

ZEISS DriveSafe.

Safety and comfort for challenging driving conditions.

Driving a car is a necessity for most spectacle wearers and many drivers are faced with discomfort and anxiety when driving in difficult lighting and conditions of poor visibility. Their fear is justified: statistics reveal a much higher risk of fatal accidents in those conditions. The causes are well understood and a spectacle lens for drivers should mitigate the risks of discomfort glare from automotive headlamps and the reduced spatial and temporal vision abilities that accompany mesopic vision. ZEISS introduces new DriveSafe lenses in both single-vision and progressive addition designs that are well-suited for all day activities but perform especially well when driving at dusk or at night.

Driving is a Stressful Necessity of Everyday Life

Our vision is confronted by changing environments and tasks throughout the course of a day. One response has been the development of special purpose lens designs adapted to specific task requirements such as sports, sun protection or computer use. These designs are usually better suited as 2nd or 3rd pairs of glasses because they lack utility for a wide range of activities. Driving an automobile presents especially great challenges. But, driving is also not such an unusual task with narrow requirements that it should always demand a specialized set of 2nd or 3rd pair of lenses. Moreover, recent market research conducted by ZEISS¹ has revealed that driving is anything but a leisure activity for the 83% of spectacle wearers who are drivers. The great majority (72%) are very interested in a single pair of eyewear to provide an everyday solution that also copes with the special challenges of driving. The same research showed that the major contributors to discomfort and stress are driving in rain, mist or fog, and driving in twilight or nighttime (Figure 1).¹

The Challenge of Illumination

Drivers have a good reason to be wary of low light conditions. A disproportionate number of fatal road injuries occur after nightfall. Thirty percent of all fatal car accidents in Germany^{2,3} happen in low light conditions and at night. In 2010 forty eight percent of fatalities among passenger vehicle occupants in the USA happened at night.⁴ A study in the UK revealed that more than half of all fatal accidents happen after dark although far fewer miles are driven at night. Furthermore, the study found the likelihood of death during an accident is twice as great when the accident happens at night. This study concluded that poor illumination was the principle cause of nighttime road accidents.⁵ A further study reported that 50% of all people find that driving a car at night is stressful due to poor lighting and that they would welcome any system that could help improve nighttime visibility.⁶

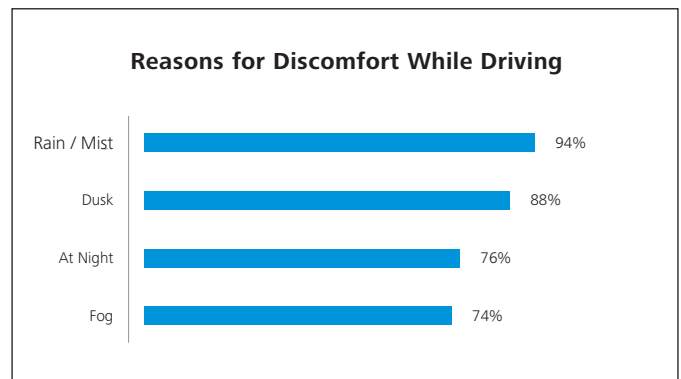


Figure 1. Reasons for wearer's discomfort while driving¹.

The Challenge of Glare

One way in which some countries responded to the problem of illumination has been to increase the number and intensity of roadway lighting. But this is expensive and impractical in many areas, and creates other problems such as increased energy consumption. Automotive lighting suppliers have responded by developing high-intensity discharge (HID/Xenon) and LED headlamps that are brighter and provide better illumination of the road. Drivers have appreciated the increased visibility of the external environment provided by these lamps.

But the increasing prevalence of automobiles with these new and brighter headlamps has led to driver complaints of glare when looking down the road toward oncoming cars. The increased brightness causes *disability glare* that reduces the ability to see objects close to the direction of the light source. In addition, the latest types of headlamps emit a higher proportion of bluish light than older halogen lights, and this color shift has increased the frequency and severity of complaints about *discomfort glare*, the unpleasant and stressful



We make it visible.

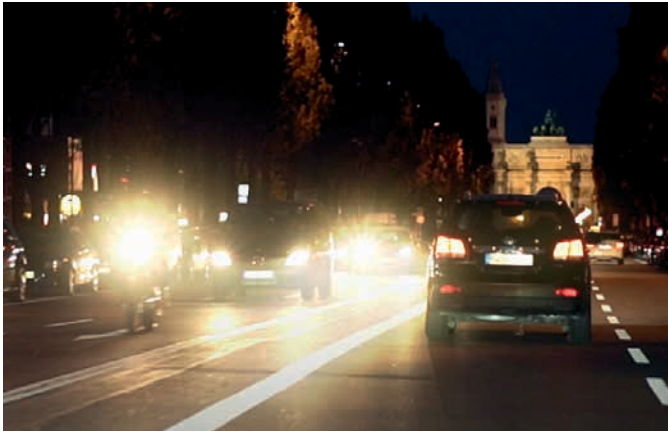


Figure 2. Glare with oncoming headlights in traffic.

sensation experienced when looking toward a bright light (Figure 2).⁷ Older drivers with increased lenticular light scatter or clinically significant cataracts often report more severe glare symptoms than younger drivers.⁸

The Challenge of Complex Visual Tasks

Driving presents a complex set of requirements, day or night. The driver must contend with a rapidly alternating set of circumstances that require frequent change of attention. One is the view down the road to see the way forward, anticipating future turns, acceleration or stopping. Another is peripheral awareness of spatial location within traffic flow as well as the detection of potential threats posed by other drivers or road hazards.⁹ Along with those requirements is a need to check several mirrors to remain aware of traffic that is coming toward the driver from behind.

A further challenging requirement is rapidly identifying important information presented in multiple visual displays on the instrumentation panel both straight ahead and to the side. In the name of safety, automobile manufacturers continue to increase the number of information sources in their cars, adding features such as proximity warning and blind spot detection lights on side mirrors. The complexity of this suite of tasks forces frequent eye and head movement with concomitant changes of gaze direction, fixation locus and accommodation.¹⁰

The effect of increased driver's attentional load and extended reaction time was confirmed with presbyopic wearers of progressive addition lenses, where also greater eye & head movement were observed.¹¹ Particularly in stressful conditions of poor visibility, reaction times increase and the time spent changing fixation becomes even more critical.

Research also has shown that even a small amount of night myopia (between -0.50 and -1.00 D) in the presence of subcritical glare level of 0.4 lx results decreases contrast sensitivity at night more than glaring LED headlamps of 1. lx when vision is fully corrected.¹²

Three Vision Challenges: Three Solutions, One Lens

ZEISS research confirms that unfavorable light conditions, glare and the stressful visual and accommodative tasks presented to drivers have a high impact on the quality of vision while driving. The various findings indicate the complexity of designing adequate lenses for safe driving in critical conditions. During the development of DriveSafe, these three vision challenges were targeted with corresponding solutions developed in one product, available either as a single vision or progression addition design according to the accommodative needs of the wearer.

I. Illumination Challenge

While driving, the visual system must adapt quickly to different light levels. The pupil light response provides the fastest reaction to a change in illumination, and has a significant effect on the performance of spectacle lenses. Minimum pupil size occurs at the highest levels of ambient illumination, at a time when drivers feel safest. The most threatening time to drive is after dusk or in darkness, when light levels are low and pupils are large.

Three general levels of illumination are recognized: the photopic, scotopic and mesopic ranges (Figure 3).

Photopic vision leads to the best temporal and spatial contrast sensitivity and acuity and is fully active at an illuminance level of 1 lx and higher. This heightened temporal and spatial ability is contributed by the cone photoreceptors, whose combined sensitivity to light peaks at a wavelength of about 555 nm. Only the cones contribute to color vision, and so the sensitivity to color differences is best in photopic vision. At photopic light levels the rods of the retina are saturated and therefore contribute very little to vision.

Scotopic vision is most sensitive to light at blue-green wavelengths of about 505 nm - 510 nm and is fully active at illuminance levels of 0.01 lx or lower. This condition is rarely experienced when

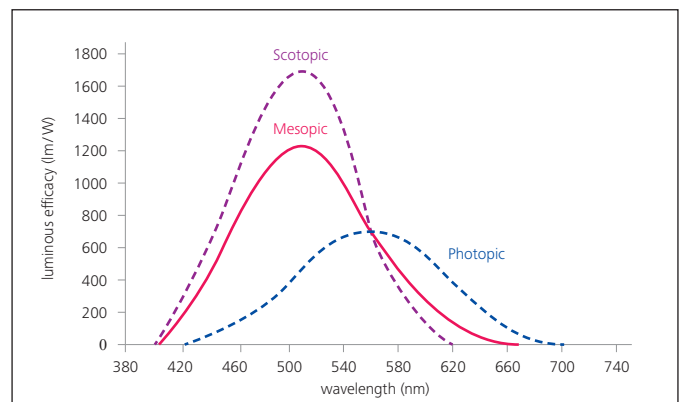


Figure 3. Peak luminous sensitivity of the human eye shifts from green toward blue at low illumination levels.

driving, occurring only in the darkest places without artificial illumination, for example on a moonless night with an overcast sky. Scotopic vision is provided by the rod photoreceptors; since there is only one kind of rod, scotopic vision is without sensation of color, only brightness. The rods have poor acuity and they are slow to respond, providing poor input to reaction time. Furthermore, achieving best vision in scotopic light levels requires adapting for at least twenty minutes.

Typical automotive headlamps cast an illuminance of about 0.3 lx at a range of 150 m in US and 0.4 lx at a range of 50 m in Europe (in relation to different standards and norms), approaching the photopic range.^{13, 14} However, a driver's peripheral vision may be challenged to detect poorly illuminated hazards outside the illuminated patch provided by a car's headlamps, even if they are not at a truly scotopic level of illumination.

Mesopic vision falls between the photopic and scotopic ranges with illumination levels between 0.01 and about 1 lx. Both rods and cones take part in this intersection of vision. Most night and twilight driving is illuminated at the mesopic level, and the most common driver complaints about poor illumination happen at this level. At the mesopic level both acuity, color sensitivity and temporal responses are reduced compared to photopic levels.

The pupil light response produces the smallest pupils at photopic light levels (miosis) and the widest pupil at scotopic levels (mydriasis). But pupil dilation is still quite significant at mesopic levels and the dilation occurs at the cost of increased aberrations and decreased acuity (Figure 4). One effect of a larger pupil is that high order aberrations (HOA) of the eye have an increased impact (Figure 5), decreasing the contrast of the retinal image and changing the effective refractive error so that a different set of correcting dioptric powers are needed than ones measured when the pupil is small.¹⁵

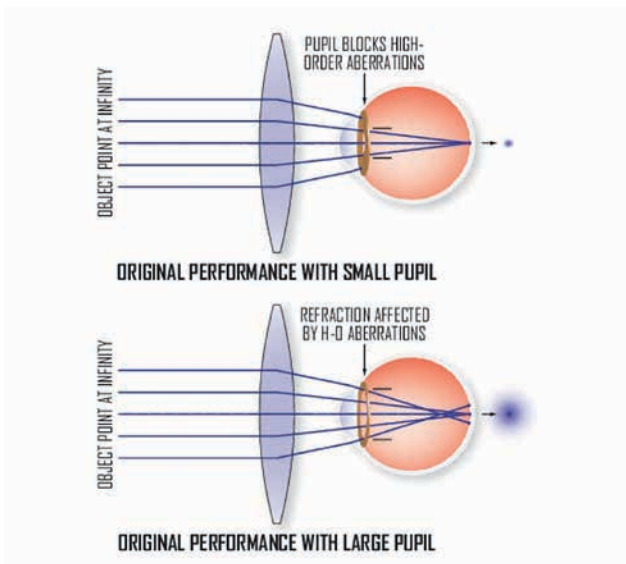


Figure 4. Effect on HOA and pupil size on retinal image.

PROBLEM: Visibility and Contrast

At mesopic illumination levels, acuity and contrast sensitivity decrease intrinsically at the retina and in the visual pathways of the brain. The increased pupil area produced by its dilation in response to reduced light level further reduces retinal image contrast. In the presence of fog and rain, the contrast of objects outside the car is also reduced by light scatter from water droplets in the air. When the visual system's physiological response is reduced by low light and object contrast is further reduced by atmospheric effects, it is imperative that the optical performance of spectacle lenses be as good as possible. Yet the off-axis aberrations of single vision lenses and the intrinsic second order aberrations of progressive lenses can further interact with the enlarged pupil to create even worse image quality.

SOLUTION: Luminance Design® Technology

The traditional way of designing a lens is by following a "chief ray"¹⁶ at any point of interest on a lens, determining the curvatures of the lens at the points where the chief ray intersects the lens surfaces and calculating the change in dioptric powers according to the angles at which the chief ray strikes the surfaces.¹⁷ In effect, this means that the traditional calculation assumed that the pupil has only a location, not a diameter.

ZEISS recently introduced Luminance Design technology in its ZEISS Progressive Individual® 2 lens to overcome that limitation. The new method of lens computation calculates dioptric powers using the entire beam of light that passes through the pupil. Individual 2 is optimized for the expected frequency and lighting level of various daily tasks; it is designed as a general-purpose progressive lens. With DriveSafe lenses the calculations and optimization are performed for the larger pupil sizes expected in mesopic lighting conditions.

Figure 6 illustrates the concept schematically. The figure shows an eye looking ahead through a point on a progressive lens surface. With the traditional method, the dioptric power at that point on the surface would have been calculated using only the vergence of

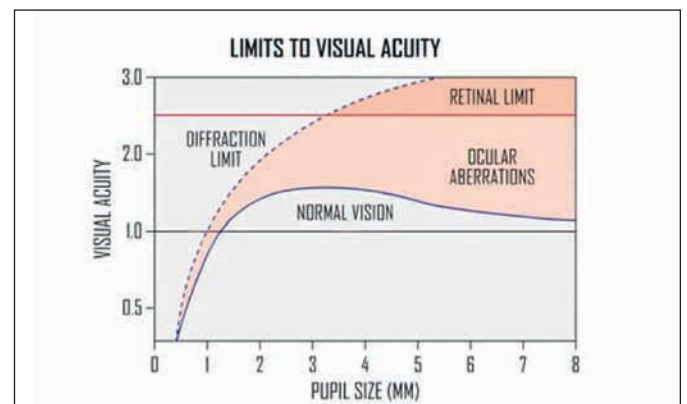


Figure 5. Limits to visual acuity as function of pupil size.

a single ray intersecting the surface, its horizontal and vertical angle of intersection with the surface, and the curvatures of the surface at that point. In Luminance Design, many rays are mapped that span the aperture defined by the pupil to calculate the dioptric power of the entire beam of light. The left side panel illustrates how pupils get bigger under mesopic light levels, thereby producing a wider beam through the pupil. The lower panel shows how the pupil constricts under brighter daylight conditions, thereby resulting in a narrower beam. The rear panel shows a projection of the two different beam diameters upon the target dioptric power distribution of the progressive design. The two concentric red circles represent the two pupil sizes, showing that the larger pupil spans a wider area of dioptric power gradient.

With a progressive lens designed using traditional methods, the eye with a larger mesopic-size pupil will “sample” a larger part of the blurry transition along the border of areas of peripheral astigmatism, resulting in constricted viewing zones and reduced contrast. When looking through an area near the edge of a zone that is supposed to be perfectly clear, the effect is reduced contrast and smeared vision, resulting in the perception of decreased clarity. By compensating the progressive surface using Luminance Design, those errors are corrected in DriveSafe lenses, resulting in improved contrast and acuity.

Of course, single vision wearers do not have to concern themselves with progressive viewing zones. However, all spectacle lenses, whether single vision or progressive, suffer from off-axis aberrations that decrease optical quality as the eye turns to look away from the center of the lens. Pupil size also has an effect on these aberrations, so the optimization of the single vision design using Luminance Design Technology also includes a dilated pupil in the optimization calculations.

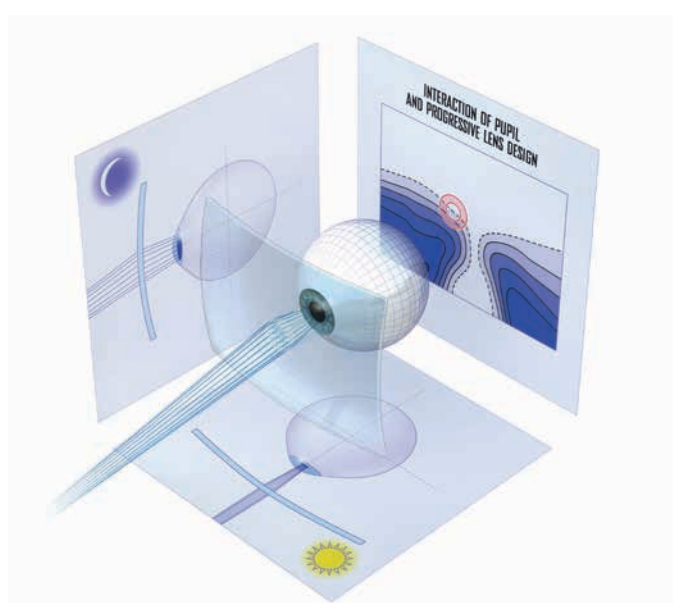


Figure 6. Schematics of ZEISS Luminance Design Technology.

Mesopic Pupillary Diameters

After careful consideration of the frequency and duration of various tasks and light levels via an illuminance weight factor (Figure 7), ZEISS established a median pupil diameter of 3.3 mm for the optimization of Individual 2. Because the most troublesome driving conditions arise under mesopic conditions, ZEISS has recalculated the frequency and duration of driving tasks at a lower level of light for DriveSafe lenses. This resulted in the choice of a 4.3 mm pupil diameter for the DriveSafe progressive lens and 5.0 mm for the DriveSafe single vision lens. The slightly smaller pupil size used in the progressive lens Luminance Design calculations is a consequence of age-related miosis, in which pupil size declines throughout middle age. Because DriveSafe progressive lenses are primarily for presbyopes falling within the range of middle age, the database of pupil sizes according to light level contained correspondingly smaller values than the database used for the single vision design.

II. Glare Challenge

Light is vitally important especially for our physical and emotional well-being. Our circadian rhythm and our cognitive capacities are influenced by light’s spectral properties, period of exposure, intensity and spatial distribution. But when illuminance increases suddenly, adaptation lags and glare is the result. This problem is especially acute when background luminances are low, especially at night but also when skies are darkened by storm clouds. The problem can be intensified by reflections from wet pavement that acts like a mirror for overhead roadway lighting and headlamps. Unfortunately, disability glare is a consequence of light scatter between the viewer and the object being viewed and it is strongly influenced by fog, rain and dirt or water on the windshield of an automobile. It also is strongly dependent on the spectral properties, brightness and luminous density of the glare source and exposure time. The main protection

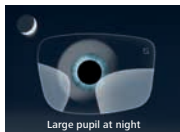





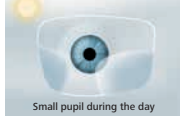
	Pupil Diameter	Illuminance (lx)	Visual task (examples)	Illuminance Weight Factor
	big	0,01	Night	0%
		1	Twilight	5%
		100	Cinema	10%
		500	Office / PC work	50%
		1000	10 min. after sunrise	20%
	small	2500	gloomy weather	15%

Figure 7. Consideration of the frequency and duration of various tasks and light levels.

method is to block disability glare using a visor, holding up a hand or lowering the gaze. In contrast, discomfort glare is less dependent on external factors and ZEISS research has shown that the causative factors may be treated.

PROBLEM: Discomfort Glare Caused by Oncoming Traffic

Discomfort glare is a subjective phenomenon caused by the presence of one or more bright light sources in the field of view with highly different illumination levels and before the visual system has had time to adapt. Since adaptation time increases with age, discomfort glare is especially a problem for older drivers.^{18, 19}

Discomfort glare is worse in the presence of oncoming Xenon/HID or LED headlamps compared to older halogen types. Studies have shown a relationship between the amount of blue light in the glare source and the amount of discomfort glare that is experienced.²⁰ Discomfort glare is not only uncomfortable but is also distracting, and distraction leads to unsafe driving.



Figure 8. Different color temperatures of LED, HID/Xenon and Halogen headlights when compared side by side (examples).

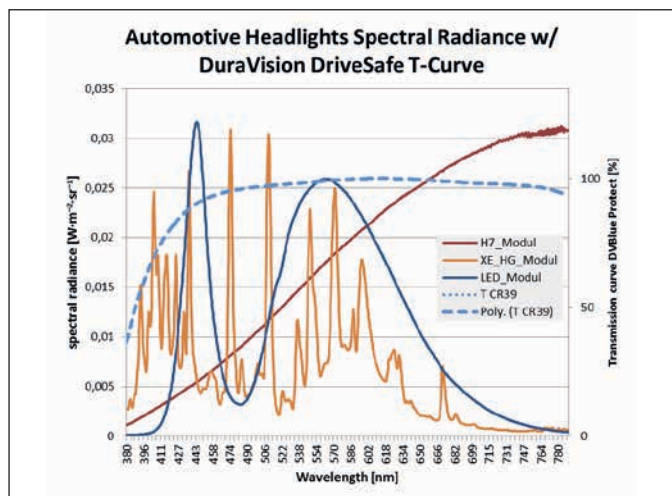


Figure 9. Solid lines: Spectral radiance of various automotive headlights (LED, HID/Xenon and Halogen). (Hella KGaA Hueck & Co.) Dashed line: transmission spectrum of DriveSafe coating with decreased transmission in the blue spectrum.

Figure 8 shows the pronounced blue-white LED illumination with a noticeable color shift (5500 K color temperature) compared to a yellowish halogen light source at 2800K. The LED type also is much brighter than the halogen due to the greater emission of bluish wavelengths in the new, more efficient lights.

Although any kind of headlamp may cause disability glare, the tight beam and bluish spectral shift make these modern light sources a greater risk for discomfort glare.¹³

SOLUTION: DuraVision® DriveSafe Coating

The DuraVision DriveSafe antireflective coating has been designed for a light transmission spectrum that optimizes performance against discomfort glare in the presence of HID and LED headlights. Figure 9 illustrates the typical spectral radiance of a Xenon/HID and a white light LED module used in headlamps and the transmission of DuraVision DriveSafe on hard resin (CR39®) and polycarbonate lens substrates. The maximum peak of the spectral intensity of a white light LED lies at 440 nm in the blue end of the visible light spectrum. On the other hand, the maximum sensitivity of the visual system under mesopic light conditions lies between the photopic peak of about 550 nm and the scotopic peak near 510 nm.²¹ The transmission of DuraVision DriveSafe is at a maximum for the mesopic range but decreases significantly for shorter wavelengths that are most likely to cause discomfort glare. By comparison, ZEISS DuraVision Platinum has no specific attenuation at shorter wavelengths.

To assess the effectiveness of the DuraVision DriveSafe coating, a ZEISS study including 50 subjects compared its efficacy against glare with DuraVision Platinum and another AR coating. The study used a white light LED source to present two glare conditions (Figure 10) in accordance with ECE-regulation 112 in an experimental procedure widely accepted in the automotive industry.¹⁴ The effect of the three AR coatings on glare in traffic was tested and evaluated. The study results confirmed that the parameters of contrast threshold, spontaneous eye blink rate (SEBR) and eye closure (squinting) are in alignment with literature findings.

When asked which lens was most comfortable for driving, DuraVision DriveSafe was preferred by more than 2 to 1 over the other coatings.

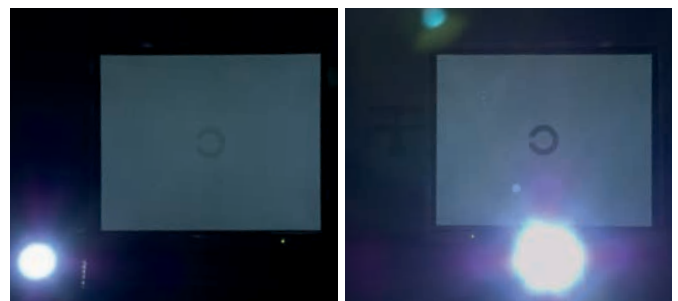


Figure 10. Glare test setup with light source and reading chart / optotype [20].

This finding is statistically significant. In another question asking which lens resulted in the most glare while driving, DuraVision DriveSafe was named far less often than the other coatings. (See Figure 11).

Although the DuraVision DriveSafe coating reduces glare by eliminating a portion of the visible spectrum, it passes most of the mesopic and photopic range, ensuring maximum ability to see the surrounding environment for safe night driving. Like DuraVision Platinum, DuraVision DriveSafe is anti-static to repel dust, and offers superior scratch resistance and easy cleaning.

III. The Challenge of Complex Visual Tasks

For single vision lenses, but even more for progressive addition lenses, it is important to map the distribution of optical properties to the spatial and temporal composition of the environment and tasks. Drivers face conflicting requirements that compete for attention. The view down the road, in the periphery, along the instrument panel and through the rear-view mirrors must all be considered. This competing set of tasks requires frequent eye and head movement accompanied by changes of gaze direction, fixation and accommodation. Analysis by ZEISS of the demands of driving has led to the development of new designs for both single vision and progressive lenses.

PROBLEM: Accommodative/Convergence Stress and Dynamic Vision

The dynamics of the vision process while driving include changes of gaze direction, convergence and accommodation. The dynamics of cognition follow the dynamics of vision but the cognitive changes relate to the focus of attention for a given task. Both the focus of attention and the visual dynamics are powerful influences on driving safety.²²

Each dynamic task element has unique requirements. The view down the road requires parallel lines of sight for the two eyes, i.e. there is no convergence and therefore no accommodation. Ideally a spectacle lens for this purpose should have a very wide field of clear

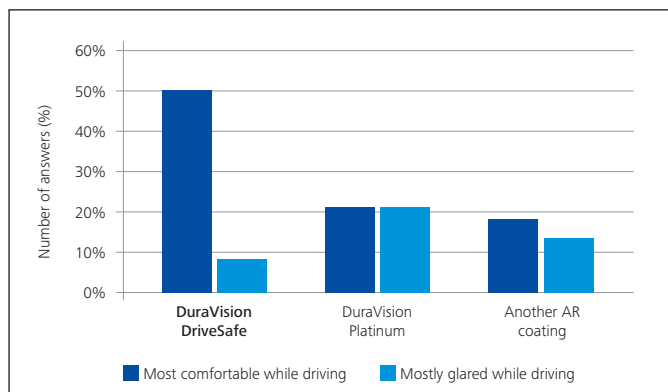


Figure 11. Study results showing effectiveness of DriveSafe coating: Most comfortable while driving, and control question: least perceived glare (questionnaire allowed multiple answers and including weighting via DeBoer scale).

far vision. In a similar way the view through rear-view mirrors requires no convergence or accommodation, but the field of view is small.

On the other hand, locating the mirror during a fast saccadic eye movement is critical so that as little time as possible is lost in the effort. This requires that spectacle lenses minimize spatial distortions and present little or no blur in areas typically used to look through the mirrors. This requirement can only be understood according to the amount of head movement that is used together with the eye rotation angle that defines the final coordinates of gaze.

On the other hand, viewing an instrument panel requires both convergence and accommodation in most drivers (the exception is for very advanced presbyopes requiring high addition powers, who rely entirely on their lenses for refractive dioptric power). Therefore, one must be able to locate the object pre-selected by a change of attention. Research reveals that experienced drivers spent more of their attention on trajectory planning than on fixating down the road.²³ For example, to check speed a driver must plan to look at the speed indicator, then find it through a change of gaze angle accompanied by convergence and accommodation. Looking for a control on the center panel, perhaps to adjust the temperature, requires a different planned visual trajectory and accurate, fast localization. If the progressive lens is not designed optimally, these changes of gaze and convergence may be followed by a corrective change in head position in order to achieve best focus. Preferably, a spectacle lens will enable this to occur efficiently on the first attempt by providing a clear, wide intermediate field of view that does not present visual obstacles to effective spatial localization.

To understand these requirements better, ZEISS commissioned a study by the Research Institute of Automotive Engineering and Vehicle Engines Stuttgart (FKFS)²⁴ using advanced full-motion driving simulators. The simulators included head and eye tracking systems to observe driver visual behavior. In addition, a real world course was developed for further testing. Data from 44 subjects was recorded

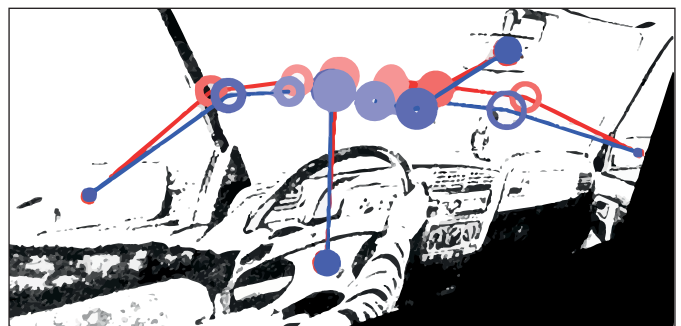


Figure 12. Head and Eye Movements to Regions of Interest (ROI). Progressive wearers shown in red, non-progressive in blue. The connected circles show movements toward side mirrors and dashboard ROI. The center circle of each movement trajectory shows head position at the completion of the movement. Progressive wearers move their heads farther toward the ROI.

totalling more than 33 hours net driving time.

The study found that drivers focus on the street ahead and distant moving objects about 97% of the time, look at the dashboard 2% of the time and alternate viewing dynamically between the several rear-view mirrors 1% of the time. If elapsed time was the only consideration in lens design, it would seem obvious to design driving lenses only for distance vision. But the situation is complicated because it is during those moments of quick changes of task and attention that increased reaction time might lead to an accident.

In the visual dynamics of driving, head and eye movements interact and are coordinated. Progressive lens wearers need to move their heads more than single vision wearers do in order to avoid zones that do not provide the correct addition power for a given task or that have higher levels of aberration. The study at FKFS found that progressive lens wearers make greater horizontal head movements in order to keep their gaze in clear viewing zones while looking at different regions of interest (ROI) (Figure 12). Furthermore, progressive lens wearers hold their heads more upright and point their heads more often straight ahead, indicating that the reduction of distance field of vision in progressive lenses affects head position (Figure 13). A further finding of ZEISS's research is that the closest object viewed on the instrument panel is approximately 75 cm away from the driver's eye. This implies that while driving, the near zone of a progressive lens, designed for a much closer distance, is virtually unused.

SOLUTION: DriveSafe Design Technology

The DriveSafe Design was established to provide excellent visual dynamics with extra width and clarity for distance vision. In the single vision lens the periphery is optimized for distance visual acuity. In the progressive design the width of the distance zone was increased to allow easier location and viewing through side mirrors. Because

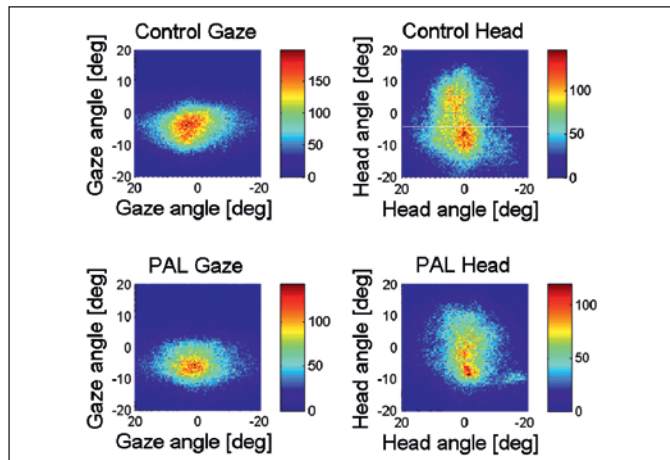


Figure 13. Heat maps for eye and head movement. Progressive wearers spend more time with their heads held higher and eyes looking straight toward distant points on the road. Non progressive wearers spend more time with head turned to the left and down, reflecting less restriction on head position.

quick and natural gazes toward the instrument panel are essential for accurate information, the entire progressive design is shifted upward slightly relative to the fitting cross; this helps relieve some of the stiff, unmoving head posture observed in the FKFS simulator studies. The extra width of the distance zone helps reduce the effect of quick onset of addition power, and the design's longer corridor decreases the slope of power increase. Taken all together, the span of the distance zone is increased while the intermediate zone is expanded in all directions including slightly upward. The near zone of the DriveSafe progressive has been slightly diminished in size compared to other ZEISS progressives, but with the longer corridor offset by the upward shift, it provides sufficient near vision performance for typical tasks of daily life away from driving.

In Figure 14 the left plot shows the power increase of the DriveSafe progressive and the right plot shows the peripheral astigmatism. The successful fusion of the specified features results in a usable field size which is increased up to 14% for the far field distance vision zones and up to 43% compared to ZEISS Precision Plus (Figure 15). These design characteristics lead to a wider view of the road, easy access to side mirrors and support faster, easier switching between the dashboard instruments and other driving tasks.

Taken all into account, the DriveSafe designs enhance the possibility of comfortable, less-stressed driving. Yet both the single vision and progressive DriveSafe lens designs are entirely suitable for all-day use in all kinds of activities.

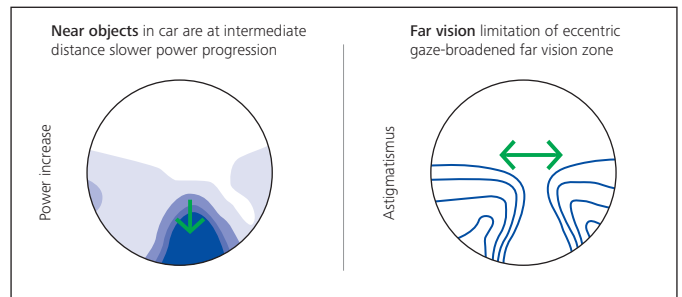


Figure 14. Drive Safe Lens.

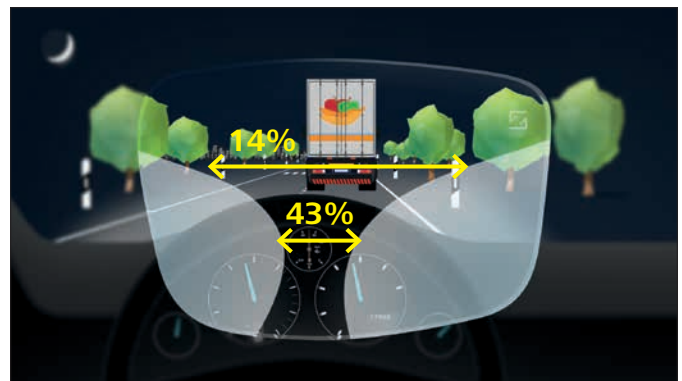


Figure 15. Larger vision zones for far and intermediate distance with DriveSafe lens.

ZEISS DriveSafe Lenses Tackle All Three Major Challenges to Provide Enhanced Comfort and Safety

Three major visual challenges of driving were identified and addressed with ZEISS DriveSafe lenses:

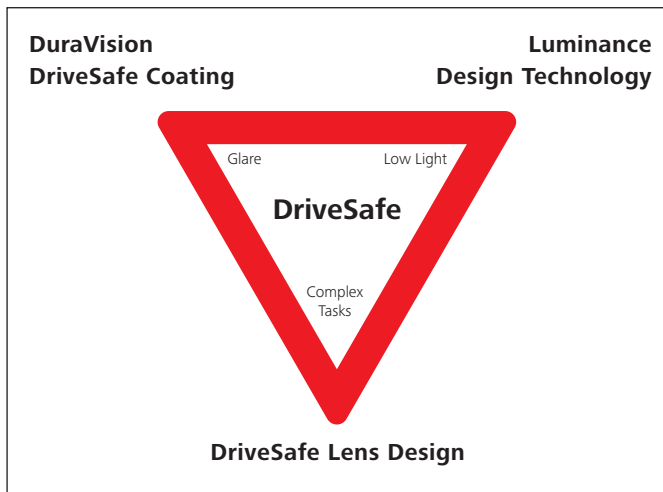
- difficulty seeing when light levels are low
- discomfort glare caused by modern high-intensity headlamps
- the stress of demands created by the complexity of dynamic vision

In response ZEISS developed DriveSafe lenses to establish a triad founded on safety. *Luminance Design Technology* preserves wide and clear viewing zones even with pupils enlarged during low-light driving. The *DuraVision DriveSafe coating* relieves the problem of discomfort glare caused by modern headlamps like LED and Xenon/HID. *DriveSafe lens designs* are engineered for increased comfort and reduced stress during the demanding visual tasks of driving. All three work together to enhance safety, especially during hazardous driving conditions created by low light levels, fog or rain.

These characteristics are defined to respond to concerns and needs of the 83% of spectacle lens wearers who drive. They also meet the needs of the 72% of spectacle lens wearers who have expressed a strong interest in having a single pair of spectacles to cope with the special challenges of driving.

Clinical trials²⁵ were conducted to compare the effectiveness and acceptance of DriveSafe lenses. The trials revealed very high satisfaction levels greater than 95% for DriveSafe lenses. Factors that were assessed included overall satisfaction while driving, driving in the dark and twilight, dynamic vision in near, intermediate and far vision, perception of colors, and dazzle from headlights. Subjects also rated DriveSafe lenses highly for general purpose activities when working in office or at home.

ZEISS DriveSafe lenses are the only lenses designed for enhanced driving while enabling a full range of daily life activity.



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