Daimler-Chrysler, General Electric, Hella, Lighting Research Center, Philips, OSRAM SYLVANIA, Visteon |

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| **Title:** | **Nachtfahreignung augen-gesunder personen verschiedener altersstufen**<br>**Night driving capacity of ophthalmologically healthy persons of various ages** |
| **Published:** | Scharwey K, Krzizok T and Herfuth M (1998)<br>Ophthalmologe, 1998 (95) 555-558; Springer-Verlag |
| **Link:**<br>**Free/priced:** | http://www.ncbi.nlm.nih.gov/pubmed/9782732<br>Priced |
| **Objectives:** | To re-examine established limits for twilight vision and glare sensitivity and their relevance to night-time collisions |
| **Methodology:** | A total of 117 normal volunteers between 10 and 79 years of age underwent ophthalmological examinations including measurement of contrast acuity and glare sensitivity by means of the Mesotest II (Oculus, Germany). |
| **Key Findings:** | Contrast acuity and glare sensitivity deteriorate in an age-dependent fashion. Thus, night driving ability decreased with increasing age. |
| **Keywords:** | Night driving, glare sensitivity |
| **Comments:** | Article in German |

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| **Title:** | **Benefits and costs of ultraviolet fluorescent lighting** |
| **Published:** | Lestina D C, Miller T R, Knoblauch R and Nitzburg M (1999) 43rd annual proceedings of the Association for the Advancement of Automotive Medicine (AAAM), 20-21 September 1999, Barcelona (Sitges), Spain: AAAM. |
| **Link:**<br>**Free/priced:** | http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3400228/<br>Priced |
| **Objectives:** | To demonstrate the improvements in detection and recognition distances using fluorescent roadway delineation and auxiliary ultra-violet (UVA) headlights and determine the reduction in crashes needed to recover increased costs of the UVA/fluorescent technology. |
| **Methodology:** | Field study comparisons with and without UVA headlights. Crash types potentially reduced by UVA/fluorescent technology were estimated using annual crash and injury incidence data from the General Estimates System (1995-1996) and the 1996 Fatality Analysis Reporting System. Crash costs were computed based on body region and threat-to-life injury severity. |
| **Key Findings:** | Significant improvements in detection and recognition distances for pedestrian scenarios, ranging from 34% to 117%. A 19% reduction in night time motor vehicle crashes involving pedestrians or pedal-cycles will pay for the additional UVA headlight costs. Alternatively, a 5.5% reduction in all relevant night time crashes will pay for the additional costs of UVA headlights and fluorescent highway paint combined. |
| **Keywords:** | Benefit/cost, UltraViolet fluorescent lighting (UVA), |
| **Comments:** | Seems to build on the field trials of the Federal Highway Administration, adding evidence to the suggestions regarding benefits of auxiliary ultraviolet lights. |

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| **Title:** | **A meta-analysis of studies concerning the safety effects of daytime running lights on cars** |
| **Published:** | Elvik R (1996)<br>Accident Analysis and Prevention, 28 (6) 685-694; Pergamon |
| **Link:**<br>**Free/priced:** | http://www.ncbi.nlm.nih.gov/pubmed/9006637<br>Priced |
| **Objectives:** | A meta-analysis of 17 studies that have evaluated the effects on traffic safety of using daytime running lights (DRL) on cars |
| **Methodology:** | The studies included in the meta-analysis were retrieved by means of literature surveys that were part of previous evaluation studies and by scanning recent reports. A total of 17 studies were included. |
| **Key Findings:** | The intrinsic effect of DRL was found to be very robust with respect to both study design and definition of the dependent variable. The best estimate of the intrinsic effect of DRL on cars is a 10-15% reduction in the number of multi-party daytime accidents. |
| **Keywords:** | Daytime running lights, Evaluation studies, Meta-analysis, Safety effects |
| **Comments:** | All studies of the aggregate effect of DRL are non-experimental before-and-after studies. This study design does not take account of all confounding factors that are likely to be present. |

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| **Title:** | **Effectiveness of daytime motorcycle headlights in the European Union** |
| **Published:** | Bijleveld F D (1997)<br>SWOV Institute for Road Safety Research, The Netherlands; Report number R-97-9 |
| **Link:**<br>**Free/priced:** | http://www.swov.nl/rapport/R-97-09.pdf<br>Free |
| **Objectives:** | A synthesis of the state of the art of the (obligatory) use of daytime running lights by motorcycles in the European Union.<br>In particular attention is directed at Austria, in which country a new law was introduced in 1982 mandating the use of daytime running lights for motorcycles. |
| **Methodology:** | Victim counts were analysed for a number of years under eight conditions. Starting for 1976 through until 1995 counts of fatalities and injuries are available for Austria disaggregated as:<br>• Motorcycle (driver or passenger) versus car (driver or passenger).<br>• Daytime versus night time. Local definition is used to distinguish between night and day. This may differ among countries.<br>• Single accidents versus multiple accidents (against other driving vehicles).<br>As the series is about twenty years long and overall developments are of no interest here, the data were analysed using a Generalised Linear Model. In this case, the SAS procedure GENMOD. |
| **Key Findings:** | It is believed that the measure on daytime running lights in Austria is effective in reducing the number of victims on motorcycles at daytime in accidents involving other vehicles compared with the number of victims in other accidents. A decrease of multiple daytime accidents involving motorcycles of about 16% compared with the pre-law period may be a reasonable, although rather large, estimate based on the results above. |
| **Keywords:** | Motorcycle, dipped headlight, daylight, risk taking, accident rate, prevention, danger, perception, motorcyclist, legislation, analysis (math), statistics, Europe. |
| **Comments:** | Care was taken to avoid an anomalous year, 1980. |

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| **Title:** | **Daytime Running Lights (DRL): a review of the reports from the European Commission** |
| **Published:** | Knight I, Sexton B, Bartlett R, Barlow T, Latham S and McCrae I (2006)<br>TRL Limited, Published Project Report PPR170: Wokingham, UK |
| **Link:**<br><br>**Free/priced:** | https://trl.co.uk/reports/PPR170<br><br>Free |
| **Objectives:** | To carry out a critical review of the research carried out for the EC. |
| **Methodology:** | TRL experts reviewed specific parts of the research reports produced for the EC, comparing with other related research and carrying out a sensitivity analysis on the cost benefit model used. |
| **Key Findings:** | The investigation of the effect of DRL for passenger cars on the conspicuity of vulnerable road users appeared, in general, to be a well-controlled experiment. |
| **Keywords:** | Daytime Running Lights (DRL), review |

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| **Title:** | **Advanced front lighting system – safety improvements at night** |
| **Published:** | Neumann R (2003)<br>Proceedings of the 22nd PIARC World Congress, 19-25 October 2003, Durban, South Africa |
| **Link:**<br>**Free/priced:** | http://trid.trb.org/view.aspx?id=843512<br>Priced |
| **Objectives:** | Evaluate the potential safety benefit of an Advanced Front lighting System (AFS) |
| **Methodology:** | A survey was conducted in which subjects were asked to drive a vehicle along a test track. The subjects passed the test track several times using both, standard Halogen and AFS mode. Along the test track there were various obstacles and the subjects had the task to detect the obstacles and to indicate their recognition by pressing a button, which was placed on the steering wheel. |
| **Key Findings:** | The increase in seeing distance and the time to react when detecting an obstacle demonstrates that AFS will be an appropriate means to increase safety on the road. |
| **Keywords:** | Accident rates, headlamps, improvements, safety, street lighting |

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| **Title:** | **Benefits of applying adaptive lighting to the U.S. and European low-beam patterns** |
| **Published:** | Sivak M, Flannagan M J, Schoettle B and Nakata Y (2001)<br>The University of Michigan Transportation Research Institute, Report Number UMTRI-2001-20 |
| **Link:**<br>**Free/priced:** | http://deepblue.lib.umich.edu/handle/2027.42/49447<br>Free |
| **Objectives:** | To examine the potential benefits of applying two embodiments of adaptive lighting to the U.S. and European low-beam patterns: curve lighting that involves shifting the beam horizontally into the curve, and motorway lighting that involves shifting the beam vertically upward. |
| **Methodology:** | The curve lighting simulations paired 80-m radius left and right curves with a horizontal beam shift of 15°, and 240-m radius curves with a shift of 10°. The motorway lighting simulations involved upward aim shifts of 0.25° and 0.5°. For both curve and motorway lighting, changes in both visibility and glare illuminance were considered. |
| **Key Findings:** | Curve lighting, as simulated here, would substantially improve seeing performance on curves for both types of beams. On U.S. left curves (but not on right curves) there would be an increase in disability glare for oncoming traffic. No major discomfort glare problems would be expected. |
| **Keywords:** | Adaptive lighting, intelligent lighting, AFS, low beams, passing beams, benefits, visibility, seeing, glare, U.S., Europe |
| **Comments:** | Sponsored by the University of Michigan Industry Affiliation Program for Human Factors in Transportation Safety |

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|---|---|
| **Title:** | **Why HID headlights bother older drivers** |
| **Published:** | Mainster and Timberlake (2003)<br>British Journal of Opthalmology, 2003 (87) 113-117 |
| **Link:**<br>**Free/priced:** | http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1771460/pdf/bjo08700113.pdf<br>Free via Road Safety Knowledge Centre |
| **Objectives:** | To offer a perspective on the topic via a review of published material |
| **Methodology:** | Review article |
| **Key Findings:** | Brightness rather than blueness is the primary reason for the visual problems that HID headlights can cause for older drivers who confront them. |
| **Keywords:** | HID headlights, older drivers, glare |
| **Comments:** | An interesting perspective. It would be interesting to see whether the safety benefits offered by the greater illumination outweigh the safety costs caused through glare. |

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| **Title:** | **UN Regulation 99, Uniform provisions concerning the approval of gas-discharge lamp units of power-driven vehicles** |
| **Published:** | United Nations (1995), as amended |
| **Link:**<br>**Free/priced:** | http://www.unece.org/trans/main/wp29/wp29regs41-60.html<br>Free |
| **Objectives:** | |
| **Methodology:** | |
| **Key Findings:** | |
| **Keywords:** | Vehicle, lighting, gas-discharge, lamp units |
| **Comments:** | |

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|---|---|
| **Title:** | **Benefits of intelligent headlamp technologies to pedestrian safety at roundabouts** |
| **Published:** | Bullough J D and Skinner N P (2012)<br>Lighting Research Center, Rensselaer Polytechnic Institute, Troy, N.Y., U.S.A., Report TLA2012-01 |
| **Link:**<br>**Free/priced:** | http://www.lrc.rpi.edu/programs/transportation/TLA/pdf/TLA-2012-01.pdf<br>Free |
| **Objectives:** | A study of the influence of vehicle headlamps and roadway lighting on the ability of drivers to see pedestrians along crosswalks in roundabout intersections |
| **Methodology:** | An outdoor field experiment was conducted to assess observers' ability to detect and identify the walking direction of pedestrian targets in the field of view. |
| **Key Findings:** | The results suggest that vehicle headlamps have a significant role to play in pedestrian detection along roundabout intersections. Systems such as HID headlamps, which produce greater amounts of peripheral illumination can result in shorter identification times for pedestrians. |
| **Keywords:** | Headlamps, roadway lighting, roundabouts, pedestrians, safety |
| **Comments:** | Transportation Lighting Alliance 2012 members: Audi, Automotive lighting, Hella, OSRAM Sylvania, Philips lighting, Visteon |

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|---|---|
| **Title:** | **Optimization of forward lighting: headlamp intensity and visibility along curves** |
| **Published:** | Bullough J D and Van Derlofske J (2005)<br>Lighting Research Center, Rensselaer Polytechnic Institute, Troy, N.Y., U.S.A., Report TLA2005-01 |
| **Link:**<br><br>**Free/priced:** | http://www.lrc.rpi.edu/programs/transportation/TLA/pdf/TLA-2005-01.pdf<br><br>Free |
| **Objectives:** | To measure peripheral visual performance under various headlamp conditions, including conditions typical of halogen and high intensity discharge (HID) headlamps |
| **Methodology:** | A field study simulated an approach of left- and right-hand turns. Target of varying size were located at different locations along the edges of the curves and different headlamp illumination conditions were used. Eleven subjects participated in the study. Reaction times and missed targets were measured. |
| **Key Findings:** | The results were consistent with previously published studies showing a benefit of increased peripheral illumination commonly found in HID headlamps on peripheral detection. |
| **Keywords:** | Automotive, headlamp, lamp, intensity, HID, halogen, targets, peripheral, illumination, visibility, beam, target, field study |
| **Comments:** | |

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| **Title:** | **Benefits of headlamp levelling and cleaning for current U.S. low beams** |
| **Published:** | Flannagan M J, Sivak M and Schoettle B (2007)<br>The University of Michigan Transportation Research Institute, Report UMTRI-2007-46 |
| **Link:**<br><br>**Free/priced:** | http://deepblue.lib.umich.edu/bitstream/handle/2027.42/58733/100247.pdf&lt?sequence=1<br><br>Free |
| **Objectives:** | To examine whether the recent changes in the sharpness of the vertical gradient in U.S. low beams have changed the importance of headlamp levelling and cleaning systems. |
| **Methodology:** | The study consisted of three parts.<br>• In the first part, new data on dynamic distributions of pitch angles for a passenger car, a minivan, and an SUV in traffic were collected.<br>• In the second part, the new dynamic pitch data (combined with recent static pitch data) were applied to representative low-beam patterns to estimate the changes in the benefits of levelling systems. These estimates were made for a comprehensive combination of static and dynamic sources of misaim.<br>Three sets of photometric data were used in the analysis: market-weighted 1997 and 2004 tungsten-halogen beam patterns, and a representative 2004 HID beam pattern.<br>• In the third part, a previously derived model for the effects of dirt was applied to the three beam patterns to estimate the changes in the benefits of cleaning systems.<br>The effects on both visibility and glare were considered. |
| **Key Findings:** | The results indicate that the importance of headlamp levelling systems for U.S. low beams has recently increased substantially with the introduction of tungsten-halogen and especially HID lamps with sharper beam edges than older headlamp designs. |
| **Keywords:** | Headlamps, low beams, levelling, cleaning, visibility, glare |
| **Comments:** | Sponsored by The University of Michigan Industry Affiliation Program for Human Factors in Transportation Safety. |

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| **Title:** | **Recent changes in headlamp illumination directed toward traffic signs** |
| **Published:** | Sivak M, Schoettle B and Flannagan M J (2006)<br>The University of Michigan Transportation Research Institute:<br>Ann Arbor, Michigan,U.S.A. |
| **Link:**<br><br>**Free/priced:** | http://deepblue.lib.umich.edu/bitstream/handle/2027.42/58720/99779.pdf?sequence=1<br><br>Free |
| **Objectives:** | To examine the differences in sign light between 1997 tungsten-halogen and 2004 HID low-beam headlamps manufactured for use on U.S. vehicles |
| **Methodology:** | Combined luminous intensities were calculated for the two lights on the front of a range of vehicles in the US fleet with either halogen or HID lights. These were compared at various viewing distances, sign heights and road layouts to provide an idea of respective sign illumination under those conditions |
| **Key Findings:** | The results indicated that the HIDs tended to deliver less light above the horizontal straight ahead and to the left of the vertical, and less light to the right of the vertical above about 1.5° up.<br>The results imply that with current HID low beams, sign retroreflective efficiency would need to be increased to maintain the effectiveness that a given sign had a decade ago with tungsten-halogen low beams. |
| **Keywords:** | Headlamps, low beams, traffic signs, illumination, trends |
| **Comments:** | It is not clear how this assessment would match with current vehicle lighting designs in Europe. |

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| **Title:** | **Countermeasures for reducing the effects of headlight glare** |
| **Published:** | Mace D, Garvey P, Porter R J, Scwab R and Adrian W (2001)<br>AAA Foundation for Traffic Safety: Washington, D.C., U.S.A. |
| **Link:**<br>**Free/priced:** | https://www.aaafoundation.org/sites/default/files/HeadlightGlare.pdf<br>Free |
| **Objectives:** | This report provides the reader with a working knowledge of glare and the methods used to measure and control glare. It is a rather technical report aimed at engineers and experts in lighting and traffic safety. |
| **Methodology:** | Review of literature related to glare and countermeasures to reduce glare whilst driving |
| **Key Findings:** | Although HID lamps offer an enormous increase in visibility, they can also result in a comparable increase in glare. |

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| **Keywords:** | Headlight glare, countermeasures, HID |

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| **Title:** | **Relation between glare and driving performance** |
| **Published:** | Theeuwes J, Alferdinck W A M, Perel M (2002)<br>Human Factors, 44 (1) 95-107; Human Factors and Ergonomics Society |
| **Link:**<br>**Free/priced:** | http://ems.psy.vu.nl/userpages/theeuwes/95.pdf<br>Free |
| **Objectives:** | To investigate the effects of discomfort glare on driving behaviour |
| **Methodology:** | Participants in the study drove an instrumented vehicle with a simulated light source mounted on the hood along an experimental stretch consisting of urban, rural, and highway roads. The light source on the hood was either off (control condition), or had one of three glare intensities: one corresponding to just admissible discomfort glare, one similar to the European beam, and one close to the U. S. beam (Economic Commission of Europe, 1976; Federal Motor Vehicle Safety Standard, 1991).<br>Driving behaviour in terms of speed and steering wheel reversal and the detection distance of particular objects was determined. |
| **Key Findings:** | The results show that the relatively low glare source caused a significant drop in detecting simulated pedestrians along the roadside.<br>Older participants showed the largest drop in pedestrian detection performance and reduced their driving speed the most.<br>The deBoer rating scale, the most commonly used rating scale for discomfort glare, is practically useless as a predictor of driving performance. |
| **Keywords:** | Glare, driving performance |
| **Comments:** | 24 participants. |

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| **Title:** | **The immediate effects of glare and electrochromic glare-reducing mirrors in simulated truck driving** |
| **Published:** | Ranney T A, Simmons L A and Masalonis A J (2000)<br>Human Factors, 42 (2) 337-347; Human Factors and Ergonomics Society |
| **Link:**<br>**Free/priced:** | http://www.ncbi.nlm.nih.gov/pubmed/11022889<br>Priced |
| **Objectives:** | To extend the previous findings of driving impairment from glare to incorporate more varied driving tasks |
| **Methodology:** | A fixed-base driving simulator was used to replicate the essentials of driving in a medium-size heavy truck. The participants were 12 men aged 31 to 53 years.<br>To simulate following-vehicle headlights, light sources with computer-controlled shutters were positioned on each side of the driver so that a light beam was directed into each mirror.<br>The driving task combined two target detection tasks with vehicle control on straight and curved roadway segments. |
| **Key Findings:** | Evidence was found of impaired driving performance in the presence of glare in both target detection and vehicle control.<br>There was only meagre evidence that electrochromic glare reduction improved target detection performance, and no evidence that glare reduction improved vehicle control, despite the fact that participants consistently voiced positive preferences for the glare reduction in exit interviews. |
| **Keywords:** | Glare, glare-reducing mirrors, simulated driving |
| **Comments:** | Twelve experienced truck drivers drove a fixed-base driving simulator for three eight hour sessions under simulated night time driving conditions. |

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| **Title:** | **Discomfort and disability glare from Halogen and HID headlamp systems** |
| **Published:** | Bullough J D, Fu Z, van Derlofske J (2002)[a]<br>SAE World Congress, 4-7 March 2002: Society of Automotive Engineers, Inc. (SAE), SAE technical paper 2002-01-0010 |
| **Link:**<br><br>**Free/priced:** | http://nlpip.org/programs/transportation/pdf/SAE/2002-01-0010.pdf<br><br>Free |
| **Objectives:** | A series of experimental investigations using halogen, HID, and blue-filtered halogen illumination to measure their relative impact on discomfort glare and disability glare under conditions matching those that might be experienced by oncoming drivers at night. |
| **Methodology:** | Two experiments were conducted to measure subjective responses and measures of visual performance under three different types of headlamps.<br>Discomfort glare was determined using the scale devised by de Boer; and disability glare by measuring subjects' contrast sensitivity under different lighting conditions. |
| **Key Findings:** | The HID glare source resulted in consistently lower (more glaring) De Boer ratings than the halogen and blue-filtered halogen at all luminance levels, and the halogen glare source had the highest (least glaring) ratings.<br>The results of the disability glare study, in terms of threshold contrast under the various glare conditions show an effect of illuminance and of viewing angle for the glare source. A within-subjects analysis of variance found both of these to be significant main effects ($p<0.01$). Unlike the results of the discomfort glare study, the effect of lamp type was not significant ($p>0.05$). |
| **Keywords:** | Discomfort, disability, glare, Halogen, HID (high intensity discharge), headlamp systems |
| **Comments:** | |

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| **Title:** | **A safety evaluation of UVA vehicle headlights** |
| **Published:** | U.S. Department of Transportation, Federal Highway Administration (1999) |
| **Link:**<br><br>**Free/priced:** | http://www.fhwa.dot.gov/publications/research/safety/99079/field.cfm<br><br>Free |
| **Objectives:** | To determine the effectiveness of ultraviolet headlamp technology in the context of forward visibility studies |
| **Methodology:** | A field evaluation of ultraviolet (UVA) headlamps and fluorescent traffic control devices (TCDs) involved eight experimental procedures. The procedures were conducted on a closed series of roadways and involved objective and subjective methods. The visibility of roadway delineation and staged roadway scenes depicting pedestrians, bicycles, and disabled vehicles was compared using standard U.S. headlights, European specification headlights, and UVA headlights. |
| **Key Findings:** | The UVA headlights outperformed the U.S. headlights for all roadway delineation scenarios. With the UVA headlights, the edge line was visible 28.9 m, or 14.46%, farther away than with the U.S. headlights. The centerline with the UVA headlights was visible 27.67 m, or 49.35%, farther away. Both of these differences are highly significant.<br><br>Improvements in recognition distances were dramatic in three of the four scenarios. Although the more visually complex disabled vehicle scene was recognized 32.84 m sooner with the U.S. headlights compared to the UVA headlights, this was not statistically significant. The detection distance differences demonstrate that UVA/fluorescent technology does not work as well in some situations as it does in others.<br><br>Apparently, the dramatic increases in detection and recognition distances associated with the UVA headlights do not translate to a measurable change in the driver performance measures examined. This was probably because the relatively new delineation in combination with any of the headlights tested was more than adequate to optimize driver speed maintenance and lane tracking.<br><br>Analysis for possible interactions between age and headlight condition (U.S./UVA) found no significant difference. Thus, UVA headlights helped younger drivers and older drivers equally. |
| **Keywords:** | UltraViolet (UVA) headlamps |

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| **Comments:** | |

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| **Title:** | **CLS-Class – Coupé and Shooting Brake brochure** |
| **Published:** | Mercedes-Benz (2013) |
| **Link:**<br><br><br><br>**Free/priced:** | http://www2.mercedes-benz.co.uk/content/media_library/unitedkingdom/mpc_unitedkingdom/passenger_cars_ng/pdfs/e-brochures/cls-class-coupe.pdf<br><br>Free |
| **Objectives:** | Brochure for the latest CLS-Class |
| **Methodology:** | Product description |
| **Key Findings:** | |
| **Keywords:** | |
| **Comments:** | Available from the Mercedes-Benz internet site |

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| **Title:** | **Automotive forward lighting with use of high flux white Light-Emitting-Diodes** |
| **Published:** | Hsu J-T and Wang W-L (2006)<br><br>Society of Automotive Engineers, Inc. (SAE); SAE International 2005: 2006-01-0104. |
| **Link:**<br><br><br><br>**Free/priced:** | http://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&frm=1&source=web&cd=1&ved=0CC0QFjAA&url=http%3A%2F%2Fwww.artc.org.tw%2Fchinese%2F03_service%2Fdown.aspx%3Ffile_name%3Dtw_knowledge_IA-95-0013.pdf%26file_value%3D3&ei=3HmLUtL1Jeid0AWb64DYCg&usg=AFQjCNGRp5DtWS8fEVmxsDaV0i-MKRJxzg&sig2=bQzNJIn11ztQoXQdqJ95_Q<br><br>Free |
| **Objectives:** | Design of a LED headlamp with AFS function |
| **Methodology:** | Design, simulation, experimentation, demonstration and consideration of potential applications |
| **Key Findings:** | The results showed that the accurate positioning of the optical components is very important and that with the restrictions of the LED luminance available at that time, the AFS functional requirements could not be met.<br><br>However, the authors conclude that in the near future LED headlamp will be used on vehicles everywhere. |
| **Keywords:** | Automotive lighting, Forward lighting, Advanced Front lighting System (AFS), Light-Emitting-Diodes (LEDs) |
| **Comments:** | We are now entering the next generation of headlamp design that the authors identify in their conclusions, where LED |

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| | technology has moved on to make this application realistic. |

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| **Title:** | **Difference in geometry of pedestrian crashes in daylight and darkness** |
| **Published:** | Sullivan J M and Flannagan M J (2011)<br>Journal of Safety Research, 42 (2011) 33-37: Elsevier |
| **Link:**<br>**Free/priced:** | http://www.ncbi.nlm.nih.gov/pubmed/21392627<br>Priced |
| **Objectives:** | To provide information about how details of pedestrian crashes may differ between daylight and darkness |
| **Methodology:** | All pedestrian crashes that occurred in daylight or dark conditions in Michigan during 2004 were analysed in terms of the variables included in the State of Michigan crash database.<br>Additional analysis of the narratives and diagrams in police accident reports was performed for a subset of 400 of those crashes – 200 sampled from daylight and 200 sampled from darkness |
| **Key Findings:** | The results provide some preliminary quantification of the how the differences between the right and left sides of typical headlamps may affect pedestrian crash risk. This provides some supporting evidence of the benefit of advanced frontal lighting systems which offer additional illumination during turns. |
| **Keywords:** | Pedestrian collisions, visibility, conspicuity, night-time, light distribution, approach path |

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| **Title:** | **Light has to go where it is needed: future light based driver assistance systems** |
| **Published:** | Könning T, Amsel C and Hoffmann I (no date) |
| **Link:**<br>**Free/priced:** | http://media1.mypage.cz/files/media1:4aae40a7dffe1.pdf.upl/P1.4_079_Koenning_Thomas_Hella.pdf<br>Free |
| **Objectives:** | Product description of Adaptive Cut-off Line System |
| **Methodology:** | Written by authors from Hella |
| **Key Findings:** | Future light based driver assistance systems do not only adapt the light distribution automatically to the street and weather conditions, furthermore, those systems adapt its lighting distributions to the actual traffic situation. Those systems are based upon the interaction of CMOS image sensors with an image processing unit and state-of-the-art lighting technology. |
| **Keywords:** | Driver assistance systems, Lighting systems, Light based driver assistance systems, camera technology, Image |

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| | processing technology |
| **Comments:** | Not certain of the reference for this document. Difficult to place temporally. |

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| **Title:** | **High beam assist** |
| **Published:** | Volkswagen (2013) |
| **Link:**<br><br>**Free/priced:** | http://www.volkswagen.co.uk/technology/comfort-and-convenience/high-beam-assist<br><br>Free |
| **Objectives:** | Describing the technological feature available on Volkswagens |
| **Methodology:** | |
| **Key Findings:** | High Beam Assist dips your high beam automatically to improve driver control and safety for both the driver and other road users. |
| **Keywords:** | High beam, dipping, control, safety |
| **Comments:** | Available as an option on the Golf Mk. VII |

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| **Title:** | **BMW Night Vision with Dynamic Light Spot** |
| **Published:** | BMW (2013) |
| **Link:**<br><br>**Free/priced:** | http://www.bmw.co.uk/en_GB/new-vehicles/5/saloon/2013/driverassistance.html<br><br>Free |
| **Objectives:** | Document the features available on the 5-Series |
| **Methodology:** | Product description |
| **Key Findings:** | Dynamic Light Spot is an option on production vehicles. |
| **Keywords:** | Night vision, Dynamic Light Spot, pedestrian, animal, |
| **Comments:** | |

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| **Title:** | **Daytime running lights: a closer look at their justification for Australia** |
| **Published:** | Symmons M A (2009)<br>ATRF 2009: 32nd Australasian Transport Research Forum: the growth engine: interconnecting transport performance, the economy and the environment: 29 September-1 October 2009, Auckland, New Zealand |
| **Link:**<br>**Free/priced:** | http://trid.trb.org/view.aspx?id=914641<br>Priced |
| **Objectives:** | To assess the potential benefit in accident reductions or mitigation through the adoption of daytime running lights in Australia. |
| **Methodology:** | Treating Victoria as a case study, a road crash database is analysed for crashes that might be averted or reduced in severity through implementation of daytime running lights. Further, meteorology data is used to eliminate crashes that occur during hours of darkness and twilight, times during which drivers are likely to have turned their lights on anyway. |
| **Key Findings:** | Applying the 5.9 % reduction in accidents, across all severities (taken from Knight et al., 2006), the Victoria data result in an average prevention of 212 crashes through the adoption of daytime running lights. |
| **Keywords:** | Daytime running lights, Australia, |
| **Comments:** | Effectiveness estimates taken from previous sources such as Knight et al. (2006) |

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| **Title:** | **Daytime running lights as a vehicle collision countermeasure: The Swedish evidence reconsidered** |
| **Published:** | Theeuwes J and Riemersma J (1995)<br>Accident Analysis and Prevention, 27 (5) 633-642; Pergamon © Elsevier Science Ltd. |
| **Link:**<br>**Free/priced:** | http://www.ncbi.nlm.nih.gov/pubmed/8579694<br>Priced |
| **Objectives:** | To re-examine the evidence from Sweden regarding the effectiveness of daytime running lights on multiple collision reductions |
| **Methodology:** | The authors show that in the original analysis a peculiarity in the pre-intervention data may have caused an unsupported overestimation of the baseline number of collisions. The workings are repeated with adjustments for this anomaly. |
| **Key Findings:** | None of the methods used provided solid evidence for the effect of daytime running lights on accidents with bicyclists or pedestrians. This was due to a lack of independent measures of exposure. |
| **Keywords:** | Daytime running lights (DRL), vehicle collision |

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| | countermeasure, Sweden, accidents |

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| **Title:** | **The effectiveness of Daytime Running Lights for passenger vehicles** |
| **Published:** | Wang J-S (2008)<br>U.S. Department of Transportation, National Highway Traffic Safety Administration (NHTSA): Washington, D.C., U.S.A.; Report number DOT HS 811 029 |
| **Link:**<br>**Free/priced:** | http://www-nrd.nhtsa.dot.gov/Pubs/811029.pdf<br>Free |
| **Objectives:** | To evaluate the effects of daytime running lights (DRLs) against three types of target crashes:<br>1. Two-passenger vehicle crashes excluding rear-end crashes<br>2. Single-passenger vehicle to pedestrians/cyclists crashes<br>3. Single-passenger vehicle to motorcycle crashes. |
| **Methodology:** | Each crash type was examined at three crash severity levels – fatal, injury, and all severity. The basic approach was a control-comparison analysis of real-world crash involvements for DRL-equipped vehicles and non-DRL vehicles. Ratio of odds ratios were used to derive the DRL effects and a 95-percent confidence interval was used to infer statistically significant conclusions. The Fatality Analysis Reporting System (FARS) and the State Data System were the crash data sources used for this analysis. |
| **Key Findings:** | The analysis found that DRLs have no statistically significant overall effects on the three target crashes. When combining these three target crashes into one target crash, the DRL effects were also not statistically significant. |
| **Keywords:** | NHTSA, FARS, State data, daytime running lights, DRL, ratio of odds ratios, simple odds, statistical analysis. |
| **Comments:** | The summary of results shows the trends identified. These are not reported in the abstract summary due to the lack of significance at the 95 percent level. |

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| **Title:** | **Study of mandatory 24-hour vehicle lighting** |
| **Published:** | Minnesota Department of Public Safety and Minnesota Department of Transportation (2011) |
| **Link:**<br><br>**Free/priced:** | http://www.dot.state.mn.us/govrel/reports/2011/dlr/24hr_vehicle_lighting_011811_PDF.pdf<br><br>Free |
| **Objectives:** | Summarise the most recent studies regarding daytime running lights and 24-hour use of low-beam headlights |
| **Methodology:** | Synthesis of other research studies |
| **Key Findings:** | Research suggests a potential reduction in crashes involving daytime multiple-vehicle crashes, especially head-on and front-corner collisions, with the 24-hour use of low-beam headlights. Additionally, the research suggests potential crash reduction benefits involving bicycles, pedestrians and motorcycles. The research doesn't demonstrate increases in crashes of any type.<br><br>Studies tend to agree that the environmental impact of DRL use or of 24-hour headlight use is relatively small, and is a relatively small portion of overall annual vehicle costs. Overall the major studies show that requiring daytime headlight use in vehicles not equipped with automatic DRL would likely have a positive benefit-cost ratio and a measurable impact on reducing crashes, injuries and deaths on Minnesota roadways. |
| **Keywords:** | Implementation, daytime running lights (DRL), 24-hour headlight use, crash prevention, motorcycle, bicycle, pedestrian, environmental consequences |
| **Comments:** | A useful summary document. |

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| **Title:** | **The effects of motor vehicle fleet Daytime Running Lights (DRL) on motorcycle conspicuity** |
| **Published:** | Pierowicz J, Gawron V, Wilson G and Bisantz A (2011) U.S. Department of Transportation, National Highway Traffic Safety Administration (NHTSA): Washington, D.C., U.S.A.; Report number DOT HS 811 504 |
| **Link:**<br><br><br><br><br><br>**Free/priced:** | http://www.nhtsa.gov/Research/Human+Factors/Vehicle+conspicuity<br>http://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&frm=1&source=web&cd=1&ved=0CD4QFjAA&url=http%3A%2F%2Fwww.nhtsa.gov%2FDOT%2FNHTSA%2FNVS%2FCrash%2520Avoidance%2FTechnical%2520Publications%2F2011%2F811504.pdf&ei=QYGYUtKxBYSzhAf8jYGIDg&usg=AFQjCNGuWSdrVnoBhTTJzmxZimTS6ObccA&sig2=YZyu3kupl_lP6dEHIyDNVw&bvm=bv.57155469,d.ZG4<br>Free |
| **Objectives:** | To evaluate the effects of motorcycle conspicuity treatments on other drivers' left turn gap acceptance. For the U.S. situation, a left-turn means to the offside, crossing the oncoming flow of traffic |
| **Methodology:** | In Phase 1, a test track study measured participants' left turn gap judgment as a function of motorcycle DRL treatments. This study was designed to determine which treatments yielded the largest gaps, thereby making that treatment a good candidate for the on-road portion. No treatment was clearly better, so lighting systems currently in use on motorcycles were selected for the on-road study.<br><br>In Phase 2, an on-road study measured gap acceptance, then followed up with intercept surveys of observed drivers. This phase included data collection in the United States (low fleet DRL use) and Canada (high fleet DRL use) in order to evaluate the effect of DRL use in the vehicle fleet. |
| **Key Findings:** | The treatments: Reduced Intensity Upper Beam, Driving Lights with Lower Beam, and Modulating Lower Beam showed no benefit in gap acceptance during the track trials.<br><br>Canadian drivers provided longer gaps than American drivers in the baseline conditions. Although, among Canadian drivers, there were no differences between gaps provided to motorcycles and those provided to other traffic.<br><br>The current data did not allow the authors to determine whether gaps afforded to passenger vehicles with and without DRL were different or not. |
| **Keywords:** | Motorcycle conspicuity, Daytime Running Lights, DRL |
| **Comments:** | Unfortunately, several null results. |

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| **Title:** | **Automatic Headlamp On** |
| **Published:** | ACEM (Association des Constructeurs Européens de Motocycles; no date provided) |
| **Link:**<br><br>**Free/priced:** | http://www.acem.eu/index.php/policy-access/safety/conspicuity/qautomatic-headlamp-onq<br>Free |
| **Objectives:** | Press release |
| **Methodology:** | Statements regarding the safety-related commitments of the ACEM |
| **Key Findings:** | ACEM committed themselves to equip all their models including mopeds with Automatic Headlamp-On (AHO) since 2003. |
| **Keywords:** | Automatic Headlamp On, AHO |

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| **Title:** | **Motorcycle Conspicuity and the effect of fleet DRL: Analysis of two-vehicle fatal crashes in Canada and the United States 2001-2007** |
| **Published:** | Jenness J W, Jenkins F and Zador P (2011)[a]<br>U.S. Department of Transportation, National Highway Traffic Safety Administration (NHTSA): Washington, D.C., U.S.A.; Report number DOT HS 811 505 |
| **Link:**<br><br><br><br>**Free/priced:** | http://www.nhtsa.gov/Research/Human+Factors/Vehicle+conspicuity<br><br>http://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&frm=1&source=web&cd=1&ved=0CC8QFjAA&url=http%3A%2F%2Fwww.nhtsa.gov%2FDOT%2FNHTSA%2FNVS%2FCrash%2520Avoidance%2FTechnical%2520Publications%2F2011%2F811505.pdf&ei=vIGYUu_cAdGVhQeRwYHQCw&usg=AFQjCNGSqjusGFaHqgUErQkdrE4zYHUctg&sig2=qoO5CgsufbHK5F0U5yeZbQ&bvm=bv.57155469,d.ZG4<br>Free |
| **Objectives:** | To examine the Fleet DRL Hypothesis that widespread use of daytime running lights (DRL) among the motor vehicle fleet is associated with an increased risk for certain types of multi-vehicle motorcycle crashes. |
| **Methodology:** | Crash data from the Fatality Analysis Reporting System (FARS) for the period of 2001 – 2007 were compared to fatal crash data from the Canadian National Collision Data Base (NCDB) for the same years. Crash scenarios that were plausibly relevant to frontal conspicuity of the involved vehicles were defined as DRL-relevant. The proportion of DRL-relevant crashes was modelled by country, year, and whether the crash involved a motorcycle. Separate models we applied for crash data that occurred in four groups defined by time of day (Day, Night) and location (Rural, Urban) of the crash. |
| **Key Findings:** | The results supported seven of ten predictions indicating that the Fleet DRL Hypothesis may be true for urban roadways (but may not be true for rural roadways). |
| **Keywords:** | |

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| **Comments:** | The conclusion from this study is subject to some limitations of the data and analysis and should be interpreted cautiously. |

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| **Title:** | **Errors in judging the approach rate of motorcycles in nighttime conditions and the effect of an improved lighting configuration** |
| **Published:** | Gould M, Poulter D R, Helman S and Wann J P (2012)[a]<br>Accident Analysis and Prevention, 45 (2012) 432-437: Elsevier. |
| **Link:**<br>**Free/priced:** | http://www.ncbi.nlm.nih.gov/pubmed/22269527<br>Priced |
| **Objectives:** | To explore drivers' abilities to make judgments of motorcycles and car approach speeds in night time driving conditions, when only the headlights are visible, as well as the effectiveness of a tri-headlight configuration on the accuracy of motorcycle speed judgments. |
| **Methodology:** | A sample of 13 participants was subjected to visual stimuli. The stimuli were presented on a 34 cm × 27 cm Cathode Ray Tube monitor display (1024 × 768 pixels). In this instance, participants were asked to indicate which of two visual stimuli presented sequentially was travelling at the fastest speed. The appropriate car stimulus was used as a reference vehicle in all trials, travelling towards the observation point at a fixed speed of 30 mph (13.4 m/s). |
| **Key Findings:** | Individuals were significantly more accurate at judging the speed of two car headlights compared with the standard solo headlight motorcycle. However, the inclusion of a tri-headlight formation on a standard motorcycle frame significantly improved these judgments.<br>A further investigation demonstrated that tri-headlight configurations with separation between headlights on the horizontal and vertical axes are most effective for yielding accurate speed judgments. |
| **Keywords:** | Perception, vision, looming, tau, motorcycle, conspicuity |
| **Comments:** | As noted by the authors, "The extent to which observers struggle to accurately judge motorcycle speed based on a solo headlight in night time conditions is rather alarming." |

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| **Title:** | **Judgments of approach speed for motorcycles across different lighting levels and the effect of an improved tri-headlight configuration** |
| **Published:** | Gould M, Poulter D R, Helman S and Wann J P (2012)[a]<br>Accident Analysis and Prevention, 48 (2012) 341-345: Elsevier. |
| **Link:**<br>**Free/priced:** | http://www.ncbi.nlm.nih.gov/pubmed/22664699<br>Priced |
| **Objectives:** | To investigate drivers' judgments of motorcycle and car approach speeds across a number of levels of luminance within a virtual city scene, as well as the effectiveness of a tri-headlight formation on motorcycle speed judgments. |
| **Methodology:** | A sample of 14 participants was subjected to visual stimuli. The stimuli were presented on a 34 cm × 27 cm Cathode Ray Tube monitor display (1024 × 768 pixels). In this instance, participants were asked to indicate which of two visual stimuli presented sequentially was travelling at the fastest speed. The vehicle stimuli were presented in a virtual urban city environment and travelled along the road surface towards the observation point. The ambient light levels were adjusted within the virtual scene to simulate five different daylight conditions (daylight, lower daylight, dusk, early evening and night). |
| **Key Findings:** | The study examined how accurately individuals are able to judge the speed of motorcycles and cars across a number of different ambient light level conditions. The results demonstrate that the accuracy of individuals' judgments remained constant across all lighting levels for the car stimulus. However, participant estimations of the solo headlight motorcycle speed became significantly less accurate in the degraded lighting levels of the early night and night-time conditions.<br>Increasing motorcycle headlight separation is one way of maintaining the visible width of the vehicle as night falls, and the addition of the tri-headlight formation considerably reduced the degradation in speed judgments under lower light conditions in this experiment. |
| **Keywords:** | Perception, vision, looming, tau, motorcycle, conspicuity |
| **Comments:** | |

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| **Title:** | **Improving car drivers' perception of motorcyclists through innovative headlight configurations** |
| **Published:** | Cavallo V, Ranchet M, Pinto M, Espié S, Vienne F and Dang N-T (2013)<br>10th International Symposium on Automotive Lighting (ISAL), 25 September 2013, Germany |
| **Link:**<br>**Free/priced:** | http://hal.archives-ouvertes.fr/hal-00866062<br>Free |
| **Objectives:** | To evaluate three innovative headlight configurations that accentuated the vertical and horizontal dimensions of the motorcycle. |
| **Methodology:** | The study was conducted on a small-scale interactive driving simulator, comprising control devices as well as visual and auditory rendition systems. The target vehicles were motorcycles equipped with different headlight configurations as well as cars, vans and trucks. Four motorcycle headlight configurations were used: "standard" (one central headlight), "horizontal" (one central light + 2 lights on the ends of the handlebar), "vertical" (one central headlight + one light on the helmet and 2 lights on the fork), "combined" (combining the horizontal and vertical configurations).<br>The gaps adopted by the drivers in a left-turn situation towards motorcycles equipped with these light configurations were compared with those adopted when facing a motorcycle with a standard headlight or a car. The first experiment was dedicated to night time conditions, and the second experiment to dusk and daytime conditions. |
| **Key Findings:** | Analysis of variance for the night time experiment indicated a significant main effect of headlight configuration and vehicle type, with longer accepted gaps for the vertical and combined configurations than for the standard and horizontal configurations.<br>However, for the daytime conditions, statistical analysis revealed no effect of headlight design on accepted gaps which were found to be similar for all motorcycles, whatever their headlight configuration. |
| **Keywords:** | Perception, motorcyclists, headlight configurations |
| **Comments:** | |

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| **Title:** | **Motorcycle Conspicuity and the effect of auxiliary forward lighting** |
| **Published:** | Jenness J W, Huey R W, McCloskey S, Singer J, Walrath J, Lubar E and Lerner N D (2011)[b]<br>U.S. Department of Transportation, National Highway Traffic Safety Administration (NHTSA): Washington, D.C., U.S.A.; Report number DOT HS 811 507 |
| **Link:**<br><br><br><br><br><br><br><br>**Free/priced:** | http://www.nhtsa.gov/Research/Human+Factors/Vehicle+conspicuity<br>http://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&frm=1&source=web&cd=1&ved=0CC8QFjAA&url=http%3A%2F%2Fwww.nhtsa.gov%2FDOT%2FNHTSA%2FNVS%2FCrash%2520Avoidance%2FTechnical%2520Publications%2F2011%2F811507.pdf&ei=RIKYUs2oO8rX7AaDkYDgDA&usg=AFQjCNFNmDOATWtXCxNlBKBr1JlGMM9ELg&sig2=2FDRxGmGu3gSPo_9p6hYmg&bvm=bv.57155469,d.ZGU<br>Free |
| **Objectives:** | To determine whether the conspicuity of approaching motorcycles viewed in daylight may be improved by various forward lighting treatments |
| **Methodology:** | A field experiment was conducted with 32 participants. The treatments tested included pairs of low-mounted auxiliary lamps (LA), high-mounted auxiliary lamps (HA), both high- and low-mounted auxiliary lamps (LHA), low-mounted LED lamps (LED), and a modulated high beam headlamp (MHB). Participants viewed approaching traffic and indicated when it would be safe (and not safe) to initiate a left turn across the path of approaching vehicles in an opposing lane of traffic. They were not informed that the specific purpose of the study was to examine their reactions to motorcycles. |
| **Key Findings:** | The mean safety margin provided to an approaching motorcycle with various lighting treatments did not differ significantly between any of the experimental lighting treatments and the baseline treatment (illuminated low beam headlamp). However, having either LA or MHB lamps on the motorcycle significantly reduced the probability of obtaining a short safety margin (< 3.44 seconds) as compared to the baseline lighting treatment.<br><br>Overall the results suggest that enhancing the frontal conspicuity of motorcycles with lighting treatments beyond an illuminated low beam headlamp may be an effective countermeasure for daytime crashes involving right-of-way violations. |
| **Keywords:** | Motorcycle, conspicuity, headlamps, lighting |
| **Comments:** | As noted by the authors, these results should be interpreted cautiously in light of differences that were observed between participants. |

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| **Title:** | **Effects of sweeping, color and luminance distribution on response to automotive stop lamps** |
| **Published:** | Bullough J D, Yan H, Van Derlofske J (2002)[b]<br>Society of Automotive Engineers, Inc. (SAE); SAE 2002 World Congress: Detroit Michigan, U.S.A., 4-7 March 2002. |
| **Link:**<br><br>**Free/priced:** | Reprinted From: Advanced Lighting Technology for Vehicles (SP–1668)<br>http://papers.sae.org/2002-01-0911/<br>Available for purchase from SAE |
| **Objectives:** | Quantifying the relative impact of colour and luminance distribution on visual response of stop lamps. |
| **Methodology:** | A total of 24 adults between the ages of 23 and 60 years participated as subjects. During the experiment, subjects continuously performed a task tracking arrays of red and yellow LEDs whilst holding down a small switch on the control box. When they detected the onset of the brake light in their peripheral vision, they were instructed to release the switch as quickly as possible, and then to re-press the switch. |
| **Key Findings:** | The data presented here add to the possibility that the luminance distribution of a high-mounted central brake light is an important factor in the resulting visual response. Even though the neon and the LED had similar dominant wavelengths and provided nearly the same luminous intensity, reaction times to the neon light were consistently and significantly longer than to the LED.<br>It appears that an array of small point sources can be more effective than an equivalent (here, equivalence is defined in terms of luminous intensity in the forward direction) diffuse source at eliciting rapid visual responses. |
| **Keywords:** | Colour and luminance, automotive stop lamps, brake lights |
| **Comments:** | Building on previous research by these authors and others. |

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| **Title:** | **Study of present-day LED brightness and corresponding rear signalling concepts (LED optimization)** |
| **Published:** | NHTSA (National Highway Traffic Safety Administration, 2009)<br><br>U.S. Department of Transportation, National Highway Traffic Safety Administration (NHTSA): Washington, D.C., U.S.A.; Report number DOT HS 811 128 |
| **Link:**<br><br><br><br><br><br><br><br><br><br>**Free/priced:** | http://www.nhtsa.gov/Research/Human+Factors/Rear+signaling<br><br>http://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&frm=1&source=web&cd=1&ved=0CC8QFjAA&url=http%3A%2F%2Fwww.nhtsa.gov%2FDOT%2FNHTSA%2FNVS%2FHuman%2520Factors%2FVisibility%2520and%2520Lighting%2FTSF811128.pdf&ei=ZYKYUrWhK4ajhgeX-oCAAw&usg=AFQjCNEMCCnoDz9Dc8FVFBWwaZGJjIS9ng&sig2=2xyKSFpyBXoJSQNStWsZgQ&bvm=bv.57155469,d.ZG4<br><br>Free |
| **Objectives:** | To develop optimised rear brake lighting signal configurations using present-day lighting assemblies, but with LED (light-emitting diode) technology. |
| **Methodology:** | Work under this study included a laboratory component to quantify the brightness levels of various LED lamps, and a data collection component using human participants intended to determine optimum flash frequencies, brightness levels, and signal patterns (e.g., simultaneous versus alternating flashing). |
| **Key Findings:** | Compared with the results of earlier tests of enhanced rear signals with very high brightness levels (1376 cd), the LED assemblies evaluated here are much below this. However, it should be possible to compete favourably with the incandescent units (at least, on axis) by using multiple units.<br><br>One important finding is that the optimum flash frequencies for LED-enhanced brake signal lights are slightly higher than for incandescent lamps. This appears to occur because there is no trade-off of desired frequency and rise/fall times for LEDs, which are relatively instantaneous.<br><br>This research demonstrated that flashing all lights simultaneously or alternately flashing is a promising signal for use in enhanced brake light applications. |
| **Keywords:** | LED (light-emitting diode), brightness, attention getting, rear signalling, brake lights. |
| **Comments:** | Traffic safety facts release from NHTSA's Vehicle Safety |

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| | Research |

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| **Title:** | **An evaluation of the impact of daytime running lights on traffic safety in Canada** |
| **Published:** | Tofflemire T C and Whitehead P C (1997)<br>Journal of Safety Research, 28 (4) 257-272; Pergamon © National Safety Council and Elsevier Science Ltd. |
| **Link:**<br><br>**Free/priced:** | http://www.sciencedirect.com/science/article/pii/S002243759700011X<br><br>Priced |
| **Objectives:** | Evaluate the impact of daytime running light (DRL) legislation on the incidence of angle and opposing collisions for 1989 cars and 1990 cars in the 1991 calendar year |
| **Methodology:** | This study uses a comparative posttest design, using a virtually equivalent comparison group and comparison conditions. The incidence of collisions was compared for cars with DRL and cars without DRL in the same year.<br>Opposing collisions were head-on and side-swipe where the two vehicles are travelling in opposite directions. Angle collisions included all types of turning collisions and crossing collisions. |
| **Key Findings:** | Target collisions are reduced by a modest but statistically significant 5.3 %.<br>Making up this total value; the incidence of head collisions was lower for DRL cars than for no DRL cars by 15.0 %, whereas, the incidence of angle collisions displayed only a 2.5 % reduction which was not significant at the 5 % level. |
| **Keywords:** | |
| **Comments:** | Whilst the number of vehicles registered in 1989 was available, the figure for 1988 had to be obtained from extrapolation. There is an assumption that the use of 1989 vehicles is identical to the use of 1990 vehicles. |

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| **Title:** | **Enhanced rear lighting and signalling systems: literature review and analyses of alternative system concepts** |
| **Published:** | Lee S E, Wierwille W W and Klauer S G (2002)<br>U.S. Department of Transportation, National Highway Traffic Safety Administration (NHTSA): Washington, D.C., U.S.A.; Report number DOT HS 809 425 |
| **Link:**<br><br>**Free/priced:** | http://www.nhtsa.gov/Research/Human+Factors/Rear+signaling<br>http://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&frm=1&source=web&cd=1&ved=0CDEQFjAA&url=http%3A%2F%2Fwww.nhtsa.gov%2FDOT%2FNHTSA%2FNRD%2FMultimedia%2FPDFs%2FCrash%2520Avoidance%2F2002%2FTask%25201%2520Report.pdf&ei=UIOYUrzgK9Gihgf2xIDwDQ&usg=AFQjCNENrAoXNrV-_ZgconWKcUm_bDJTGw&sig2=s4MHyGOhpeu9a1UvSQ8_6Q&bvm=bv.57155469,d.ZG4<br>Free |
| **Objectives:** | To develop and test a small number of enhanced rear-lighting concepts that have the potential to reduce the number of rear-end collisions. |
| **Methodology:** | An expert panel consisting of twelve rear-lighting experts was assembled. The trade study was conducted electronically (email) via a series of three questionnaires. This process resulted in the recommendation of three rear-lighting configurations for further refinement. |
| **Key Findings:** | A set of enhanced rear-lighting concepts were developed after reviewing a variety of sources including literature, patent searches, and ideas provided by the expert panel, although the majority were a result of in-house concept generation. Each concept was developed to include a description, a justification, implementation details, activation criteria, deactivation criteria, and a graphic representation. In all, eight concepts were developed, |
| **Keywords:** | Rear lighting, brake lights, rear-end crashes, rear signalling, focus groups, subject matter experts, trade study |
| **Comments:** | Unclear how the concepts were taken forward from this report. Presumably this was not the final output from the project. |

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| **Title:** | **Effectiveness of LED stop lamps for reducing rear-end crashes: analyses of state crash data** |
| **Published:** | Greenwell N K (2013)<br>U.S. Department of Transportation, National Highway Traffic Safety Administration (NHTSA): Washington, D.C., U.S.A.; Report number DOT HS 811 712 |
| **Link:**<br>**Free/priced:** | http://www-nrd.nhtsa.dot.gov/Pubs/811712.pdf<br>Free |
| **Objectives:** | To analyse the crash-reduction benefits of LED (light-emitting diode) stop lamps and LED centre high-mounted stop lamps (CHMSL) using real-world crash data. |
| **Methodology:** | NHTSA statistically compared the overall ratio of rear-impact crashes to a control group of frontal impacts before and after the switch to LED. |
| **Key Findings:** | Overall, the analysis does not support a firm conclusion about whether LED stop lamps and LED CHMSL are more effective than incandescent lamps. The main analysis shows a significant overall 3.6% reduction in rear-impact crashes with LED. On the other hand, a non-parametric analysis not only fails to show improvement in significantly more than half the models, but actually shows an increase in rear impacts with LED for 9 of the 17 make-models that switched to LED. It was just the favourable results for high-sales vehicles such as the Honda Accord that pulled the overall result to a positive benefit. |
| **Keywords:** | NHTSA, NCSA, State Data System, effectiveness, evaluation, statistical analysis, automotive lighting, centre high mounted stop lamp, CHMSL, rear impact, crash avoidance, stop lamps |
| **Comments:** | None of these 17 make-models is a “clean” switch pair that shifted to LED without changing anything else. All of the switch pairs shifted to LED at the same time that they changed the rear-lighting configuration and/or redesigned the vehicle. |

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| **Title:** | **UN Regulation 48, Uniform provisions concerning the approval of motor vehicles with regard to the installation of lighting and light-signalling devices** |
| **Published:** | United Nations (1995), as amended |
| **Link:**<br>**Free/priced:** | http://www.unece.org/trans/main/wp29/wp29regs41-60.html<br>Free |
| **Objectives:** | |
| **Methodology:** | |
| **Key Findings:** | |
| **Keywords:** | Vehicle, lighting, signalling |
| **Comments:** | |

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