PERSPECTIVE

Why HID headlights bother older drivers

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Driving requires effective coordination of visual, motor, and cognitive skills. Visual skills are pushed to their limit at night by decreased illumination and by disabling glare from oncoming headlights. High intensity discharge (HID) headlamps project light farther down roads, improving their owner's driving safety by increasing the time available for reaction to potential problems. Glare is proportional to headlamp brightness, however, so increasing headlamp brightness also increases potential glare for oncoming drivers, particularly on curving two lane roads. This problem is worse for older drivers because of their increased intraocular light scattering, glare sensitivity, and photostress recovery time. An analysis of automobile headlights, intraocular stray light, glare, and night driving shows that brightness rather than blueness is the primary reason for the visual problems that HID headlights can cause for older drivers who confront them. The increased light projected by HID headlights is potentially valuable, but serious questions remain regarding how and where it should be projected.

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High intensity discharge (HID) headlights are brighter, more energy efficient, and longer lasting than conventional incandescent headlights. They allow owners to detect road hazards, signage, and pedestrians at greater distances. They are standard equipment on growing numbers of more expensive automobiles.

HID headlights probably improve the safety of night driving for their users. Unfortunately, they can dazzle viewers on two lane highways, making it more difficult for approaching drivers to identify pedestrians, road hazards, and curves in the road. Night-time driving is difficult for older individuals. Confronting HID headlights makes it even more difficult. To understand why older drivers may complain about their encounters with HID headlights, it is useful to understand automotive headlight design and how ageing affects intraocular light scattering, glare, and automobile driving.

HEADLIGHTS

Conventional headlights use incandescent light bulbs. An incandescent bulb consists of a tungsten filament mounted in a sealed glass container. The bulb is evacuated or filled with gases to prevent filament oxidation. The filament glows when it is heated by an electrical current. Higher filament temperatures produce brighter, bluer light. They also shorten a filament's lifetime.

A tungsten-halogen (halogen) bulb provides brighter light at higher filament temperatures, using a regeneration cycle to lengthen the tungsten filament's lifetime.[1] A halogen gas such as iodine is added to the bulb's atmosphere. When tungsten evaporates from a heated filament, it collects on relatively cool bulb surfaces where it combines with iodine. Volatile tungsten-halide diffuses back to the heated filament, dissociating and redepositing tungsten on the filament. Irregularities in the redeposition process eventually cause filament thinning and bulb failure. Halogen bulbs are used widely in automotive headlights and also in ophthalmic instruments. The luminous power output of halogen headlights increases with increasing wavelength across the visible spectrum.[2–4]

HID lamps overcome many of the limitations of incandescent bulbs. A discharge lamp consists of two electrodes in a quartz container filled with a high pressure gas. An electronic starter initiates an electric discharge between the electrodes, producing an ionised gas (a plasma) that generates a continuous spectrum of light as well as narrow spectral lines. Mercury arc highway illumination lamps are HID devices. Xenon HID headlights produce some continuous spectrum white light, but much of their luminous power is generated as broadened spectral lines, including blue lines at 405, 435, and 475 nm.[4] HID headlamps produce two to three times more luminous power (flux) than halogen bulbs.[5 6]

The colour temperature of a light source is the temperature of a black body that emits radiation of the same subjective colour as the light source.[7 8] Higher colour temperature sources have a bluer appearance. Conventional incandescent bulbs, halogen incandescent bulbs, xenon HID bulbs, and the sun's disc at midday when viewed from ground level have colour temperatures around 2800, 3200, 4200, and 5600°K, respectively.[1 8] Thus, HID bulbs are not as blue as ordinary sunlight, but they are brighter and bluer than conventional halogen bulbs.

A HID headlight system consists of a discharge lamp, its electronics, and a reflector. Reflector design determines the illumination pattern projected ahead and adjacent to a vehicle.[3] It is also a key factor in determining how bright a headlight appears to an observer (that is, the headlight's luminance in candles/m², where a candle is luminous intensity in lumens/steradian) or how brightly the headlight lights up a surface at the observer's location (that is, the surface illuminance that the headlight produces in lumens/m² or lux).[3 9]

Automobiles have high beam and low beam illumination systems. High beam illumination is

aimed parallel to the road surface and not intended for use with oncoming traffic. Low beam headlights are aimed slightly downward to reduce glare for oncoming drivers. The brightest central area ("hot spot") in HID headlight illumination patterns is positioned away from the centre of the road so as to reduce an oncoming driver's light exposure. Compared to halogen low beam headlights, HID headlights have a larger hot spot, project light farther down the road, and project light farther to the right and left of their optical axis.

Low beam HID headlight systems in Europe and the United States have comparatively sharp and soft horizontal illumination cutoffs, respectively.[5 10 11] Luminous intensity drops off abruptly (sharp cutoff) above the height of European headlights, but declines more slowly (soft cutoff) above the height of American headlights. Each of these illumination patterns has its own advantages and disadvantages. European HID headlights provide more light close to driver and less light farther down the road than American HID headlights. The sharp cutoff of luminous intensity above the horizontal height of European headlights protects oncoming drivers from glare, but limits visibility distance. The sharp cutoff also causes "flashing" on bumpy roads when the horizontal cutoff bounces up and down, into and out of an oncoming driver's field of view. Conversely, the softer American horizontal cutoff causes more glare for oncoming drivers but provides better overhead sign visibility, less flashing, and longer visibility distances. Adaptive headlights that adjust to changing driving conditions could offer the advantages of both American and European illumination systems.[5]

LIGHT SCATTERING

Scattered light from oncoming headlights makes night driving more difficult, in part because the human eye is an imperfect optical device. Light from the visual environment enters the eye through the pupil and is imaged on the retina. Additional light enters the eye by transillumination through the iris and sclera. Some light is absorbed in photoreceptor photopigments or other pigments such as melanin, haemoglobin, xanthophyll, and lipofuscin. Some of it is deflected by light scattering in ocular tissues.

Light that has been scattered in the eye is termed "stray" light. Stray light reaching the fovea decreases the contrast of foveal images, producing disability glare. Light scattering, reflection, and absorption determine the spectrum of intraocular stray light.[12–16]

The directionality and spectrum of scattered light depends on the density and size of the particles that scatter the light. Particle density determines the intensity of light scattering.[7] Particle size determines its directionality and wavelength dependence.[17 18]

Small particle or Rayleigh scattering has no preferential direction, but small particles scatter shorter wavelengths more efficiently than longer wavelengths.[7 17 19] Daylight sky is blue because light reaching an observer from any direction other than directly out of the sun is scattered by atmospheric particles that are small in comparison to visible light wavelengths. Conversely, light coming directly from the setting sun appears red because shorter wavelength light is scattered out of the sun's image during atmospheric transit.

Large particle or Mie scattering is not wavelength dependent, but light is preferentially scattered in the forward direction.[7 17] Mie scattering by retinal pigment epithelial melanin granules, roughly 1000 nm in diameter,[20 21] improves retinal image contrast by suppressing side scattered light.[22] Fog doesn't change the apparent colour of automobile headlights because large fog droplets scatter all visible wavelengths equally effectively.

Stray light from the cornea and lens decreases with increasing wavelength,[16] showing the influence of small particle scattering. Stray light from fundus reflectance or transillu-mination increases with increasing wavelength,[16 23] showing the influence of the decreased optical absorption of melanin and haemoglobin in the red end of the visible spectrum.[15] The net effect is that stray light reaching the fovea has little wavelength dependence.[16 24 25] Thus, blue-white HID headlights should produce no more foveal stray light or disability glare than white headlights of the same luminance.

GLARE AND PHOTOSTRESS

Glare can cause discomfort or disability.[26 27] Discomfort glare does not impair vision, but it can be startling or distracting to a driver, and cause blinking, squinting, ocular aversion, and fatigue. The physiological and psychophysical origins of discomfort glare remain uncertain.[28 29]

Disability glare does impair visual performance. It has been divided classically into "veiling," "dazzle," and "scotomatic" glare based primarily on the type of glare source.[30]

Veiling disability glare occurs when a diffuse light source reduces the contrast of a visual target by "somewhat uniformly" superimposing light on the visual target's retinal image.[30] Veiling glare makes outdoor reading more difficult in bright sunshine.[30] It also obscures indoor visualisation of material between two adjacent windows illuminated by brilliant sunlight.[30]

Dazzle disability glare occurs when a bright glare source is imaged at an extrafoveal location.[30 31] Ocular transit scatters some light from the glare source light onto the viewer's fovea. This stray light decreases the contrast between the lighter and darker details of a visual target's foveal image.[14 32–34] Dazzle glare from an oncoming vehicle's headlights makes it more difficult at night for a driver to identify the edge of a curving two lane highway.

Scotomatic disability glare occurs when a brilliant light source decreases visual sensitivity ("puts a retinal area temporarily out of business").[30] Sensitivity is diminished while the visual system rapidly light adapts during glare exposure and then more slowly dark adapts after glare exposure. This "photostress" may startle and disorient observers, producing afterimages that interfere with vision.[35] Scotomatic glare occurs during flash photography and momentary exposure to an inept lecturer's laser pointer beam.[36] It is caused primarily by rapid bleaching and subsequent slower regeneration of retinal photoreceptor photopigments.[30 31 37–39]

Clinical glare terminology is influenced by its testing methods. In ophthalmic parlance, clinical disability glare generally refers to classic veiling and classic dazzle glare[30] produced by intraocular stray light.[14 34] Clinical photostress refers to classic scotomatic glare[30 40 41] caused by photopigment bleaching, regeneration, and associated psychophysical processes.[41–48] Clinical terminology will be used throughout the rest of this perspective.

Strictly speaking, clinical disability glare (classic veiling and classic dazzle glare) is an optical process which should resolve immediately after glare exposure because visual adaptation is unaffected. Conversely, photostress is a psychophysical process which should persist after light exposure because dark adaptation takes time to restore visual sensitivity to its preexposure level. In reality, most clinical glare tests don't differentiate between optical and psychophysical processes. Clinical glare sources are often bright enough to produce photostress as well as disability glare, accounting for the use of terms such as "glare recovery time"[49 50] for "photostress recovery time."[38 51 52] Light adaptation can be controlled in specialised disability glare tests,[53] but photostress sources always produce stray light and disability glare sources can alter visual adaptation.

Further confusion arises because methods other than disability glare and photostress testing can be used to study visual perception in suboptimal viewing circumstances.

Disability glare testing illuminates a patient's eye with an off-axis light source to produce stray intraocular light that decreases the contrast of a foveal target. Visual performance under adverse conditions can also be studied without a separate glare source, however, by decreasing the contrast of an extraocular target before it is imaged on the retina. For example, reduced contrast optotypes and sine wave gratings are used in variable contrast acuity and contrast sensitivity testing.[54–57] These studies are not considered to be disability glare or photostress tests, but they use light sources, so they do produce intraocular stray light and disability glare.

TESTING GLARE AND PHOTOSTRESS

Discomfort glare can be quantified from numerical estimates of the extent of discomfort that people experience when they are exposed to a particular retinal illumination while performing a specific visual task. Discomfort glare varies at different times and in different individuals, and it is worse in older than younger people.[4 26 34 58 59]

Most disability glare tests measure visual thresholds for optotype, grating, or acuity targets in the presence or absence of a glare source.[27 53 60–66] Poor performance on glare sensitivity testing is often referred to as increased "glare sensitivity" or decreased "glare resistance." Stray light that causes glare can be measured without threshold testing using an annular flickering glare source that scatters light into the fovea. The intensity of a foveal target flickering in counterphase with the glare source is adjusted until flickering from the peripheral glare source is no longer visible.[67–69]

Stray light and disability glare increase with increasing glare source intensity because there is more light scattered intraocularly to reduce retinal image contrast.[14 16 23 27 30] Light scattering increases in people over 50 years of age.[14 16 25 33 70 71] Degenerative changes throughout the visual system may reduce the efficiency of visual information processing.[38 59] Older individuals perform worse than young ones on standard disability glare tests, and even worse if they have cataract formation.[33 59 65 72 73] Disability glare is increased by cataract,[74] intraocular lens implantation,[75–77] and posterior capsule opacification.[78] Transient glare as occurs in a headlight encounter is worse than static glare from a light source of the same luminance, and this effect increases with ageing and media opacities.[66 79]

Most clinical photostress tests measure how long it takes for visual sensitivity to recover after bright light exposure. Vision is the most common test end point,[39] but pupillary[80] and visually evoked[81 82] recovery times can also be measured. Photostress luminances and exposure durations vary between protocols. Photostress recovery times have been monitored with visual acuity test letters, grating targets, and Landolt-C dark adaptometer targets.[40 51 52]

Photostress recovery time increases with photostress source luminance.[31 35 43 48] It also increases with ageing, although different rates of increase are reported for different testing methods.[38 49 50 83–85] Macular degeneration and other retinal disorders markedly prolong recovery times.[39 52 86 87]

AGEING AND NIGHT DRIVING

The older driver is visually disadvantaged. Almost all self reported and clinical measures of visual function decline with ageing.[73 88–91] Eye disorders increase this problem, and their prevalence also increases with ageing.[88 92 93] Even when high contrast visual acuity is normal, visual performance decreases with increasing age on most other sensory tests, including visual field, glare recovery time, stereopsis, contrast sensitivity, and low contrast visual acuity with and without glare.[72 89–91 94]

Successful driving is a symphony of visual, motor, and cognitive abilities.[95–99] Declining vision increases non-sensory demands, which also decline with ageing. Older drivers tend to make less efficient eye movements[100] and slower

decisions[101] in driving situations. Cataract, visual field loss, and glaucoma are all associated with increased accident risk, as are reduced mesopic vision and increased glare sensitivity.[94 102–108]

Night driving is a mesopic (intermediate brightness vision) rather than a scotopic (night-time vision) or photopic (daytime vision) task. It can push even normal visual systems to their limits. Visual acuity decreases with decreasing target illumination. This loss is greater in people over 65 years of age.[109 110] The distance at which night-time highway signs can be read decreases significantly in older individuals compared to younger people of the same visual acuity.[111] Headlight glare sensitivity also increases with ageing.[26]

The increased brightness of HID headlights is an advantage for the older drivers who use them. They enable owners to see farther down straight roads, providing them with more time to respond to potential problems. Conversely, disability glare and photostress recovery time increase with glare source luminance.[14 23 27 30 31 35 43] Thus, HID headlights can produce more glare than halogen headlamps for drivers who confront them on curving or hilly two lane highways.

Older individuals have increased intraocular stray light, glare sensitivity, and photostress recovery time.[26 33 38 49 50 72 73 83–85 112] Thus, confronting brilliant HID headlights is a greater potential problem for older than younger drivers. HID headlights also cause more discomfort glare than conventional halogen headlights of the same photopic or scotopic illuminance.[2 4 113] This potential distraction is greater in 61–77 than 20–31 year old drivers.[4]

Windshield or spectacle filters decrease night-time visibility, so they are not a useful solution for headlight glare.[114–116] Some older drivers simply choose to limit their night-time driving,[107 117 118] but there is still a need to develop screening techniques to identify drivers at greatest accident risk.[79 103 106 119 120] Promising techniques have been examined,[91 104 120 121] but the selection of appropriate methods for screening older drivers raises complex medical, social, and legal issues that remain under investigation.

Practical solutions for the highway glare problem have been studied for decades.[3 5 26] Countermeasures have never been implemented seriously because of consumer disinterest, manufacturer resistance, and lack of legislative resolve. HID headlight glare has now captured the attention of many consumers. There have been improvements in divided highway design such as wide medians and glare screens separating opposing lanes. Unfortunately, these construction advances can't be implemented on two lane, undivided highways where headlight glare is worst.

Glare countermeasures include adaptive headlights and ultraviolet headlight systems. Adaptive headlight systems monitor and compensate both optically and mechanically for changing traffic, road, and meteorological conditions. Ultraviolet headlight systems project invisible ultraviolet radiation, improving the visibility of fluorescent highway markers, signs, and objects without increasing glare for oncoming drivers. Ultraviolet radiation is especially valuable in fog because highway signs can fluoresce in the visible spectrum when exposed to ultraviolet radiation, but backscattered ultraviolet radiation is invisible so it can't reduce the contrast and legibility of the signs. This situation is similar to retinal imaging in patients with asteroid hyalosis. Ordinary reflectance images have poor detail because back scattered flashlamp light reduces the contrast and visibility of retinal features. In fluorescein angiography, however, back scattered blue light from the photographic flash is blocked from reaching the camera by a barrier filter, and green fundus fluorescence provides good retinal image contrast.

Polarising headlight systems are perhaps the best solution to the highway glare problem.[5] A polarising filter is placed in front of all automobile headlights, with its axis of polarisation inclined at 45° to the vertical. Another polarising filter known as an analyser is placed in front of the eyes of all drivers. Analysers have the same axis of polarisation as polarisers in front

of their own headlights, which is perpendicular to that of polarisers in oncoming vehicles. Thus, analysers block light from opposing traffic but transmit light scattered from roadside objects by their own headlights. Even ideal analysers block approximately 50% of the light reaching them, but HID headlights provide adequate headlamp brightness for fixed analyser systems, and there are methods for switching analysers on and off when polarised light is detected. A major drawback in the adoption of polarising headlamp systems is the fact that their cost would be borne by their owners, but the systems would benefit only oncoming drivers until they became widely used.[5]

CONCLUSION

A HID headlamp manufacturer touting the fact that a "xenon bulb produces more than twice the amount of light of a halogen bulb,"[6] answered the question "Why does xenon light sometimes appear to irritate oncoming drivers?"[6] by explaining that "due to the conspicuous colour of xenon light, drivers are more inclined to look in the headlamps."[6] Older drivers encountering HID headlights on a winding two lane highway know that "photophilia" isn't the answer.

Night driving can push any visual system to its limits. Conventional clinical glare tests underestimate disability glare from moving light sources. Disability glare increases with increasing glare source brightness. HID headlights are brighter than conventional tungsten-halogen headlights. Thus, they cause more disability glare under identical viewing circumstances.

Visual quality declines with ageing, even in individuals with 20/20 visual acuity. Glare due to intraocular light scattering increases with ageing, prompting many older drivers to curtail their night driving activities. Increased glare from HID headlights is one more visual hurdle for the older driver.

Aircraft landing lights would allow automobile drivers to see farther down a road. They would also incapacitate oncoming drivers. Brighter headlights do provide increased visibility for older drivers who use them. They also cause more glare for older drivers who confront them. The optimal balance in headlight brightness between owner visibility and viewer disability depends on the driving situation, but technologies are available for more adaptable, less bothersome headlight systems.

Governmental regulations determine which headlights we encounter. Acceptance or rejection of the current generation of HID xenon headlights ultimately depends on their record in traffic and litigation. Xenon bulbs make good headlights. They also make good glare sources. The additional light they project is valuable. Questions remain regarding how and where it should be projected. Until these questions are resolved, for many older drivers confronting stylish HID headlights on two lane roads, glare rather than beauty will be in the eye of the beholder.

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