4 Fundamental Problems with Automotive Lighting

Automotive lighting practice is becoming more sophisticated in both its ambitions and its technology. However, two fundamental problems remain that have dogged automotive lighting from its earliest days:

- At low light levels, such as occur after dark, the response of the human visual system to different wavelengths is not the same as the response at high light levels i.e. during daytime. Yet all the photometric measurements associated with the specification and design of automotive lighting assume the daytime response of the visual system.
- The easiest way to reveal the road ahead is to project a lot of light along it. The problem is that such an approach dazzles drivers coming the other way, reducing their view of the road and causing discomfort. Striking the necessary balance between visibility and glare has been a perpetual problem for the regulation and design of automotive lighting

This chapter will discuss the nature of both these problems and consider some possible solutions.

4.1 Mesopic vision

4.1.1 Mesopic vision – The problem

For all the photometric quantities used in the measurement of lighting, the conversion from radiometric units to photometric units is made using the CIE Standard Photopic Observer. This is a continuous approximation to the brightness response of the fovea at modest light levels (Viikari et al 2006). The use of the CIE Standard Photopic Observer for all light measurement poses a problem for automotive lighting, because as light level is reduced, different photoreceptors are active in different parts of the retina. Specifically, as the adaptation luminance falls below about 3 cd/m^2, the rod photoreceptors escape the grip of the cone photoreceptors and begin to become influential. Their influence continues to grow until as the adaptation luminance falls below about 0.001 cd/m^2, at which point the cone photoreceptors cease to function, the rod photoreceptors are all that are left to serve vision. Vision where both cone and rod photoreceptors are active is called mesopic vision.

As a consequence of the existence of mesopic vision, the spectral sensitivity of the visual system changes variously for different parts of the retina. Ironically enough, for the fovea there is no change. The CIE Standard Photopic Observer still applies to the fovea in the mesopic range, because medium and long wavelength cones predominate in the fovea, which is what the CIE Standard Photopic Observer is based on. However, in the rest of the visual field, the spectral sensitivity is in a state of continual change, as the balance between rod and cone photoreceptors changes with light level and eccentricity, until either rods dominate, as in scotopic vision, or cones dominate as in photopic vision.

Mesopic vision is important for automotive lighting because the lighting conditions produced by headlights and by road lighting tend to straddle the mesopic / photopic boundary. Nonetheless, all the photometric quantities that are used to characterise automotive lighting use the CIE Standard Photopic Observer. In theory, this practice can lead to situations where the photometric measurements bear little relation to the visual effect of the light source.

Whereas the CIE has produced recommendations for the spectral response of the fovea in the photopic state, the CIE Standard Photopic Observer, (and for a much larger area in the scotopic state, the CIE Standard Scotopic Observer), it has not been able to develop a system of mesopic photometry. This is not for want of trying (CIE 1989). Indeed several different systems have been suggested, most using the perception of brightness as a criterion and based on some weighted combination of photopic and scotopic measurements, to achieve a transition from the Standard Photopic Observer to the Standard Scotopic Observer. Others have abandoned the perception of brightness as the quantitative measure of visual effect, and using reaction time, have developed a comprehensive system of photometry that covers photopic, mesopic and scotopic light levels (Rea et al 2004).

Until the CIE is able to achieve international agreement on a system of mesopic photometry, the Standard Photopic Observer will continue to be used for light measurements relevant to automotive lighting and may mislead in some situations.

4.1.2 Performance in mesopic vision

Laboratory studies

The simplest place to start this discussion of the impact of mesopic vision is in the laboratory where the visual field can be lit uniformly to the same luminance, with light of the same spectrum. He et al. (1997) carried out such a laboratory experiment in which high pressure sodium and metal halide light sources were compared for their effects on the reaction time to the onset of an achromatic 2° disc, either on axis or 15° off-axis, for a range of photopic luminances from 0.003 cd/m^2 to 10 cd/m^2. The luminance contrast of the disc against the background was constant at 0.7. Fig. 4.1 shows the median reaction time to the onset of the stimulus, on-axis and off-axis, for a range of photopic luminances, for two experienced subjects. From Fig. 4.1 it is evident that reaction time increases as photopic luminance decreases from the photopic to the mesopic state, for both on-axis and off-axis detection. There is no difference between the two light sources in the change of reaction time with luminance for on-axis detection. But for off-axis detection, the reaction times for the two light sources begin to diverge as vision enters the mesopic region. Specifically, the reaction time is shorter for the metal halide lamp at the same photopic luminance, and the magnitude of the divergence between the two sources, increases as the photopic luminance decreases.

These findings can be explained by the structure of the retina. The fovea, used for on-axis vision, contains only cone photoreceptors, so its spectral sensitivity does not change as adaptation luminance decreases until the scotopic state is reached. At this point the fovea is effectively blind. The rest of the retina contains both cone and rod photoreceptors. In the photopic state the cones are dominant but as the mesopic state is reached the rods begin to have an impact on spectral sensitivity, until in the scotopic state the rods are completely dominant. Given the different balances between rod and cone photoreceptors in different parts of the retina and under different amounts of light, it should not be surprising that the metal halide lamp produces shorter reaction times for off-axis detection than the high pressure sodium lamp in the mesopic range.

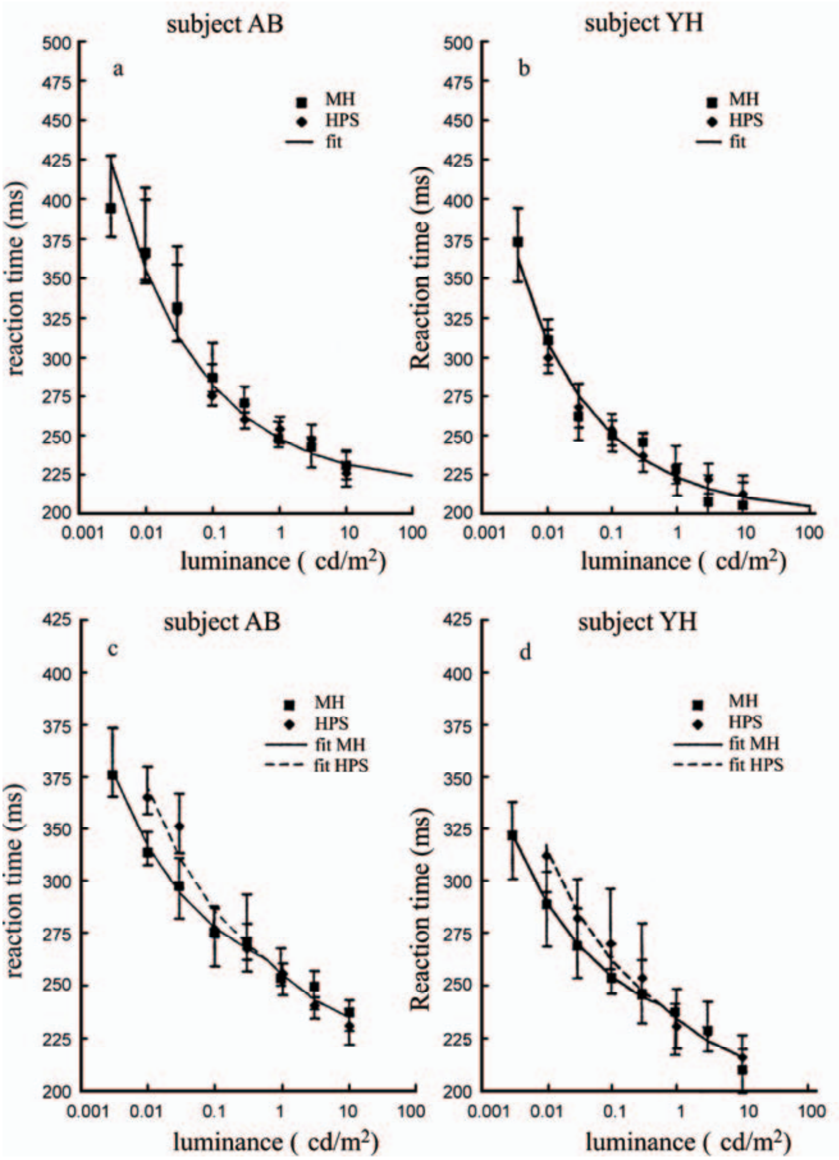

Fig. 4.1 Median reaction times, and the associated interquartile ranges, to the onset of a 2°, high contrast target seen either (a and b) on -axis or (c and d) 15° off-axis, and illuminated using either high pressure sodium (HPS) or metal halide (MH) light sources, for photopic luminances in the range 0.003 to 10 cd/m^2 (after He et al 1997)

This is because the spectral power distribution of the metal halide lamp is more effective in stimulating rod photoreceptors. It is also evident why there is no difference between the two light sources for on-axis reaction times.

Lewis (1999) has obtained similar results using illuminated tranparencies. Fig. 4.2 shows the mean reaction time to correctly identify the vertical or horizontal orientation of a large achromatic high contrast 13° by 10° grating, where the grating was lit by one of five different light sources used for road lighting: low pressure sodium, high pressure sodium, mercury vapour, incandescent and metal halide. Mean reaction time was plotted against photopic luminance. As long as the visual system is in the photopic range, there is no difference between the different light sources, provided they produce the same photopic luminance. However, when the visual system is in the mesopic state, then the different light sources produce different reaction times. The light sources that better stimulate the rod photoreceptors (incandescent, mercury vapour and metal halide) gave shorter reaction times than the light sources that stimulate the rod photoreceptors less (low and high pressure sodium).

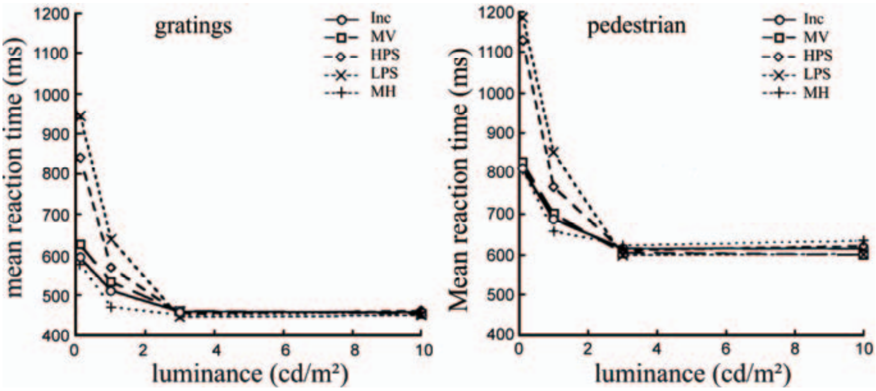

Fig. 4.2 Mean time to correctly identify the vertical or horizontal orientation of a grating and to identify the direction a pedestrian located adjacent to a roadway is facing, plotted against the photopic luminance produced by five different light sources (Inc = incandescent, MV = mercury vapour, HPS = high pressure sodium, LPS = low pressure sodium, MH = metal halide) (after Lewis 1999)

Lewis (1999) used the same technique to examine the effect of the spectral power distribution of a light source on the time taken to extract information of relevance to driving. In this case, the transparency showed a woman standing at the right side of a road in the presence of trees and a wooden fence. In one transparency the woman was facing towards the road, in the other she was facing away from the road. The subject's task was to identify which way the woman was facing. Fig. 4.2 also shows the mean reaction times for this task, under the different light sources and for a range of photopic luminances. Again, there is no difference between the light sources as long as the visual system is in the photopic state. But once it reaches the mesopic state, the light sources that more effectively stimulate the rod photoreceptors produce faster reaction times.

Another approach to evaluating the effect of light spectrum in mesopic conditions measured the probability of detecting the presence of a target off-axis. Bullough and Rea (2000) used a simple driving simulator based on the projected image of a road, controlled by computer software. The subject could control the speed and direction of the vehicle along the road with a steering wheel and accelerator. A computer monitored the time taken to complete the course and the number of crashes occurring. Filters were applied to the projected image of the course to simulate the light spectrum of both high-pressure sodium and metal halide lighting and more extreme red and blue light, for a range of luminances. Interestingly, there was no effect of light spectrum on the time taken to complete the course, i.e. on driving speed, but there was a marked effect on the ability to detect the presence of a target near the edge of the roadway. The light spectra that more effectively stimulated the rod photoreceptors (blue and metal halide) led to a greater probability of detection than light spectra that did not stimulate the rod photoreceptors so effectively (red and high pressure sodium).

Field studies

The laboratory studies discussed above leave little doubt that, for detecting off-axis targets, using light sources that more effectively stimulate the rod photoreceptors is advantageous when the visual system in the mesopic state. But is the advantage retained in the field where both luminances are much less uniform? Akashi and Rea (2001a) had people drive a car along a short road while measuring their reaction time to the onset of targets 15° and 23° off-axis. The lighting of the road and the area around it was provided either by high-pressure sodium or metal halide road lighting, adjusted to give a similar amount and distribution of light on the road, and seen with and without the vehicle's halogen headlights on dipped beam. There was a statistically significant difference between the high-pressure sodium and metal halide lighting conditions but no statistically significant effect of the halogen headlights. Specifically, the mean reaction time to the onset of the targets was shorter for the metal halide lighting than for the high-pressure sodium lighting at both eccentricities (Fig. 4.3).

Using the same experimental site and equipment, Akashi and Rea (2001b) also examined the effect of disability glare caused by halogen headlights from a stationary car in the adjacent lane, on the ability of a stationery driver to detect off-axis targets at 15° and 23° when the road lighting was provided by metal halide and high pressure sodium lighting. Again, the mean reaction times to the onset of the targets were longer for the high-pressure sodium road lighting than for the metal halide road lighting, by about 4%. As might be expected, the mean reaction times were longer when the headlights in the opposing vehicle were switched on, also by about 4%.

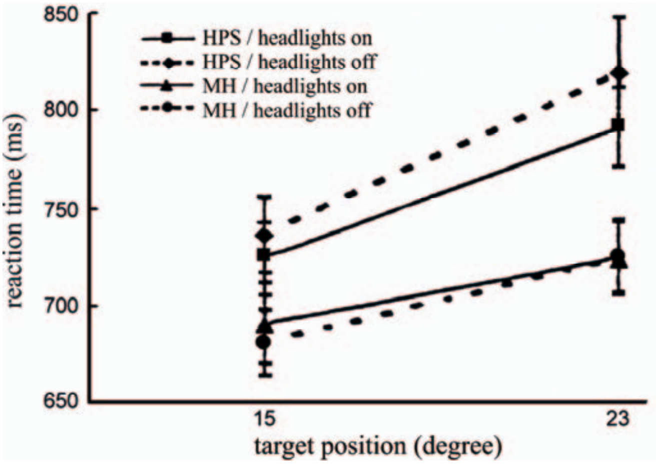

Fig. 4.3 Mean reaction times (and the associated standard errors of the mean) to the onset of a target at 15° and 23° off-axis while driving, with high-pressure sodium (HPS) and metal halide (MH) road lighting, and with halogen headlights turned on and off. The road lighting using the two light sources was adjusted to give similar illuminances and light distributions. The rectangular target subtended $3.97 \cdot 10^{-4}$ steradians for the 15° off-axis position and $3.60 \cdot 10^{-4}$ steradians for 23° off-axis position. Both targets had a luminance contrast against the background of 2.77 (after Akashi and Rea 2001a)

4.1.3 Implications for practice

Given the results discussed above there can be little doubt that light spectrum is a factor to be considered for road lighting, but the implications are rather complex. Specifically, the benefit of choosing a light source that stimulates rod more than cone photoreceptors, depends on the driver's adaptation luminance and the balance between on-axis and off-axis tasks. Provided the adaptation luminance is such that the visual system is operating in the photopic state, there is no effect of light spectrum on off-axis reaction time. If the adaptation luminance is in the high mesopic e.g. about 1 cd/m^2, the effect of light spectrum is slight. It is only when the adaptation luminance is well below 1 cd/m^2 that the choice of light source is likely to make a significant difference to off-axis visual performance. How often this occurs is open to question.

Current road lighting standards recommend average road surface luminances in the range 0.3 to 2 cd/m^2 in Europe (CEN 2002) and 0.3 to 1.2 cd/m^2 in the USA (IESNA 2000). Such luminances are close to the conventional upper end of mesopic vision, and most are above the upper limit of a recent model of a unified system of photometry in which the start of the mesopic is at 0.6 cd/m^2 (Rea et al 2004) This suggests that where there is good quality road lighting there is little benefit to be gained from using light sources that more effectively stimulate the rod photoreceptors, at least with regard to the reaction times to off-axis targets. The same conclusion applies to on-axis detection. Several studies have been made of the effectiveness of different light sources for making largely achromatic objects on the carriageway visible, without any clear conclusions. This suggests that any effects are small (Eastman and McNelis 1963, de Boer 1974, Buck et al 1975). All the measurements were made directly viewing the object i.e. the retinal image fell on the fovea of the retina.

Unfortunately for simplicity, another approach to quantifying the effect of mesopic vision has recently been published (Eloholma et al 2005). The relevant points about this approach are that it is based on performance of a battery of tasks claimed to be relevant to driving, and it appears to show mesopic effects up to 10 cd/m^2. If this approach is more suited to driving then there are likely to be benefits in choosing light sources for road lighting that are more effective in stimulating rod photoreceptors.

But what happens when driving on an unlit road relying on headlights alone? Olson et al (1990) have estimated that the adaptation luminance for a driver using dipped beam headlights on an otherwise unlit road is about 1 cd/m^2. If this were the whole story, then there would seem to be little benefit in considering the use in headlights of light sources that stimulate rod photoreceptors more effectively. Furthermore, then the use in headlights of light sources that stimulate rod photoreceptors more effectively, would be subject to the same conflicting models as road lighting. However, an average luminance masks a wide range, from the hot spot in the beam on the road to the ambient luminance beyond the reach of the headlight beam. Discussion of a single value of adaptation luminance also serves to hide the truth. The fact is the concept of adaptation luminance is a convenient fiction. It was originally developed to describe the effects of luminance on basic visual functions. Its use for this purpose was not unreasonable, as such measurements are usually made on a uniform luminance field. But where the visual field has a wide range of luminances, the adaptation of different parts of the retina will be different, depending on where the eye is fixated. If the driver has one main line of sight, such as might be the case with a driver approaching a tunnel entrance, then the average luminance within about 20° of the fixation point is a reasonable estimate of the adaptation luminance (Adrian 1976). If the observer has many fixation points i.e. the observer is rapidly moving his eyes around, then the average luminance of the whole scene is a good estimate. Measurements of eye movements while driving at night have shown that eye fixations tend to be concentrated around the upper edge of the lit area (Mortimer and Jorgeson 1974; Damasky and Hosemann 1997). Fig. 4.4 shows a contour that defines the area within which fixation occurs 90% of the time when driving on an unlit road using H4 halogen headlights.

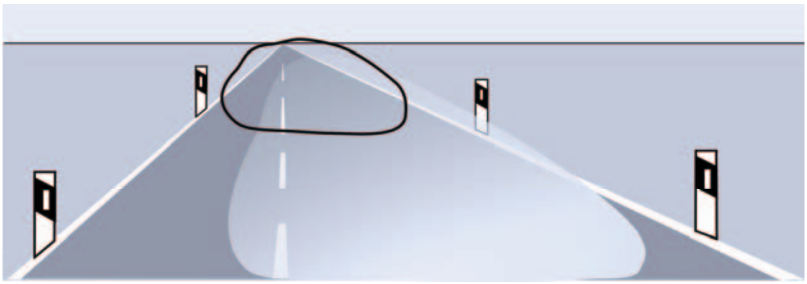

Fig. 4.4 The area within which fixations occur 90% of the time when driving on an unlit road using H4 halogen headlights (after Damasky and Hosemann 1997)

Given that the fixation points while driving on an unlit road do follow the pattern shown in Fig. 4.4, then the lower part of the retina i.e. the part where the road ahead beyond the headlight beam is imaged, could well be operating in the mesopic state, but the upper part will be operating in the photopic state. In this situation, the use of a light source that stimulates the rod photoreceptors more effectively might result in faster detection of objects further up the road. It would be interesting to test this possibility. Comparisons have been made between halogen and xenon headlights and the latter do provide greater visibility distances (Rosenhahn and Hamm 2001). But the difference between the two headlight types involves the amount and distribution of light as well as the spectrum. This being the case it is not possible to quantify the effect of spectrum alone from this data.

One other consideration is the effect of spectrum on discomfort glare. As discussed in the next section, there is evidence that discomfort caused by an off-axis glare source is enhanced by the stimulation of the short wavelength cone photoreceptors. Light sources that stimulate rod photoreceptors more effectively tend to do the same for short wavelength cone photoreceptors. Therefore it can be predicted that a light source that more effectively stimulates rod photoreceptors will produce greater discomfort glare for the same illuminance at the eye. This suggests that there would be some benefit in having different spectra in different parts of the headlight beam. Specifically, a spectrum aimed at stimulating the rod photoreceptors for the whole beam when there is no other vehicle in sight, but a shift to a long wavelength-rich spectrum in the part of the beam likely to be seen by an approaching driver, when one is present.

4.1.4 Mesopic vision – Conclusion

In principle, the existence of mesopic vision and the use of the CIE Standard Photopic Observer in the measurement of light when the visual system is operating in the mesopic state would seem to be a fundamental problem for automotive lighting. As shown above, there is no doubt that light sources that more effectively stimulate the rod photoreceptors enhance the performance of off-axis detection tasks when the visual system is operating in the mesopic state. But at what luminance the mesopic state begins is the subject of controversy. A unified model of photopic, mesopic and scotopic photometry based on reaction times defines mesopic vision starting at 0.6 cd/m^2, while a model of mesopic effects, based on the performance of tasks claimed to be important to driving, defines mesopic vision having an impact up to 10 cd/m^2.

Most road lighting is designed to produce average road surface luminances close to the conventional mesopic / photopic boundary. In this situation, the enhancement of performance is likely to be slight. Where there is no road lighting, so the only light on the road comes from the headlights, there is the possibility of being able to detect objects further down the road, with a light source that more effectively stimulates the rod photoreceptors, Whether this happens, and if it does, how large the effect is, remain to be determined. Until these questions have been answered what to do about mesopic vision as regards automotive lighting will remain an open question.

4.2 Glare

4.2.1 The forms of glare

Glare occurs because while the human visual system can operate over about twelve log units of luminance in total, it can only operate over about three log units simultaneously. Any luminance more than about two log units above the average luminance of the scene will be considered glaringly bright. Exposure to such conditions produces aversion responses e.g. looking away or shielding the eyes. Such behaviour can be taken as an indication that glare is present.

Vos (1999) has classified glare into eight different forms. Of these eight, four occur only rarely. One is flash blindness, a temporary state of complete bleaching of retinal photopigments, caused by the sudden onset of an extremely bright light source e.g. a nuclear explosion. Another is paralysing glare, so named for the phenomenon in which a person suddenly illuminated by a searchlight at night will tend to "freeze" briefly. A third is exposure to light bright enough to cause retinal damage. The last is distracting glare, produced by bright, flashing lights in the peripheral visual field e.g. lights on emergency vehicles at night. These are all special situations remote from conventional automotive lighting, so they will not be discussed further.

The other four forms of glare are more commonly experienced while driving. The first occurs when a large part of the visual field is bright. This is called saturation glare and is painful. The behavioural response is to shield the eyes by wearing low transmittance glasses. Such behaviour is common when driving in very sunny climates.

Saturation glare occurs when a large part of the visual field is at a high luminance for a long time. Another form of glare commonly experienced is adaptation glare. This occurs when the visual system is exposed to a sudden, large increase in luminance of the whole visual field e.g. on leaving a long road tunnel during daytime. The perception of glare is due to the visual system being maladapted. On leaving the tunnel the visual system is adapted to the low light level of the tunnel, but is exposed to the brightness of sunlight. Adaptation glare is temporary, in that the processes of visual adaptation will soon adjust the visual sensitivity to match the new conditions.

The other two forms of glare commonly experienced on roads are disability glare and discomfort glare.

Disability glare

Disability glare, as its name implies, disables the visual system to some extent. This disabling is caused by light scattered in the eye (Vos 1985). The scattered light forms a luminous veil over the retinal image of adjacent parts of the scene, thereby reducing the luminance contrasts of the image of those parts on the retina.

Disability glare can be associated with point sources and large area sources. Disability glare from point sources is experienced most frequently on roads at night, when facing the headlights of an approaching vehicle. Disability glare from an extended source is unusual on the road at night, apart from over-illuminated advertising signs, but it certainly can occur when approaching a road tunnel during daytime. Then, the sky above the tunnel entrance can act as a glare source.

Discomfort glare

Disability glare is well understood. It has an effect on visual capabilities that can be measured with conventional psychophysical procedures and a plausible mechanism, namely light scatter in the eye. On the other hand discomfort glare is not well understood. It is said to be occurring when people complain about visual discomfort in the presence of bright light sources. There is no known cause for discomfort glare, although suggestions have been made ranging from fluctuations in pupil size (Fry and King 1975) to distraction (Lynes 1977).

The separation between disability and discomfort glare should not be taken to mean that disability glare does not cause visual discomfort. Headlights at night can certainly be both visually disabling and visually uncomfortable. In essence, these two forms of glare, disability glare and discomfort glare, are simply two different outcomes of the same stimulus pattern, namely a wide variation of luminance across the visual field.

Spotlight

The origins of glare

The reason why

The human visual system can process information over about 12 log units of luminance, from sunlight to starlight, but not all at once. It continually adjusts itself to the prevailing conditions, aiming at reduced sensitivity and finer discrimination when there is plenty of light available and enhanced sensitivity and coarser discrimination when light is in short supply. When the visual system is adapted to a given luminance, much higher luminances appear as glaringly bright, while much lower luminances are seen as black shadows (Fig. 4.5).

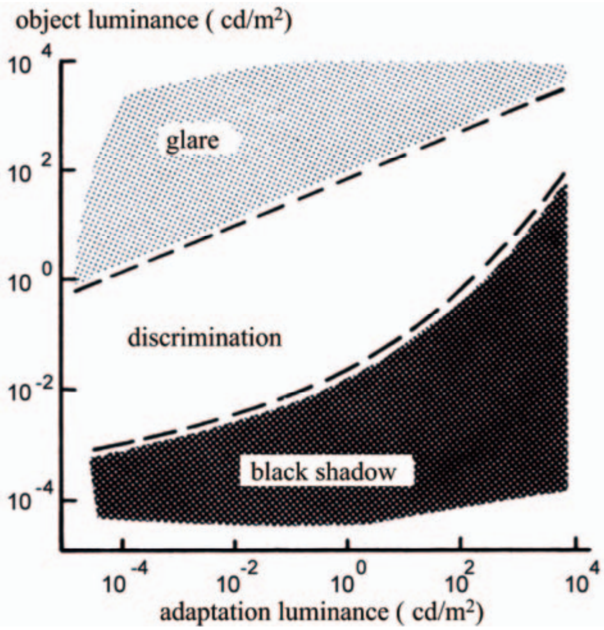

Fig. 4.5 A schematic illustration of the range of object luminances within which discrimination is possible for different adaptation luminances. The boundaries are approximate (after Hopkinson and Collins 1970)

This means that the same luminance can appear dark, comfortable or glaringly bright, depending on the state of adaptation of the visual system. An everyday example of this change in perception is the appearance of a vehicle headlight by day and night. The headlight has the same luminance under both conditions, but as the adaptation luminance decreases as night falls, the headlight becomes very uncomfortable i.e. glare occurs.

The phenomena of glare

Glare is a blanket term for a number of phenomena. The most ubiquitous is a sense of discomfort either associated with a reduction in visibility caused by scattered light in the eye producing reduced retinal image contrast, or with distraction that draws your attention away from where you should be looking. The reduction in visibility is most likely to occur when the glare source is close to the driver's line of sight. Distraction can occur over a wider angular range and is most likely to be associated with small high luminance sources.

Sources of glare

The headlights of an approaching vehicle are the most obvious sources of glare to a driver. They can cause both a reduction in visibility and act as a distraction. While the glare problems posed by headlights are well understood, and have resulted in the light distribution from headlights being carefully controlled, there are a number of other features of a vehicle that can cause glare.

The reflections of the headlights of a following or adjacent vehicle in the interior rear view mirror or the exterior wing mirrors can be a disturbing source of glare, not because they decrease the visibility of the road ahead but because they attract the driver's attention away from the road ahead.

In some countries, vehicles are fitted with high intensity rear lights for use in conditions of poor visibility, such as thick fog. The idea is to increase the luminance of the rear light sufficiently to compensate for the increased absorption and scattering of light by the atmosphere. If such rear lights are only used in conditions of poor visibility, they are not a source of glare, but unfortunately, the choice of normal or high intensity rear lights is under the manual control of the driver. Some drivers switch to high intensity rear lights at the first hint of rain. The result is glare for the following driver, causing him discomfort, and limiting his visibility of the vehicle ahead. It may also make the onset of brake lights more difficult to recognise. In dense traffic, momentary glimpses of high intensity rear lights in the distance may be interpreted as brakes being applied, resulting in unnecessarily jerky driving.

Above a certain luminance the instrument display can also be a source of glare. The effect is primarily one of distraction rather than reduced visibility of the road ahead.

Finally, there is the possibility of the fascia around the windscreen becoming an extended glare source. If the materials chosen for the car interior are of high reflectance, inter-reflected light from following vehicles, or from interior lighting, can raise the luminance of the fascia sufficiently for it to become a source of disability glare. The result will be a reduction in the visibility of the road ahead. It is interesting to contemplate that glare produced in this way occurs when the light sources producing the glare are not visible to the driver.

Possible solutions

Possible solutions to the problem of glare from headlights are discussed elsewhere.

Interior rear view mirrors that automatically change their reflection properties when a high illuminance is detected falling on the mirror are already fitted to some luxury vehicles. Extending such technology to exterior mirrors and other vehicles is a matter of economics.

Instrument displays are rarely a glare source today as most vehicles allow drivers to adjust the luminance of the display over a wide enough range to avoid discomfort.

As for the choice of materials for the car interior, this is subject to many considerations, reflectance being just one of them. Nonetheless, high reflection materials should be used with caution, particularly for the fascia.

4.2.2 The quantification of glare

Formulae exist for the quantification of both forms of glare.

Disability glare

The amount of disability glare can be measured by comparing the visibility of an object seen in the presence of the glare source, with the visibility of the same object seen through a uniform luminous veil. When the visibilities are the same, the luminance of the veil is a measure of the amount of disability glare produced by the glare source, and is called the equivalent veiling luminance. Numerous studies have led to several different empirical methods for predicting the equivalent veiling luminance (Holladay 1926; Stiles 1930; Stiles and Crawford 1937). Based on this work, an equation was developed to predict the equivalent veiling luminance from directly measurable variables. It is

$$L_v = 10 \cdot \sum E_n \cdot \Theta_n^{-2}$$

…where L_v = equivalent veiling luminance (cd/m²)
E_n = illuminance at the eye from the n-th glare source (lx)
Θ_n = angle between the line of sight and the n-th glare source (degrees)

The disability glare formulae can be applied directly to point sources but for large area sources, the area has to be broken into small elements and the overall effect integrated (Adrian 1976).

The effect of the equivalent veiling luminance on the luminance contrast of an object can be estimated by adding it to the luminance of both the object and the immediate background. The result is an inevitable reduction in the luminance contrast of the object, as shown by the increase in the denominator of the following equation.

$$C = \frac{((L_{\max} + L_v) - (L_{\min} + L_v))}{((L_{\max} + L_v) + (L_{\min} + L_v))}$$

$$C = \frac{(L_{\max} - L_{\min})}{(L_{\max} + L_{\min} + 2 \cdot L_v)}$$

...where C = luminance contrast
L_{max} = maximum luminance (cd/m²)
L_{min} = minimum luminance (cd/m²)
L_v = equivalent veiling luminance (cd/m²)

It is important to note that the formula for equivalent veiling luminance given above applies to glare sources positioned between 1° and 30° from the line of sight, and only for young test persons. Hartmann and Moser (1968) have shown that for angles less the 100 min arc. from the line of sight, the loss of visibility associated with disability glare is much greater than would be predicted from the disability glare formula. This is probably because of neural interactions occurring in the retina in addition to light scatter in the eye. As for the effect of age, the elderly have much more turbid optic media than the young, resulting in much greater absorption and scattering of light as it passes through the eye. Consequently, the CIE has developed a modified disability glare formula suitable for use in the angular range 0.1° to 30°, and for either young or old people (CIE 2002). This equation takes the form:

$$L_v = \sum \left(\frac{10 \cdot E_n}{\Theta_n^3} + (1 + (\frac{A}{62.5})^4) \cdot 5 \cdot \frac{E}{\Theta_n^2} \right)$$

…where L_v = equivalent veiling luminance (cd/m²)
A = age (years)
E_n = illuminance at the eye from the n-th glare source (lx)
Θ= angle of the n-th glare source from the line of sight (degrees)

In both the simple and the elaborated formulae for equivalent veiling luminance, the only photometric quantity involved is the illuminance received at the eye. This implies that for the same illuminance at the eye, the spectrum of the light received is unimportant, as is the size of the light source and hence the luminance. There is some support for these implications (Flannagan 1999).

Discomfort glare

Schmidt-Clausen and Bindels (1974) have produced an equation relating the illuminance at the eye to the level of discomfort produced by headlights, expressed on the de Boer scale. The equation is

$$W = 5.0 - 2\log(E / 0.003(1 + \sqrt{(L/0.04) \cdot \phi^{0.46}})$$

…where W = Discomfort glare rating on the de Boer scale
E = Illuminance at the eye (lx)
L = Adaptation luminance (cd/m²)
ϕ = Angle between line of sight and glare source (min. arc)

The de Boer Scale is a nine point glare scale with five anchor points labelled 1 = unbearable, 3 = disturbing, 5 = just admissible, 7 = satisfactory, 9 = unnoticeable. Conditions producing ratings of 4 or less are usually considered uncomfortable.

Again, the only photometric quantity in the equation related to the glare source is the illuminance received at the eye. However, for discomfort there is evidence that other factors have small effects. While the perception of discomfort from headlights is dominated by the illuminance at the eye (Sivak et al 1990; Alferdinck 1996), light spectrum (Flannagan et al 1989), headlight size (Alferdinck 1991) and light dose (Van Derlofske et al 2005) all have small effects on discomfort. Specifically, for the same illuminance at the eye, light spectra with more energy at the short wavelength end of the visible spectrum, smaller headlight sizes and longer exposure times will all tend to cause more discomfort.

4.2.3 Performance in the presence of glare

The most obvious and best understood consequence of exposure to glare is a reduction in contrast of the scene around the glare source. This should lead to a reduction in the ability to detect targets that are close to threshold in the absence of glare. One way to examine this effect is to measure the detection distance for obstacles as two vehicles approach and pass each other. Mortimer and Becker (1973), using both computer simulation and field measurements, have shown that the visibility distance for targets of reflectances 0.54 and 0.12 diminish as opposing cars close, and then start to increase rapidly (Fig. 4.6). The separation at which the visibility distance is a minimum depends on the relative luminous intensity distribution of the headlights, the relative positions of the two vehicles, the obstacles to be seen, and the physical characteristics of the obstacle.

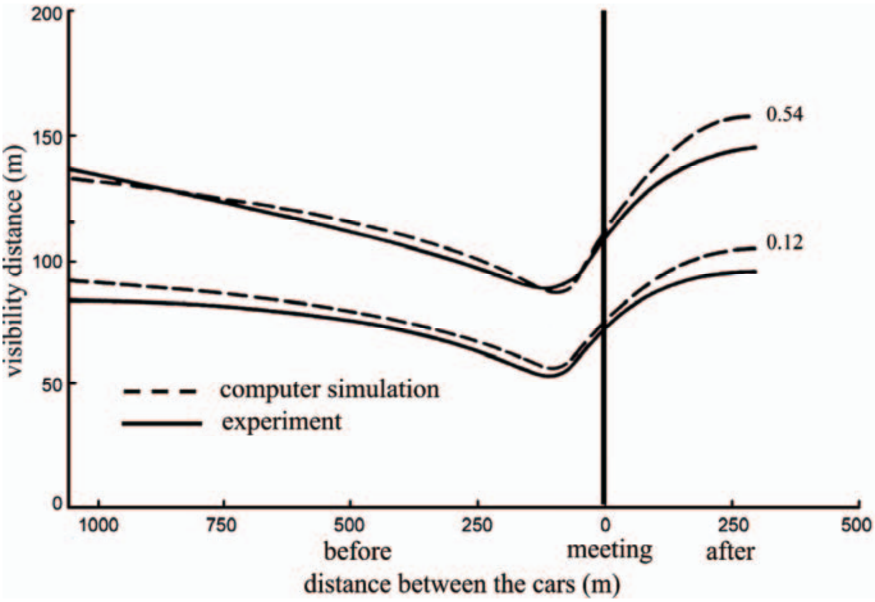

Fig. 4.6 Visibility distance for targets of reflectance 0.54 and 0.12, plotted against the distance between two vehicles approaching each other, with headlights of equal luminous intensity (after Mortimer and Becker, 1973)

Helmers and Rumar (1975) measured visibility distances for flat, dark-grey 1.0 m by 0.4 m rectangles with a reflectance of 0.045. Observers were driven towards a parked car with its headlights on and asked to indicate when they saw the obstacles. It was found that for the small dark-grey obstacle, a headlight system with the maximum high beam luminous intensity gives a visibility distance of about 220 m, when no opposing vehicle is present. This is the same as the stopping distance for a vehicle moving at 110 km/h, which is about 220 m on wet roads (AASHTO 1990). However, when two opposing vehicles have equal luminous intensity headlights, the visibility distance is reduced to about 60 - 80 m, which is much less than the stopping distance. When the opposing vehicle has a luminous intensity about three times more than the observer's vehicle, the visibility distance is reduced to about 40 - 60 m. It is clear that driving at high speeds against opposing traffic at night approaches an act of faith…

Spotlight

Luminance as criterion to evaluate disability and discomfort glare

Designing a vehicle headlamp is always a trade-off between high visible range for the driver and a minimum of glare for the oncoming traffic. The first is accomplished by bringing a lot of light on the road and the latter by minimising the light that reaches the driver of the oncoming car. Both a maximum of visual range and a minimum of glare are crucial for safety at night.

This design trade-off has always been a focus when introducing new headlamp technologies to the market. Projection systems were established at the same time as the introduction of the first gas discharge lamps with a much higher luminous flux than common halogen lamps. Thus the common reflector was no longer used to distribute light. The projection systems use a lens, the size of which defines the light emitting area of the headlamp. The projection lens is usually much smaller than the reflector size, but equipped with a gas discharge lamp, the emitted luminous flux is approximately 2.5 times higher compared to a halogen lamp. This leads to higher luminances of the light source, irrespective of the level of illuminance. This effect may be intensified by future headlamps.

The limitation of glare for automotive headlamps is today solely based on a maximum value of illuminance at the point B50L on the ECE testing wall. Further parameters and criteria such as the spectrum of the glare source and the size of the light emitting area of the headlamps are not considered as critical to minimise glare. The regulations limit the illuminance caused by one headlamp at B50L to 0.4 lx for halogen and to 0.5 lx for gas discharge systems. Despite these limitations, gas discharge lamps are often regarded as more glaring than halogen lamps. Given the facts that glare sensitivity is influenced by many more criteria than the illuminance of the glare source, and that luminance is the photometric quantity that describes human brightness perception, one might ask whether luminance of the glare source is also a significant influencing parameter that should be considered for regulations.

In comparison to the influence of illuminance, which has been examined in various studies, luminance with respect to the size of the glare source as an influencing parameter on glare was not investigated very extensively. Sivak (1988) and Alferdinck (1991) examined the influence of the size of the glare source, reporting a minor but significant effect on discomfort glare.

The following figures show the results of a study that examined the effect of luminance with respect to size on discomfort as well as disability glare, at constant levels of illuminance. Disability glare is quantified by measuring the visual impairment caused by the glare source e.g. the increase of threshold contrast, the luminance ratio at which an object is just noticeable. The average threshold contrast versus the luminance and the size of the glare source is given in Fig. 4.7 and Fig. 4.8 for different illuminance levels.

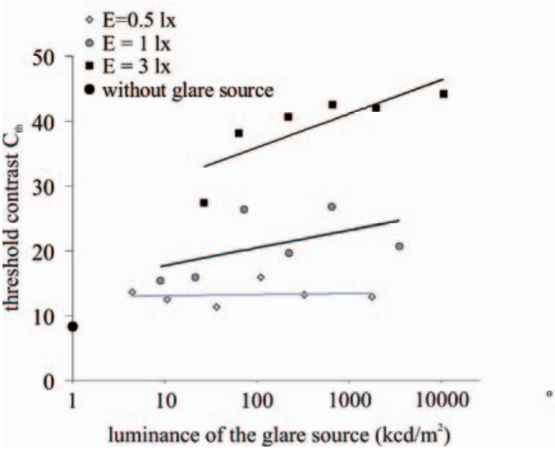

Fig. 4.7 Disability glare described by the increase of the contrast threshold $C_{th} = L_{obj}/L_{backgr}$ vs. the luminance of the glare source in kcd/m^2, for three glare illuminances, compared to the threshold contrast measured without glare

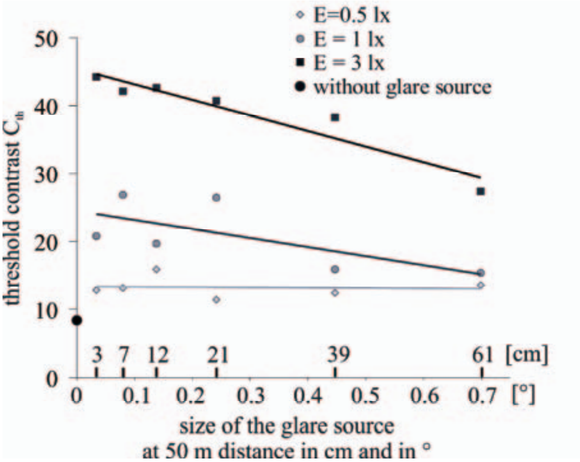

Fig. 4.8 Disability glare described by the increase of the contrast threshold $C_{th} = L_{obj}/L_{backgr}$ vs. the diameter of the glare source in cm and degrees for three glare illuminances, compared to the threshold contrast measured without glare

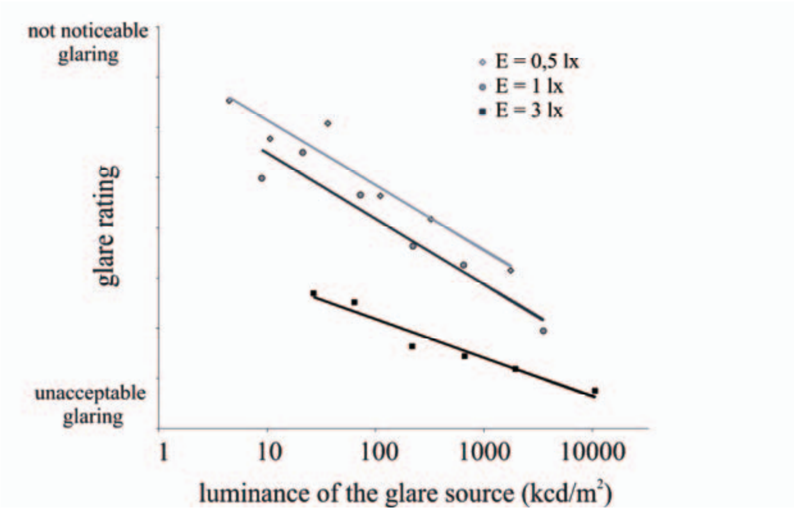

Fig. 4.9 discomfort glare rating vs. the luminance of the glare source in kcd/m^2 for three glare illuminance levels

For 0.5 lx, the upper limit for gas discharge headlamps set by the ECE, no effect was found. For higher levels of illuminance which also occur in traffic e.g. from incorrectly adjusted headlamps, and on crests, an influence of luminance on disability glare can be seen. Even though the illuminance has the strongest impact on disability glare, a limitation of the size or luminance can reduce visual impairments due to oncoming traffic.

Discomfort glare describes the level of disturbance by the glare source and is measured by rating the glare impression. The subjective evaluation for several sized glare sources is shown in Fig. 4.9 and Fig. 4.10 for three illuminance levels.

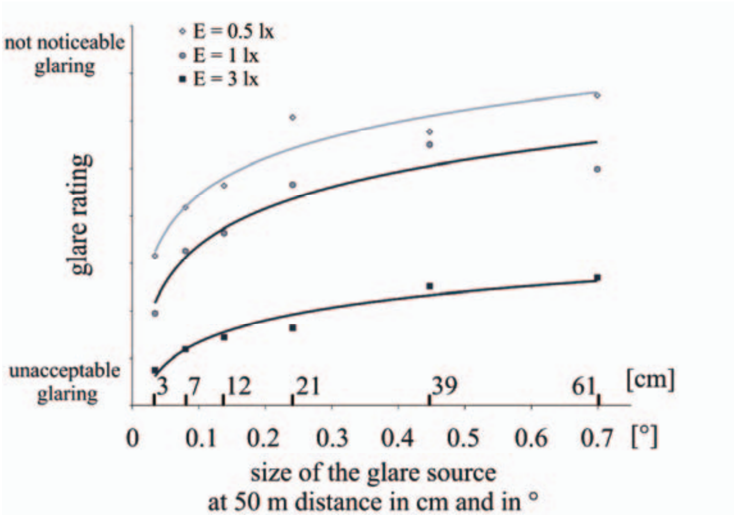

Fig. 4.10 discomfort glare rating vs. the diameter of the glare source in cm and degrees for three glare illuminance levels

The results illustrate that the discomfort glare perception is not solely based on the illuminance level, but also on luminance that directly correlates with the size of the glare source for constant levels of illuminance. This influence is relevant in particular for the three smallest glare sources that are in the range of today's headlamps. In comparison to the results for disability glare, these effects are also found for low levels of illuminance.

In conclusion we can say that although the level of illuminance is still the most decisive parameter on both disability and discomfort glare, it is advisable not to restrict the prevention of glare to this single parameter. Even if all headlamps fulfil the legal requirements, some are perceived as more glaring than others. In general it can be said that there is a correlation between glare for oncoming drivers and the luminance with respect to the size of the light emitting area of the glare source. It has however yet to be shown in which way discomfort and disability glare influence safety and comfort in traffic.

Spotlight

Don’t kill the jogger

The value of light

The presence of light reduces pedestrian fatalities. Fig. 4.11a shows the total number of fatal pedestrian accidents in 46 States of the USA occurring during the hour around dawn in the nine weeks before and after the spring daylight saving change (Sullivan and Flannagan 1999). It can be seen that in the weeks before the change, there is a steady decrease in the number of fatal accidents. But at the daylight saving change, there is a rapid return to a high level of accidents, a level that then reduces with the increasing day length. Fig. 4.11b shows analogous data for the hour around dusk. For the evening, the effect of the daylight saving change is to change the driving conditions for the same driving population from night to day. The dramatic decrease in the number of fatal pedestrian accidents with this transition is obvious. It should be noted that tiredness resulting from the daylight saving change is not a plausible explanation for these results. The human circadian system can shift its phase by about an hour a day, so adjustment to the daylight saving change should be complete within a day.

The data presented in Fig. 4.11 show the value of light to pedestrian safety. But this should not be taken to mean that light is of value for all types of accidents. Sullivan and Flannagan (1999) carried out a similar analysis for fatal accidents involving a single vehicle leaving the road on curved, rural, high-speed roads. For this type of fatal accident the change in lighting conditions produced by daylight savings time showed very little change in the number of fatal accidents. The difference in the results for the two accident types reflects the underlying causes of the accidents. Pedestrian fatalities are commonly caused by the failure of the driver to see the pedestrian. Single vehicles leaving the road are much more likely to occur because of either fatigue or intoxication.

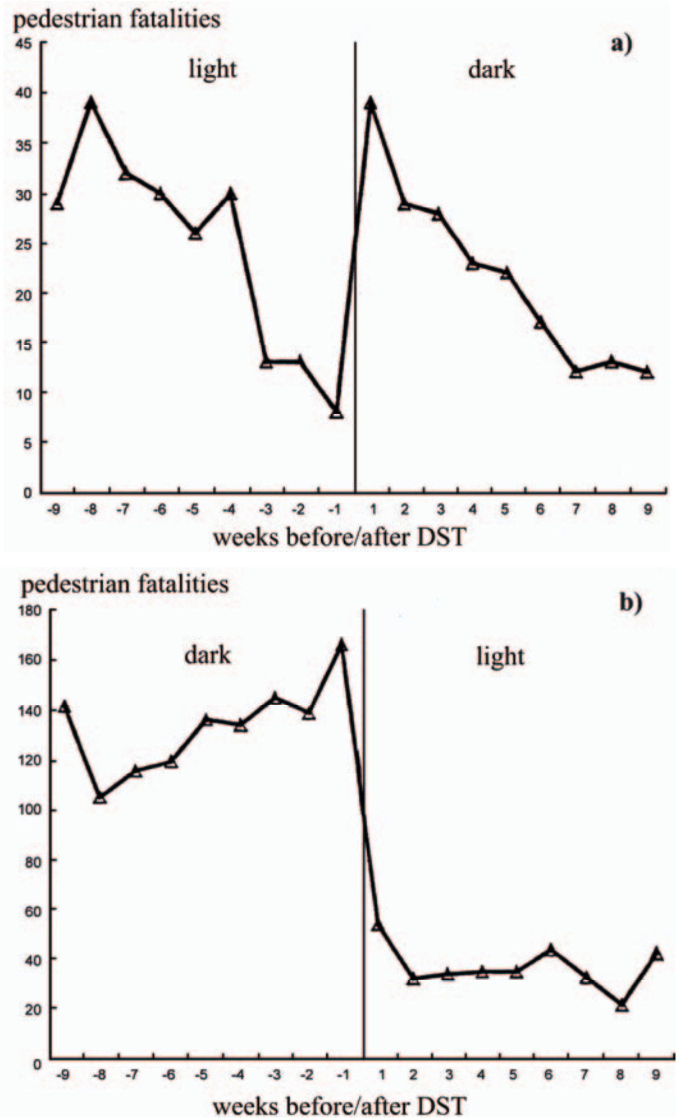

Fig. 4.11 Average number of pedestrian fatalities in forty-six states of the United States, over the years 1987 to 1997, during twilight, for the nine weeks before and after the Spring daylight saving time change (upper graph) for morning, (lower graph) for evening (after Sullivan and Flannagan 1999)

Why is current lighting practice inadequate?

Given that the presence of light enhances the safety of pedestrians, it is appropriate to ask why the existing provision of vehicle lighting, and in some places, road lighting, is inadequate. To answer this question, it is necessary to consider why pedestrians are not seen. The first and most obvious reason is the tendency for pedestrians to wear dark clothing. At night, unless walking on snow, dark clothing inevitably means low contrast for the pedestrian against the immediate background. Contrast is the primary factor in determining visibility. The second is driver expectations. We tend to see what we expect, so that if we do not expect pedestrians to be present, we are less likely to see them. Further, if we do not expect pedestrians to be present we are unlikely to fixate their location, in which case the pedestrian has to be detected off-axis where detection is less likely. All the above apply when both vehicle lighting and road lighting are present. When the driver is using vehicle lighting alone, there is another factor to be considered, namely the limited range of visibility provided by headlights, particularly when dipped. As a consequence of this limited range, the time available for the driver to respond to the presence of a pedestrian, even if he has been detected, is very short.

Reducing pedestrian fatalities

What can be done to alleviate this situation? There is little that can be done about drivers' expectations, because these depend on experience and knowledge of the locality. However, the pedestrian can do much to enhance his visibility by wearing light clothing and/or markings that provide high luminances e.g. retroreflectors. High reflectance clothing is better than markings, because although both will aid detection, clothing will make it easier for the driver to identify what has been detected as a pedestrian. As for lighting, both vehicle lighting and road lighting could be configured to provide more light and hence greater emphasis on the side of the road. This would increase the safety of the pedestrian at the side of the road, but it would not really benefit the pedestrian crossing the road.

Spotlight

Reducing the stress of driving

Two extreme situations

Driving can be stressful. Stress can occur at the two extremes of information extraction. One extreme occurs when there is no information where there should be. An example of this is driving in thick fog. In this situation, the whole world is uniform in luminance, yet we know the road has edges and there may be other people and vehicles on it. A common behaviour pattern when driving in thick fog is to get behind a vehicle ahead and then stay close. This reduces the stress of driving because it limits the amount of information we need to extract. All we need to do is follow the vehicle ahead, leaving the driver of that vehicle to sort out the unknown. The risk in this behaviour is that you are relying on the driver ahead not to lead you into danger.

At the other extreme of information extraction is information overload. An example of this is driving during the rush hour at night in a strange city in the pouring rain. Information arrives from all directions in overwhelming quantities, but the information you want may be hidden. There is little that can be done about the weather, but if you feel stressed about the prospect of driving in a strange city, try to arrive during daylight, and not during the rush hour.

The role of vehicle lighting

In between these two extremes lies a condition of minimum stress, where the information being sought is readily available and does not require a rapid response. This most commonly occurs during the day, but vehicle lighting has a role to play in achieving this nirvana after dark. Its role is to make it easier to extract the necessary information and to relax the necessary speed of response. Driving on an unlit road using high beam headlights is less stressful than driving using dipped headlights, because visibility is better over a larger area and the driver can see further down the road. In this situation, the driver has more time to detect, identify and respond to whatever lies ahead. Road lighting can fulfil a similar purpose.

The limitations of light in snow and fog

It is important to note that making more light available may not be beneficial for driving in dense fog and snow. In fog, the additional light output produced by the high beam headlights produces additional scattered light, which tends to reduce the contrast of whatever is present, thereby reducing its visibility. In snow, additional light reflected back from the snowflakes increases their visibility. The problem with this is that the snowflakes are a distraction from the information needed. For driving in both fog and snow, dipped highlights will usually be less stressful than high beam headlights. For driving in fog, low mounted fog lights with a wide, flat beam are even better, because fog is usually thinner close to the ground, so that less light is scattered per unit path length. For driving in snow, any additional lighting is best mounted as far away from the line of sight of the driver as possible, because then the increase in the luminance of the snowflakes, as seen by the driver, is minimised.

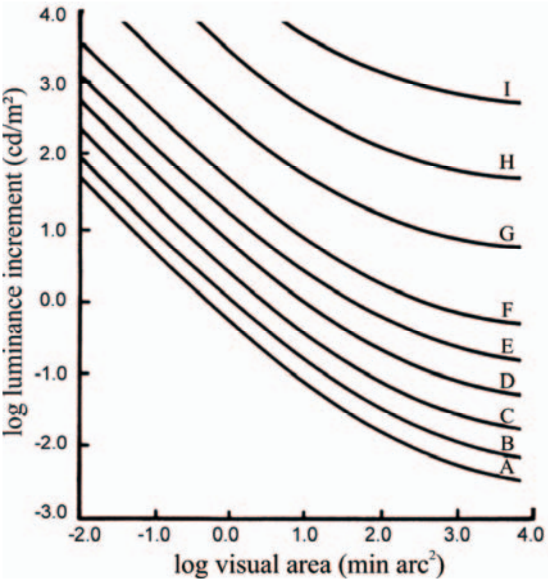

Fig. 4.12 Relationships between log luminance increment and log visual area at different background luminances, for small targets to be just visible. Each curve is for one background luminance as follows: A = 0.01 cd/m^2, B = 0.1 cd/m^2, C = 0.32 cd/m^2, D = 1.0 cd/m^2, E = 3.2 cd/m^2, F = 10 cd/m^2, G= 100 cd/m^2, H = 1000 cd/m^2, I = 10,000 cd/m^2 (after Hills 1976)

The targets used in the studies for contrast threshold do not emit light, but are seen by reflected light. Signal lights on vehicles are self-luminous. It is now necessary to consider to what extent exposure to glare from headlights might reduce the visibility of signal lights. The signal lights closest to the glare source will be those on the approaching vehicle next to the headlights. These may be sidelights, in which case their visibility is of little consequence, since the presence of the headlights is enough to mark the approaching vehicle. But they may be turn indicators, in which case not being able to see the signal light would matter. Regulations specify different luminous intensities for a turn indicator depending on the separation from the headlight.

Another situation of interest is the visibility of signal lights far enough ahead that the signal lights are not illuminated by the headlights of the driver's vehicle. Hills (1976) has produced a predictive model of the relationship between luminance increment and area for small targets, such as rear lights and pedestrians, to be just visible for a wide range of background luminances (Fig. 4.12). The ordinate in Fig. 4.12 is the logarithm of the increment of the object luminance necessary for it to be just visible against the background luminance. Different values of background luminance enable the effects of different lighting conditions to be estimated, from starlight, via road lighting, to daylight. The effect of disability glare can be taken into account by adding the equivalent veiling luminance to the background luminance.

4.2.4 Recovery from glare

The discomfort experienced when exposed to headlights is replaced by a feeling of relief almost immediately after the other vehicle passes. Likewise, the light scattered in the eye disappears with the glare source. But that does not mean vision is immediately restored to the state existing before exposure to glare. The additional light that has reached the retina of the driver from the approaching headlights will have had an effect on the state of adaptation of the photoreceptors. Therefore immediately after the other vehicle passes, the driver's vision will be maladapted. The process of adjusting adaptation is called recovery from glare.

Van Derlofske et al (2005) examined what factors determined the time taken to recover from glare. The subject was exposed to four different glare stimuli (Fig. 4.13). Two have the same maximum illuminance at the eye, but produce different light doses, this being the product of illuminance and time of exposure. The other two have an equal light dose but different maximum illuminances at the eye. Immediately after exposure, the subject was presented with a square target, the contrast of which was a fixed ratio of the individual's threshold contrast. The subject's task was to indicate when the target could first be seen. Fig. 4.14 shows the recovery times for different contrast ratios above threshold and for the different glare exposure profiles. From Fig. 4.14 it is evident that recovery times are shorter for the higher contrast target. Furthermore the recovery time is determined by the light dose and not the maximum illuminance. It is interesting to note that in the same experiment it was shown that ratings of discomfort on the de Boer scale were more closely related to the maximum illuminance at the eye than the light dose.

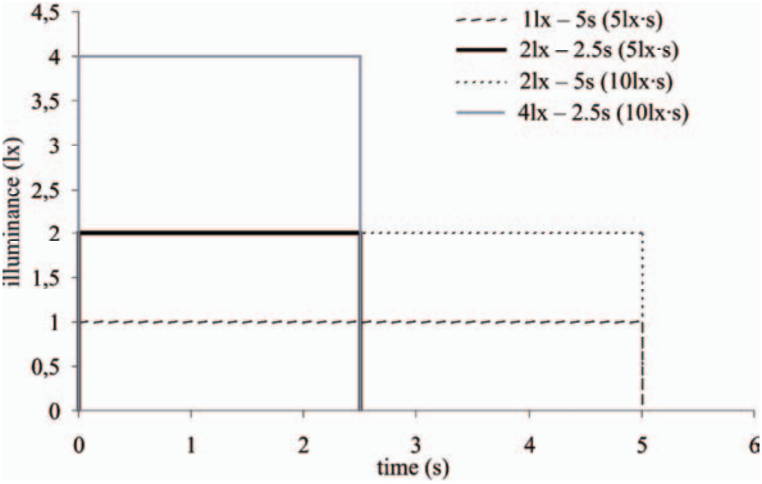

Fig. 4.13 The four glare stimuli used by Van Derlofske et al (2005) showing the maximum illuminance at the eye and the duration of exposure. The effect of these stimuli is to produce three different maximum illuminances and two different light doses

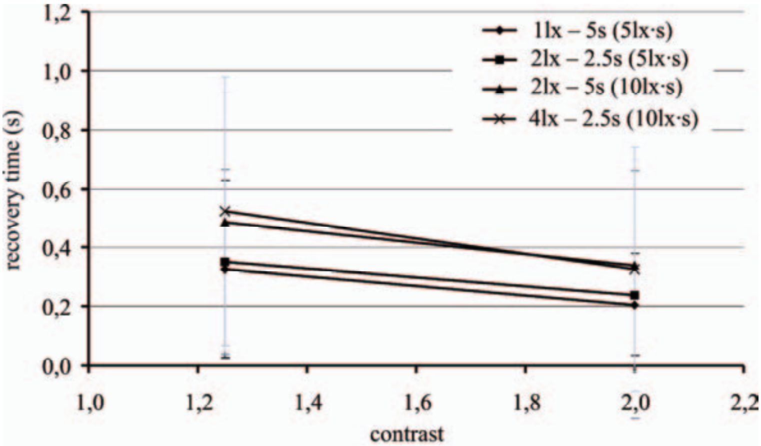

Fig. 4.14 Mean detection times for targets after exposure to the four glare illuminance profiles shown in Fig. 4.13 plotted against target contrast. Target contrast is expressed as ratio of the threshold contrast without glare (Van Derlofske et al 2005)

4.2.5 Behaviour in glare

Different illuminances received at the eye can be associated with different behaviours. The range of illuminance received at the eye during normal driving is from 0 to 10 lx (Alferdinck and Varkevisser 1991). Within this range, illuminances of the order of 1 to 3lx are sufficient to cause drivers to request dipping from the approaching vehicle (Rumar 2000). Illuminances of 3lx and more are likely to be considered very uncomfortable (Bullough et al 2002).

Given that the approaching driver does not respond to a request for dipping, how does the requesting driver respond? Theeuwes and Alferdinck (1996) conducted a test where people drove over urban, residential and rural roads at night, with a glare source simulating the headlights of an approaching vehicle mounted on the bonnet of the car. They found that people drove more slowly when the glare source was on, particularly on dark winding roads where lane-keeping was a problem. Older subjects showed the largest speed reduction. The presence of glare also caused the drivers, particularly older drivers, to miss many roadside targets.

Spotlight

"Headlights aren't nearly as good as they used to be…"

Vision changes with age

As the visual system ages, a number of changes in its structure and capabilities occur. With increasing years the ability to focus close up is diminished, the amount of light reaching the retina is reduced, more of the light reaching the retina is scattered, the spectrum of the light reaching the retina is changed and more stray light is generated inside the eye. The consequences of these age-related optical changes for the capabilities of the visual system are many and varied. At the threshold level, old age is characterised by reduced absolute sensitivity to light, reduced visual field size, reduced visual acuity, reduced contrast sensitivity, reduced colour discrimination and greater sensitivity to glare. On the road, the elderly have difficulty seeing far at night, moving from bright to dark conditions suddenly as on entering a tunnel during the day, detecting low contrast pedestrians at night and recovering from glare exposure. On top of all this are the changes in their cognitive capacity that occur simultaneously. These make understanding a dynamic situation more difficult and the necessary responses slower.

Behavioural changes

As a consequence of these changes, the elderly tend to modify their behaviour. The most extreme behaviour modification is to give up driving at night entirely. Less extreme but also common behaviours are to restrict the routes taken at night to those that are familiar and to drive more slowly. Also frequently found are drivers who adjust their speed according to the circumstances. So next time you are behind a vehicle travelling unusually slowly at night, or one that slows down markedly every time another vehicle approaches, have a little patience and remember that if you are lucky, you will be that driver one day.

Helping the elderly driver

The elderly driver is faced with two major problems: the need to make decisions rapidly and a reduced ability to collect the information on which to base those decisions. Any lighting that gives the elderly driver more time in which to collect the necessary information and to act on it will be beneficial.

Probably the most useful contribution in this respect is made by road lighting. Good quality road lighting i.e. road lighting providing a high road surface luminance without glare, will allow the elderly driver to explore the road a considerable distance ahead. It will also provide guidance about the direction of the road. Further, by increasing the background luminance, good road lighting will also reduce the impact of glare produced by headlights.

As for vehicle lighting, the major contribution it can make to the abilities of the elderly driver is in the limitation of glare. This requires attention to installation and to use. There is an inevitable conflict between the driver behind a set of headlights and the driver facing them. The driver behind the headlights wants them to be a bright as possible while the driver facing them wants them to be as dim as possible. So far, the compromise adopted to resolve this conflict is the two state, main and dipped beam headlight, although the future may offer much more effective opportunities. At the moment, the essential actions you can take to limit glare are to keep your vehicle’s headlights clean and to switch to dipped headlights whenever another vehicle approaches, well before that vehicle is close. It is also worth remembering that glare can also be caused by headlights seen in mirrors, so be sure to switch to dipped headlights as you approach a vehicle from the rear.

4.2.6 Glare in practice

So far this discussion of glare has been concerned with the phenomenon rather than the reality. In practice, headlight systems are designed to meet different specifications in different parts of the world. Further, there is a large difference between the luminous intensity distribution of a new headlight and a headlight on a vehicle that has been on the road for some time. Headlights on a vehicle on the road may produce different luminous intensities in important directions, because the vehicle may not be level, or the headlight is incorrectly aimed or dirty. Yerrel (1971) reported a set of roadside measurements of headlight luminous intensities in Europe and found a very large range of luminous intensities for the same direction. Alferdinck and Padmos (1988) found similar results from roadside measurements in the Netherlands. They also examined the importance of aiming, dirt and lamp age on the luminous intensity in a series of laboratory measurements.

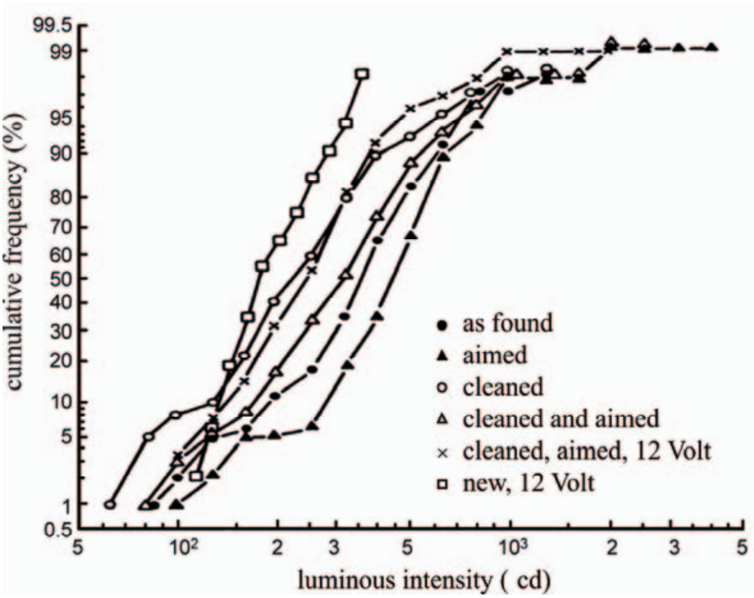

Fig. 4.15 Cumulative frequency distributions of luminous intensities in a direction important for glare to oncoming drivers, for headlights on fifty cars as found; aimed; cleaned; cleaned and aimed; cleaned, aimed and operated at 12 V; and for new headlights (after Alferdinck and Padmos 1988)

Fig. 4.15 shows the cumulative frequency distributions of luminous intensity in a direction important for glare to an oncoming driver, for fifty cars taken from a parking lot. From Fig. 4.15 can be seen that the headlights, as found, tend to produce more glare than new headlights. Adjusting headlights which were aimed too low makes things slightly worse. But cleaning headlights reduces glare caused by luminous intensity and again brings it close to that of new headlights. The ranges of luminous intensities shown in Fig. 4.15 suggest that fine differences between the recommended headlight luminous intensity distributions used in America and in Europe are trivial compared to the differences that occur in practice, due to aiming, lamp age and dirt. This in turn supports the installation of automatic levelling and cleaning systems for headlights on vehicles.

4.2.7 Xenon and halogen headlights

The most dramatic change in headlights over the last decade has been the widespread adoption of the high intensity discharge (HID, xenon) headlight. Xenon headlights differ from conventional halogen headlights in three respects; the size of the light source, the luminous intensity distribution from the headlight and the spectral power distribution of the light emitted.

The arc tube of the xenon light source is smaller than the filament of halogen light sources, with the result that headlights using xenon light sources can be smaller. This is of little consequence for glare, because headlights usually subtend such a small solid angle from the normal viewing distance, that headlight area has only a small effect on discomfort.

As for the luminous intensity distribution of xenon headlights, the recommended minimum and maximum luminous intensities used in different parts of the world, apply regardless of the light source used; so xenon headlights are designed to meet these requirements. However, the xenon light source has a much higher luminous efficacy than halogen light sources. Thus xenon headlights typically have a higher maximum luminous intensity than tungsten-halogen headlights. They also send more light to the sides of the vehicle in areas that are not controlled by the current regulations. These differences in the amount and distribution of light from xenon headlights, together with the variability introduced by aiming, dirt, and the different geometries that can occur between two approaching vehicles, are probably enough to explain the widespread anecdotal complaints of disability and discomfort glare from drivers meeting vehicles equipped with xenon headlights. It also explains why people driving vehicles equipped with xenon headlights like them. Fig. 4.16 shows contours for the detection of a 40 cm square target of reflectance 0.1, by drivers using either dimmed xenon headlights or dimmed halogen headlights (Rosenhahn and Hamm 2001). Clearly, the xenon headlights conforming to the same regulations, allow objects to be detected at greater distances and over a wider range of angles than tungsten halogen headlights. It is also worth noting that a driver meeting a car equipped with xenon headlights is likely to be exposed to higher illuminances for longer than if the car was using tungsten halogen headlights. Consequently, the time for recovery from glare should be longer for the xenon headlight.

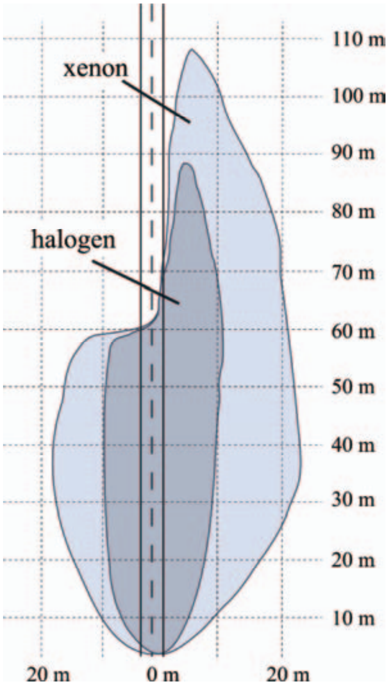

Fig. 4.16 Contours for the distance at which a target 40 cm square, with a reflectance of 0.1, is detected by drivers for either dipped xenon headlights or dipped halogen headlights (after Rosenhahn and Hamm 2001)

The spectral power distribution of the xenon headlight is very different from that of the halogen headlight having much more energy at the short wavelength end of the visible spectrum. This alone will tend to lead to greater discomfort for the same illuminance at the eye (Bullough et al

2003). Fig. 4.17 shows ratings of discomfort on the de Boer rating scale for tungsten halogen and xenon headlights (Fu 2001). It is clear that the illuminance at the eye is the major factor in producing discomfort, but there is no doubt that the spectrum has an effect as well.

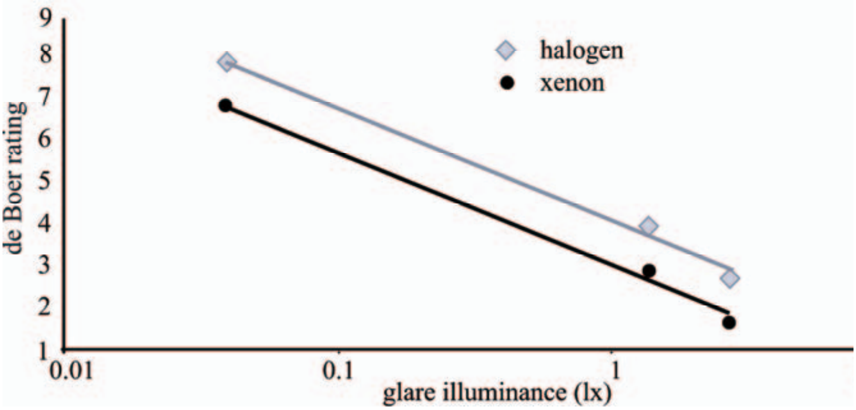

Fig. 4.17 Mean de Boer glare ratings for exposure to halogen and xenon headlights producing the same illuminances at the eye (after Fu 2001)

To evaluate the effect of any specific headlight spectrum on discomfort glare, Dee (2003) has proposed a spectral sensitivity curve as follows:

$$V_{dg}(\lambda) = V_{10}(\lambda) + (0.19 \cdot SWC(\lambda))$$

…*where* $V_{dg}(\lambda)$ = *Discomfort glare spectral sensitivity*
$V_{10}(\lambda)$ = *Photopic spectral sensitivity for a 10 degree field*
SWC (λ)) = *Short wavelength cone spectral sensitivity*

The discomfort glare spectral sensitivity normalised to unity is shown in Fig. 4.18. This discomfort glare spectral sensitivity has been shown to rectify discomfort glare ratings for conditions simulating exposure to headlights from both white light and monochromatic glare sources (Watkinson 2005).

Given the tendency for expensive options first introduced in up-market vehicles to gradually spread into cheaper vehicles, it seems likely that xenon headlights will soon become much more widely used, replacing halogen headlights, just as they replaced tungsten headlights. This is also likely because the higher luminous intensities available with xenon headlights and the smaller possible headlight sizes place fewer constraints on automobile design. The problems of disability and discomfort glare can be solved by regulating the maximum luminous intensity allowed in all directions relevant for glare. This could be achieved by more precise optical design, and by greater attention to the aiming and cleanliness of headlights already installed in vehicles. Already some countries require that a vehicle equipped with xenon headlights be fitted with a self-levelling suspension, while others require the installation of headlamp cleaning systems.

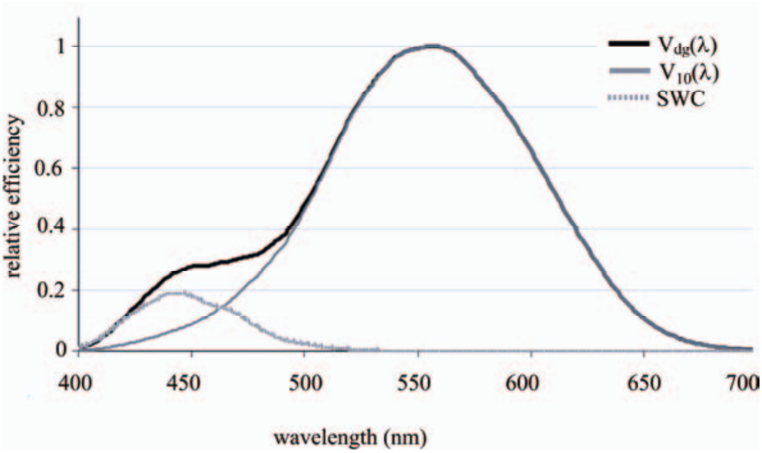

Fig. 4.18 Proposed discomfort glare spectral sensitivity normalised to unity (after Watkinson 2005)

4.2.8 Conclusion

By now it should be apparent that simultaneously providing good visibility to both drivers of two opposing vehicles remains a problem for automotive lighting. There are many ways that drivers attempt to solve this problem, some more effective than others, but all pay a price. Until a means whereby parts of the headlight beam can be dimmed as necessary, particularly those parts of the beam that are illuminating the opposing driver, the balance between glare and visibility is likely to remain a problem.

Spotlight

20 ways of dealing with glare

When driving at night I dislike approaching undipped headlights. My wife feels irritated driving in daylight when the sky seems too bright. Driving instructors recommend avoiding looking directly into the headlights of an oncoming car.

Glare can be painful, disabling or both. Most of the time we just put up with it. But some of us have our own ways of dealing with glare. The following is a list of avoidance tactics. N.B. some of them are inadvisable and should not be copied.

Daytime

- Bright sunlight - use sunglasses on bright days
- Tunnel entry - close one eye a little before entering a tunnel in order to be adjusted (beware: loss of stereo vision!)
- Tunnel entry - many tunnels now have a threshold zone which adjusts the light levels gradually,
- Bright sky - when driving during the day use the visor to shield the eyes from the bright sky
- Bright sky - install a tinted screen or an external visor at the top of the windscreen
- Wet road reflection - shield the eyes with your hands to avoid reflections of the sun on a wet road

Dusk or dawn

- Low sun - shield the eyes with the visor or your hand against low sun rays
- Low sun flickering through trees lining road- shield eyes with hand or flip visor to the side
- Fog or Snow – reduce the glare produced by your own vehicle by dipping the headlights
- Fog or Snow – reduce the glare produced by your own vehicle by driving with just the fog lights (not permissible in many countries)

At night

- Other traffic - many people, particularly senior citizens, do not drive at night at all
- Other traffic - use special sunglasses (beware: loss of brightness)
- Headlights from behind - dim rear view mirrors (beware: loss of brightness in rear vision)

- Headlights from behind or the neighbouring lane – tilt wing mirrors (beware: some loss of rear vision)
- Headlights from behind – fit low transmission glass to rear window (not permissible in some countries. Beware reduced visibility when reversing)
- Oncoming traffic - dip headlights
- Oncoming traffic - remind the oncoming driver to dip his headlights by flashing your own (N.B. in many countries this is not legal)
- Oncoming traffic - avoid looking directly into the headlight of the oncoming car
- Oncoming traffic - close one eye a little before meeting the other car (beware: loss of stereo vision!)
- Following traffic - use handbrake when motionless to avoid glaring the driver behind
- Wet road reflection - Shield the eyes with your hands to avoid reflections of the headlamps on wet road

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