DRIVESAFE LENSES BY ZEISS

Safety and comfort for challenging driving conditions

Driving a car is a modern 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 decreased 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 basic but 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 suited 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 it is not a highly specialised task with very narrow requirements, so it is not suited for such specialised 2nd or 3rd pair lenses. Moreover, recent market research conducted by ZEISS [1] 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 at low light conditions and night. In 2010 forty eight percent of fatalities among passenger vehicle occupants in the USA happened at night[4]. Another study showed that in the UK more than half of all fatal accidents happen after dark although far fewer miles are driven at night. Furthermore the likelihood of death during an accident is twice as great when the accident happens at night. The latter study concluded that poor illumination was the principle cause of nighttime road accidents[5]. Another 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].

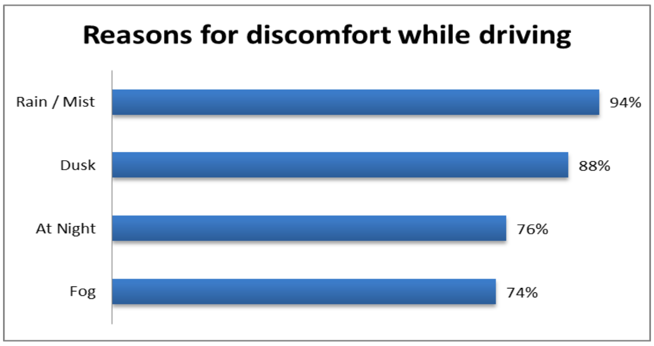


Figure 1: Reasons for wearer's discomfort while driving

The challenge of glare

One way that in which many countries have responded to the problem of illumination is by increasing the number and intensity of roadway illumination lamps. But this is not a practical solution in all areas and leads to 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 complaints of glare when looking toward oncoming cars. The increased brightness can cause 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 colour shift has increased the frequency and severity of complaints about discomfort glare, the unpleasant and stressful sensation experienced when looking toward a bright light (*Figure 2*). The severity of the discomfort seems to be great, based on the increased brightness of these light sources and its influence on the visual system, and appears to be related to their bluish spectral shift[7]. Older drivers with manifest but not yet treated cataract often report more severe glare symptoms. Light scattering in the opaque and hazy crystalline lens is considered a major cause for these symptoms [8].

Figure 2: Glare scenario in road traffic.

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 and 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]. Yet another is the information presented in multiple visual displays on the instrumentation panel both straight ahead and to the side. Along with those requirements is a need to check several mirrors to remain aware of traffic that is coming toward the driver from behind. 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 the 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 larger 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.

Three vision challenges – three solutions – one lens

ZEISS research confirms that unfavourable light conditions, glare and the stressful visual and accommodative tasks presented to drivers have a high impact on the quality of vision while driving. Research also has shown that an uncorrected night myopia of a driver (-0.50 dpt; -1.00 dpt) and a subcritical glare level of 0.4 lx results in a higher contrast vision threshold performance at night than with a full correction glasses and glaring LED headlamps of 1.2 lx [12]. All together the various findings give clear reason of designing adequate lenses for better vision while driving in critical light conditions. During the development of DriveSafe lenses the three vision challenges were targeted and solutions were developed to be combined in one product, either in 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 is the fastest one to change in illumination and it has a significant effect on the performance of spectacle lenses. As it is well known the 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 recognised: the photopic, scotopic and mesopic ranges (*Figure 3*).

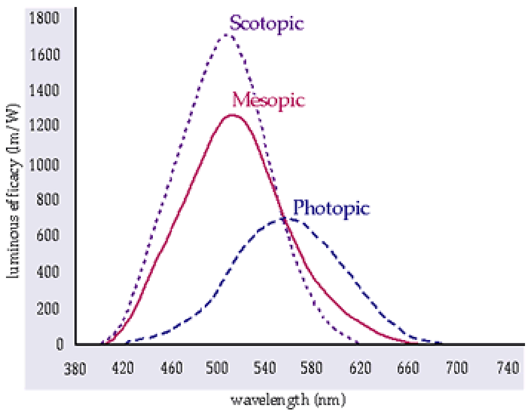


Figure 3: Peak luminance sensitivity of the human eye shifts from green toward blue spectrum at low illumination levels

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 colour vision, and so the sensitivity to colour differences is best in photopic vision. At photopic light levels the rods of the retina are saturated and unresponsive so they contribute very little to vision.

Scotopic vision is fully active at illuminance levels of 0.01 lx or lower but it is rarely experienced when driving. It happens only in the darkest places without artificial illumination, e.g. 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 colour, only brightness. The scotopic visual system has peak sensitivity to light at a wavelength of about 505nm - 510 nm. The rods also are incapable of good acuity and they have a slow response; in fact, to be able to perceive scotopic light levels requires being exposed to those light levels for at least twenty minutes to provide enough time to adapt. One way to recognise scotopic vision is blurriness of all form and a total lack of colour. By contrast, 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 this is the light level that is prevalent when drivers complain about poor illumination. At the mesopic level both acuity and colour sensitivity are reduced. Also at this illumination level visual responses are slower than in the photopic range.

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 *Figures 4 and 5*). One effect of a larger pupil is that high order aberrations (HOA) of the eye have an increased impact, 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].

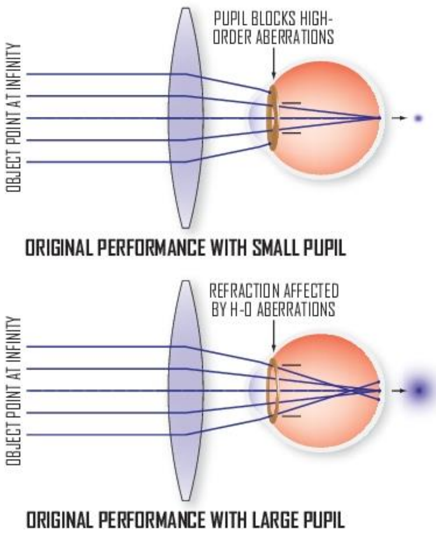


Figure 4: Effect on HOA and pupil size on retinal image

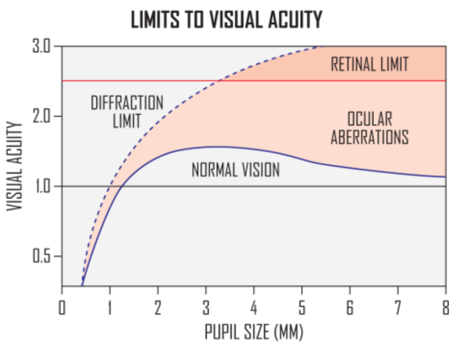


Figure 5: Limits to visual acuity as function of pupil size

Problems with 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 progressive 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 Individual 2 progressive 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. In the ZEISS Progressive Individual 2 lens, the resulting lens is optimised 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 optimisation 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 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.

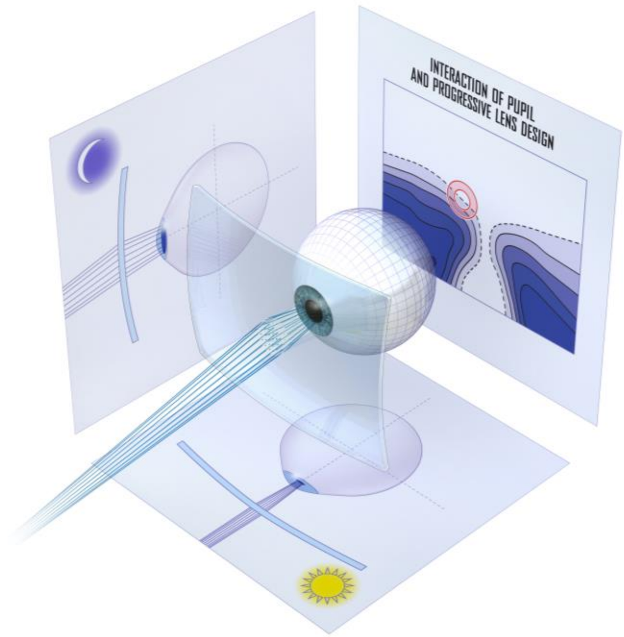


Figure 6: Schematics of ZEISS Luminance Design Technology

With a progressive lenses 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 centre of the lens. Pupil size also has an effect on these aberrations, so the optimisation of the single vision design using the Luminance Design® technology also includes a dilated pupil in the optimisation calculations.

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 optimisation of ZEISS Progressive Individual 2. Because the most troublesome

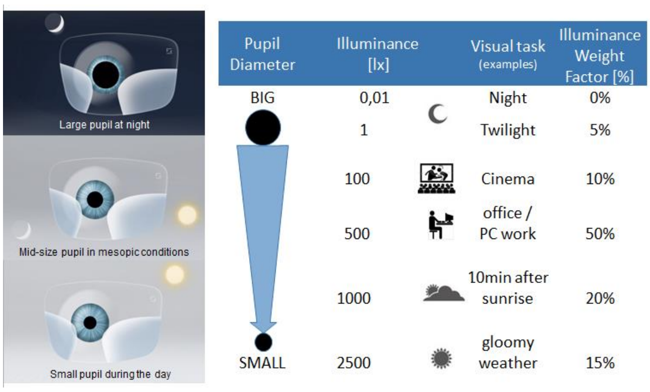


Figure 7: Consideration of the frequency and duration of various tasks and light levels

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 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 wellbeing. 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 so the main protection is to block it using a visor, holding up a hand or lowering the gaze. By consequence discomfort glare is dependent upon external factors and ZEISS research has shown that the problem may be treated.

Problem of 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, same as disability glare, can be assumed to be an problem specifically in 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, it is distracting, and distraction leads to unsafe driving.

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

Figure 8 shows the pronounced blue-white LED illumination with a noticeable colour shift (5500 K colour 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.

In general every kind of oncoming cars' headlamps are able to glare the driver, but especially a small exit pupil of illumination and the spectral proportion with a bluish shift are responsible for the risk of discomfort glare [13].

Solution: DuraVision® DriveSafe Coating

The DuraVision® DriveSafe antireflection coating has been designed for a light transmission spectrum that optimises 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® [21] 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 [22]. The transmission of DuraVision® DriveSafe is 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.

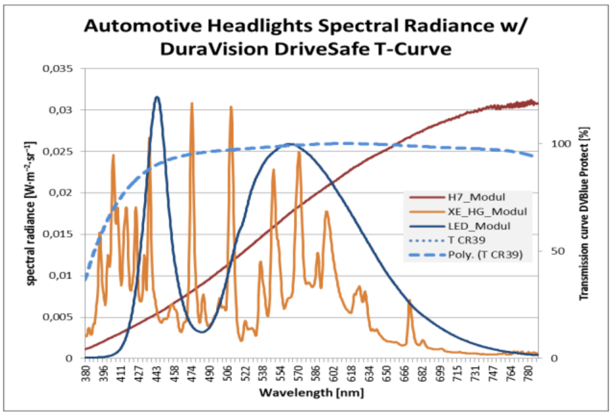


Figure 9: solid lines: Spectral radiance of various automotive headlights (LED, HID/Xenon and Halogen). See the emphasis in the bluish spectrum band for LED and HID/Xenon. Dashed line: transmission spectrum of DriveSafe coating with specific transmission drop in the blue spectrum (Hella KGaA Hueck & Co.)

To assess the effectiveness of the DuraVision® DriveSafe coating versus two other premium AR coatings, a ZEISS study [14, 27] including 52 subjects compared its efficacy for a) visual comfort and for b) perceived glare under controlled setup conditions. The study used a white light LED source to present two glare conditions (*Figure 10*) in accordance with ECE-regulation 112 and in alignment with automotive standards, as in use by automotive supplier Hella KGaA Hueck & Co.[14] In this study the effect of three AR coatings on glare in traffic has been tested and evaluated. The study results confirmed that the parameters of contrast threshold (negative contrast in darkened room), spontaneous eye blink rate (SEBR) and eye closure are in alignment with literature findings. The magnitude of discomfort glare was evaluated by according to the DeBoer scale from 9 (barely perceptible glare) to 1 (unbearable glare) which has been used in a questionnaire [23].

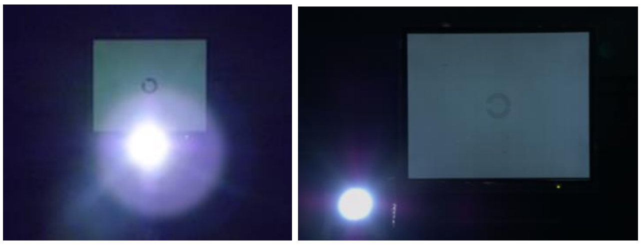


Figure 10: Glare test setup with light source and reading chart / optotype [20]

- DriveSafe Coating was strongly preferred by almost 50% over the alternative coatings A (22%) and B (18%) as being "most comfortable while driving" (*Figure 11a*).
- DriveSafe coating was rated best for "least perceived glare" compared to the other premium AR coatings. A difference of 64% compared to AR coating A, and 40% compared to AR coating B was shown (*Figure 11b*).

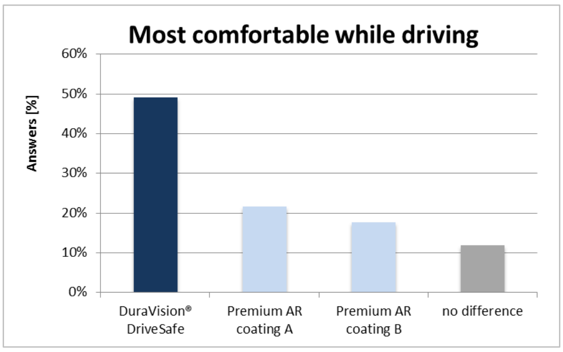


Figure 11a: Study results showing DriveSafe coating rated "Most comfortable while driving" *(questionnaire allowed multiple answers and includes weighting via DeBoer scale)*

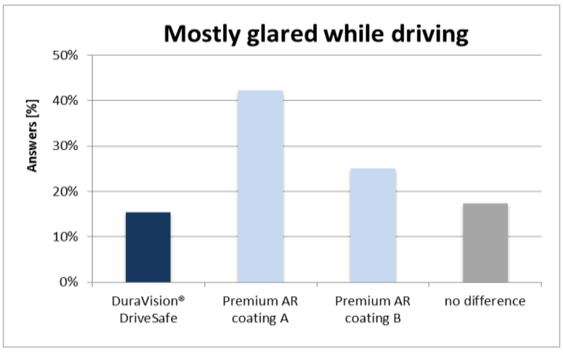


Figure 11b: Study results showing DriveSafe coating rated lowest for "perceived glare" *(questionnaire allowed multiple answers and includes weighting via DeBoer scale)*

Although the DuraVision® DriveSafe coating reduces glare by eliminating a portion of the visible spectrum, it passes virtually all of the region of maximum mesopic and photopic sensitivity, ensuring maximum ability to see the surrounding environment for safe night driving. Like DuraVision® Platinum, DuraVision® DriveSafe is antistatic so that it repel dust, and offers excellent scratch resistance and easy cleaning.

III. The Challenge of Complex Visual Tasks

Even for single vision lenses, but particularly with progressive addition lenses, it is important to map the distribution of optical properties in a spectacle lens 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.

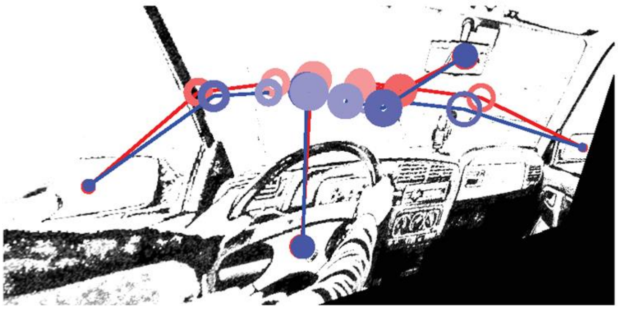


Figure 12: Driver's points of visual attention in an automotive environment

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 [24].

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 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 little time is lost in the effort. This requires that spectacle lenses minimise spatial distortions and ideally that there is little or no blur located in the part of the lens typically used to look through the mirrors. This position 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). One must be able to locate the object pre-selected by a change of attention. Research reveals that experienced driver spent most of their attention to trajectory planning than on road-ahead fixations [25]. For example, to check his speed the driver must plan to look at the speed indicator, then find it through a change of gaze angle, convergence and accommodation. Looking for a control on the centre panel, perhaps to adjust the temperature, requires a different planned visual trajectory and accurate, fast localization. Ideally a spectacle lens will enable this to occur efficiently 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) [26] using advanced full-motion driving simulators. The simulators included head and eye tracking systems to observe driver visual behaviour. In addition, a real world course was developed for further testing. Data from 44 subjects was recorded 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 time were the only consideration in lens design, it would seem obvious to design driving lenses only for distant vision. But the situation is complicated because it is during the changes of task and attention that slow reaction time may lead to accidents.

In the visual dynamics of driving, head and eye movements interact and are coordinated. Progressive lens wearer need to move the head more often than single vision wearers in order to avoid zones that do not provide the correct addition power for the task or that have higher levels of aberration. The study together with FKFS found that progressive lens wearers make larger horizontal head movements in order to keep the gaze in clear viewing zones (*Figure 13*). Furthermore progressive lenses wearers hold the head more upright and turn the head significantly stronger towards the left mirror than non-progressive wearers. Another study's result presents that PAL wearers turn the eyes significantly less for looking into the overhead mirror than single vision lens wearers. A further finding of ZEISS's research is that the closest object viewed on the instrument pane 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.

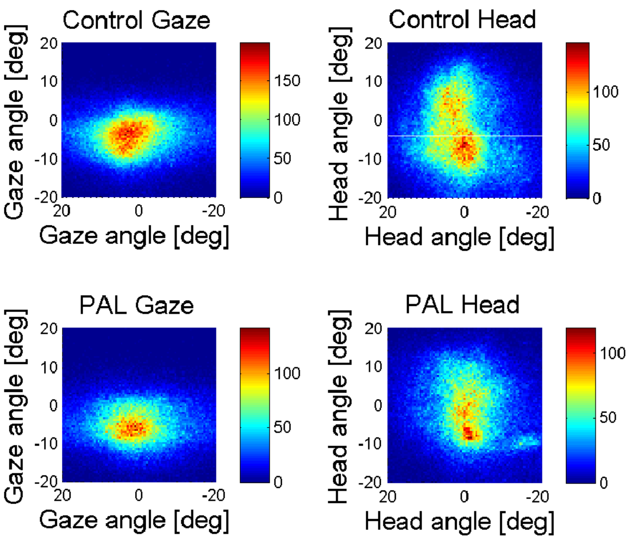


Figure 13: Results from Eye-Head-Measurement of driving study

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 optimised 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 quick and natural gazes toward the instrument panel is 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.

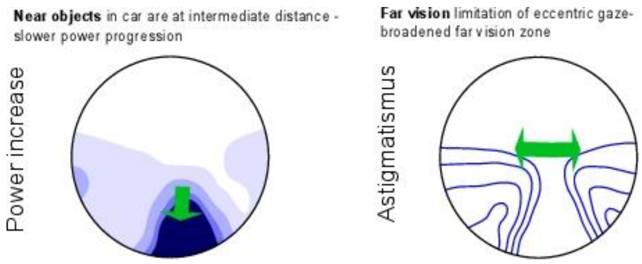


Figure 14: DriveSafe Lens

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 Superb (*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, unstressed driving. Yet both the single vision and progressive DriveSafe lens designs are entirely suitable for all-day use in all kinds of activities.

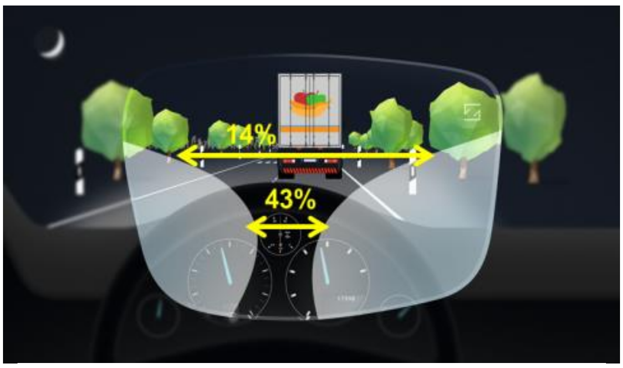
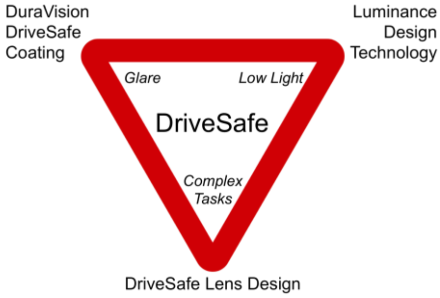


Figure 15: Larger vision zones for far and intermediate distance with DriveSafe lens

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 decreased stress during the demanding visual tasks of driving. All three work together to enhance safety, especially during hazardous driving conditions created by dim light, fog or rain.

These characteristics are defined to respond to concerns and needs of the 83% of spectacle lens wearers who drive. They also respect the requirement of the 72% of spectacle lens wearers who are very interested in having a single pair of spectacles that provide a solution to cope with the special challenges of driving.

Extensive wearer trials[27] compared the effectiveness and acceptance with exiting solutions of advanced PAL design and AR coatings. The trials reveals extraordinary satisfaction levels of <95% for Drive Safe lens in tested categories while driving (i.e. overall satisfaction while driving, driving in the dark and twilight, dynamic vision in near, intermediate and far distance, perception of colours, dazzle from oncoming / following car headlights), but also for general purpose activities like wearing comfort when working in office and at PC, reading.

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

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