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Research Article

Mesopic Visual Function Attained with Lenses Specifically Designed for Night Driving

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Abstract

Purpose: Low illumination conditions induce changes in the visual perception such as loss of visual acuity, increased glare or night myopia. Recently, a new lens design has been proposed to improve mesopic vision that provides a slight negative defocus in a small region just above the DRP. The goal of this study is to compare the mesopic visual function of users wearing general-use lenses and lenses optimized for mesopic vision.

Method: 56 subjects participated in this observational, prospective and double-masked trial. Visual function in mesopic conditions after 15 minutes of dark adaptation was evaluated while users were wearing 2 different lenses: A) General-use design with standard power distribution and anti-reflective coating (control lens) and B) Special design for night driving characterized by a region with a slight negative defocus above the fitting cross along with a specially designed filter (test lens). Participants under 45 years of age tested SV lenses (Group 1, n = 26) and subjects over 45 years of age tested PPL (Group 2, n = 30). The analyzed parameters were mesopic visual acuity (VAm), mesopic clear viewing field (VFm), glare recovery time (GRt) and subjective user's feedback (SS). Statistical analysis was performed using Statgraphics Centurion XVI.II software.

Results: Clinical assessment revealed that lenses optimized for mesopic vision provided significantly wider VFm and lower GRt for both groups. Test lenses provided a 24% wider VFm and GRt was 22% smaller in comparison with the control lens. SS was significantly higher for group 1.

Conclusion: A new lens-design concept characterized by inducing a slight negative defocus above the fitting cross and incorporating blue-light filter, improved mesopic visual function. These lenses provided a wider field of clear vision for distance objects, lower glare-recovery time and higher user satisfaction in general, and specifically when driving.

Keywords: *Ophthalmic Lenses; Driving; Mesopic Vision; Visual Acuity; Glare; Visual Field*

Abbreviations

AR: Anti-Reflective; GRt: Glare Recovery Time; PPL: Progressive Power Lenses; SS: Subjective User's Feedback; SV: Single Vision; VAm: Mesopic Visual Acuity; VFm: Mesopic Clear Viewing Field

Introduction

Driving is a complex task that requires specific visual skills and optimal vision to clearly detect and react to traffic signals, traffic lights, pedestrians and other vehicles. So, drivers should have good visual capabilities related to driving such as visual acuity, visual field, contrast sensitivity, motion perception or depth perception. Some recent surveys point out that peripheral vision seems to play a more critical role for safe driving [1].

Regarding the use of the different visual areas of the lens, it has been demonstrated that distance vision is the most important area of vision when driving. According to a study carried out by the University of Michigan (Serafin), the driver fixates far points down the road 50% of the time, while fixation at other road features is lower than 9% [2].

Night-driving requires different fixation patterns than day-driving. At night-time driving, the area of fixation is smaller than in daytime driving, and the eye tends to fixate lower. According to Brimley., *et al*. [3] these differences can be attributed to reduced visibility and reliance on headlamps at night. At night, drivers cannot see elements of the roadway or environment beyond the headlamp beam. Consequently, they do not look as far ahead of the vehicle at night as they do during the daytime.

The night-time driving environment presents challenging visual conditions for drivers, including dim street lighting, glare from oncoming headlights, and the need to quickly adapt across a wide range of lighting levels. In fact, disability glare is mainly reported under night illumination conditions decreasing contrast sensitivity and degrading image quality, including starburst and halos [4]. As a consequence, low illumination and glare make driving at night particularly difficult [5]. Studies have shown that approximately one third of drivers over 45 years report night-time driving difficulties [5-7] and these problems increase with age. In fact, driving at night is one of the most commonly reported self-restrictions among older drivers, likely due to a decline in vision that makes night-time driving more challenging [7].

At night, visual acuity decreases, sensitivity to glare increases and in some patients night myopia appears [8] a condition in which the eye becomes nearsighted in dim illumination. Night myopia is a complex phenomenon not fully understood, as there are different factors that may contribute to it with different strengths, depending on the person: pupil-related factors as uncorrected myopia or excess positive spherical aberration, trigger of accommodation caused by spherical aberration, chromatic aberration at the peak sensitivity wavelength of rod cells, dark focus status, etc [8]. In any case, most persons affected with night myopia report improved vision using some negative correction.

Recently, both single-vision and progressive power lenses (SV and PPL) have been proposed to improve day and night driving (Inmotion, Indizen Optical Technologies S.L., Spain). These lenses have variations in the progression profile of the lens, providing a slight negative defocus in a small region just above the pupil. The power distribution maps are also optimized for distance vision and a specially designed filter is applied to the lens to enhance to enhance the contrast during night driving.

Aim of the Study

The goal of this study is to compare the mesopic visual function of users wearing general-use lenses and these lenses specifically designed for night driving.

Materials and Methods

Study design

A comparative wearer trial was done to analyze the subjective perception of the users after testing different types of lenses for 7 days each. Different aspects of the Visual Function in mesopic illumination were evaluated while users were using a general-use design (Control lens) and a lens specifically designed for night driving (Test lens). Participants under 45 years of age tested single vision lenses (SV) and subjects over 45 years of age tested progressive power lenses (PPL). The study was approved by the Ethics Committee of San Carlos Clinical Hospital (Madrid, Spain). All subjects signed the informed consent according to Helsinki declaration.

Participants

The population sample met the following inclusion criteria: a) Drivers aged 18 and over who have a valid driving license, b) Refractive error between -6.00D and +4.00D of myopia/hyperopia with astigmatism lower than 2.50D and addition between 1.00 and 3.00D (for the participants in the group over 45 years), c) Best corrected monocular visual acuity better than 0.1logMAR in both eyes, and d) Anisometropy lower than 1.50D. Subjects were excluded if presenting any significant binocular anomaly, ocular pathology or being under drug treatments that could affect visual function.

Lens characteristics

Subjects under 45 years of age tested SV lenses. The control lens is a conventional one, without compensation of oblique aberration in which the lensometer power is mainly constant all over the surface of the lens. The test lens (Inmotion SV, IOT, Spain) was specially designed for night driving and is a customized SV free-form lens with compensation of the oblique aberrations depending on the position of wear, frame, interpupillary distance and pupil height. In addition, the test lens has slight negative defocus of -0.25D in a small region just 8 mm above the pupil. Progression profile and power distribution maps of both lenses are presented in the figure 1.

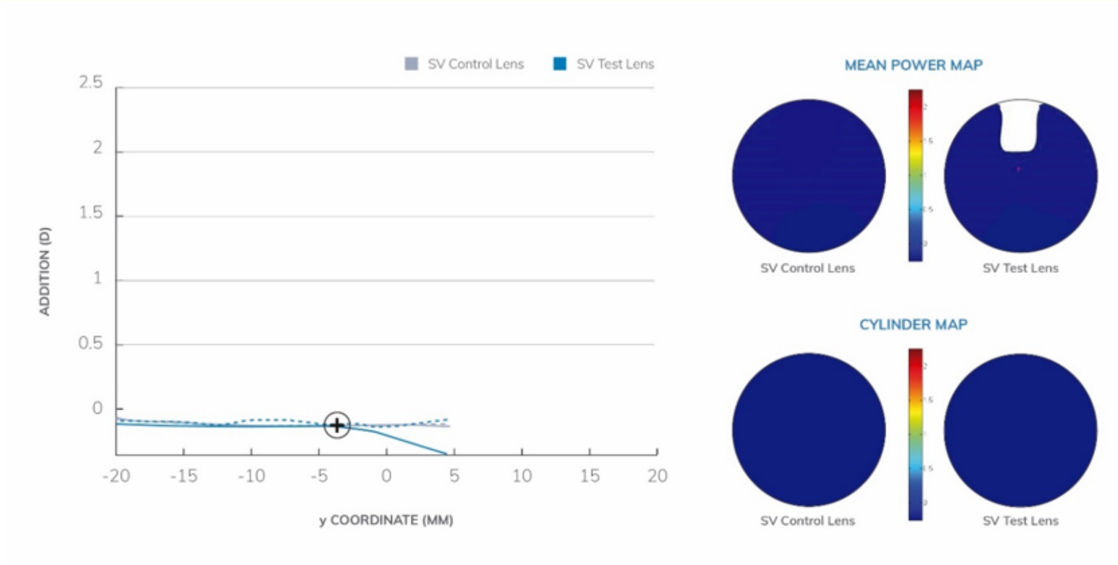

Figure 1: *Progression profile and power distribution maps of single-vision lenses (control and test) used by subjects under 45 years.*

Subjects over 45 years of age tested free-form PPLs customized according to the position of wear. The control lens is a general-use one (AlphaH45, IOT, Spain) and the test lens was specifically designed for night driving (Inmotion PAL, IOT, Spain). PPL test lenses also have a slight negative defocus of -0.25D in a small region just 8mm above the pupil, but they also have a progression profile much softer in distance and upper intermediate distances providing wider distance areas according to Sheedy criteria [9]. Progression profile and power distribution maps of both lenses are presented in the figure 2.

In addition, control and test lenses differed in their transmission properties. Control lenses incorporate a standard antireflective antireflective (AR) coating, while the test lenses include a specific filter with a high reflexive coating that partially blocks short-wavelength light. Transmission curves of both treatments are presented in figure 3.

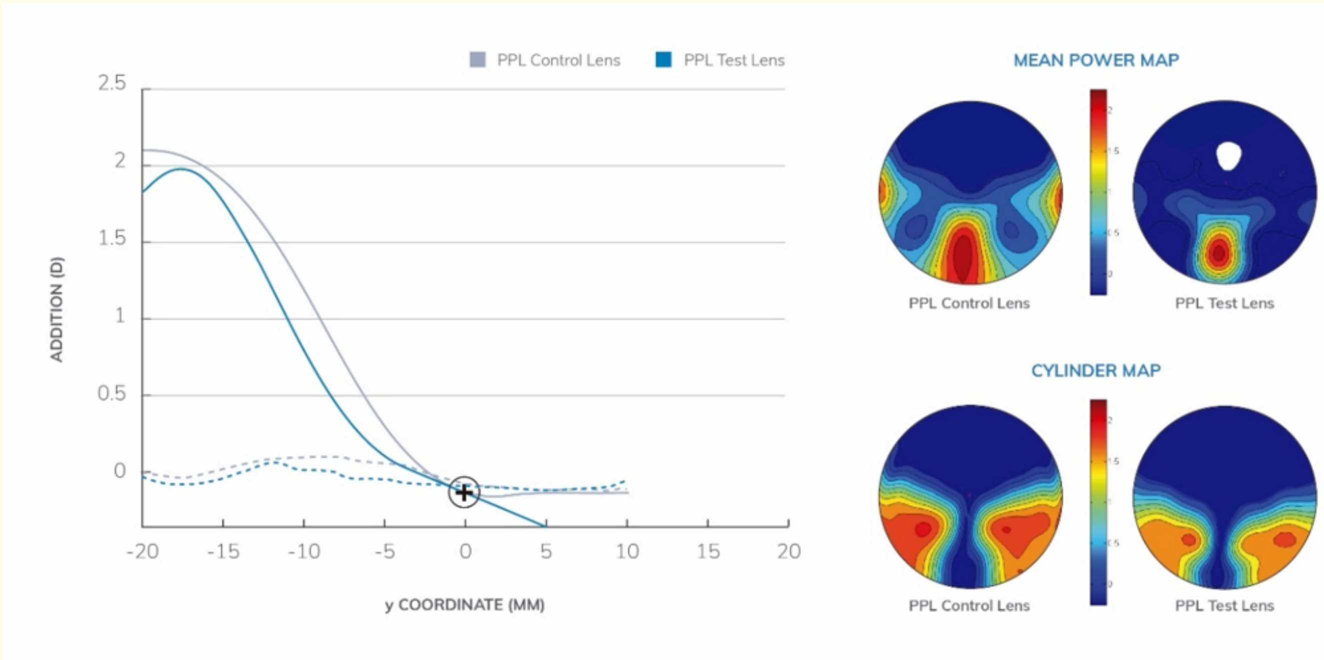

Figure 2: *Progression profile and power distribution maps of progressive power lenses (control and test) used by subjects over 45 years.*

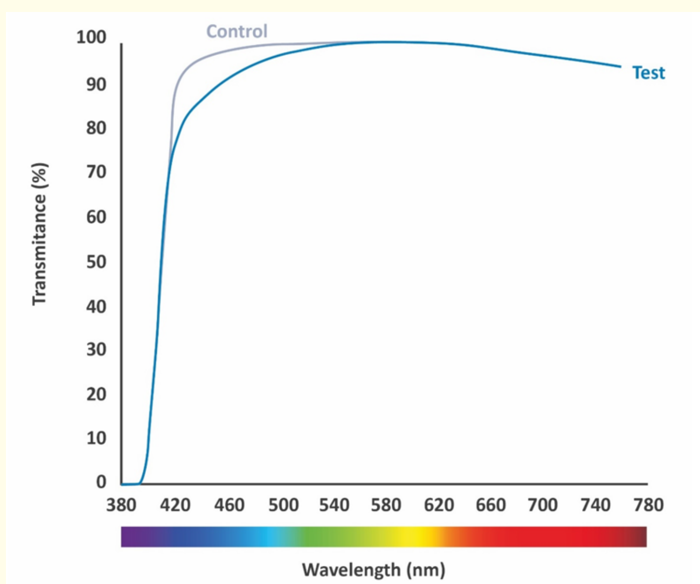

Figure 3: *Transmission curves of antireflective coatings used for control and test lenses.*

Procedure

Before starting the clinical examination, a full optometric evaluation was done to ensure the subjects met the inclusion criteria. Visual exams consisted of detailed anamnesis, visual acuity measurement, binocular refraction, stereopsis assessment with Titmus test, Worth test, cover test and ocular motility. After checking that the subject met the criteria, tolerance to defocus was measured in mesopic conditions. Next, the subject selected a frame model from an inventory of frames and then fitting and position of wear parameters were measured (same frame model was used for both pair of lenses). The pupillary distance was measured using an automated pupillometer, pupil height was measured manually and the additional fitting parameters, which included pantoscopic tilt, back vertex distance and frame wrap angle, were measured using a special ruler (Personalization Key®, IOT, Spain). Both the test and control lenses were manufactured with identical prescriptions, monocular pupillary distances and pupil heights, frame parameters, lens materials (index 1.6) and anti-reflective coating. All the spectacles were verified upon receipt (power, mounting and fitting terms) according to ISO tolerances. Additionally, all lenses were measured with a Dual Lens Mapper (Automation and Robotics, Verviers, Belgium) to ensure that they had been correctly processed. Once both pairs of spectacles were received and checked, 3 main visits with 7 days of difference between visits were scheduled. At visit 1, all subjects were informed about the process of adaptation using the new lenses and, according to the random assignment, the first pair of lenses were dispensed. The sort order of glasses delivery was randomized, ensuring that half of the subjects started the study by testing the control lenses while the other half started by testing the test lenses. At visit 2, the subjects returned the first pair and the second pair was dispensed. At visit 3, objective and subjective differences between the two designs is assessed by measuring, with both glasses, mesopic visual acuity (VAm), mesopic undistorted viewing field (VFm), glare recovery time (GRt) and subjective user's feedback.

Illumination conditions

Measurements of visual variables was done in mesopic illumination after 15 minutes darkness adaptation. EDTRS optotypes generated by the PVAAT software (Precision Vision, USA) were used on a screen covered by a neutral density filter with a transmittance of 11.89% (E211.9, Rosco Iberica, Spain). The luminance on the subject's eye was 1 cd/m^2 and the screen was located 5.5m from subject's eye.

Tolerance to negative defocus

VAm was measured with the subjects wearing their best-corrected prescription and while inducing a negative defocus of -0.25D. The observed variation DVAm = VAm(defocus) - VAm(best correction) was used to classify the participants into three subgroups. Subgroup 1 contained those participants for which DVAm > 0.06 logMAR. Subgroup 2 contained those for which |DVAm| ≤ 0.06 logMAR. The remaining subjects, which experienced a reduction of VAm bigger than 0.06 logMAR with the negative defocus were classified into subgroup 3.

Mesopic visual acuity

VAm was measured monocularly at contrast 100% in the dominant eye.

Mesopic undistorted viewing field

VFm was measured with a device consisting of a forehead and chin rest securely mounted on a table attached to a rotating platform which allows rotating the subject with respect to the optotype screen, while keeping its head fixed with respect to the rotating table. Subjects were monitored to ensure that their heads remained immobilized and that they could move only their eyes to fixate the optotypes. Binocular clear distance viewing area was evaluated as the total angular sweep in which the subject is able to recognize an EDTRS letter of size 0.1 logMAR with 10% contrast (Figure 4).

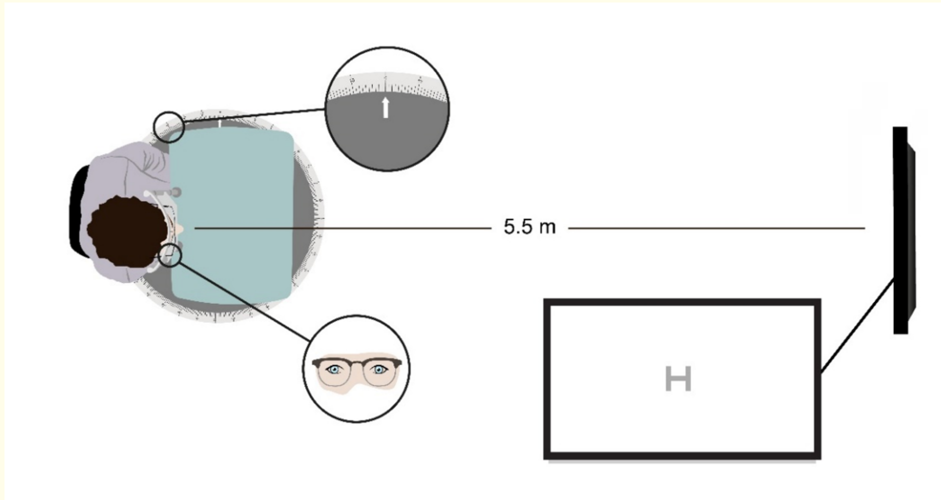

Figure 4: *Method used for measuring undistorted distance visual fields.*

Glare recovery time

GRt was recorded using a bright light from an off camera-flash. The subject was sitting 20 cm away from this lamp, which rendered a strong beam of light for a short and fixed period of time. Immediately after the flash, a letter was displayed on the screen located 5.5m away from the subject. The glare recovery time is defined as the time elapsed from the moment the optotype is presented to the moment the patient is able to recognize it (Figure 5).

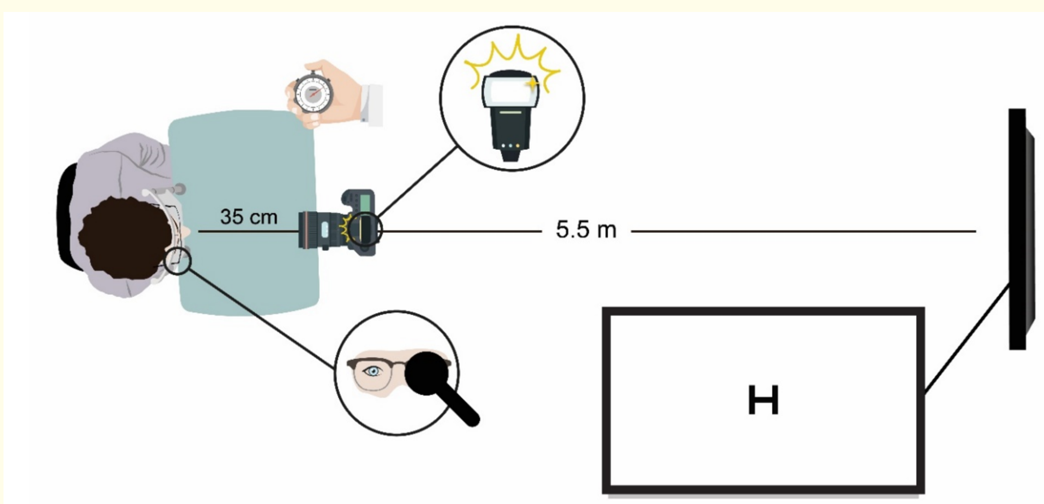

Figure 5: *Method used for measuring glare recovery time.*

Subjective user's feedback

After using the lenses for 7 days, subjects were asked to rate their satisfaction with a scale from 1 to 5, where 1 was the worst possible value and 5 was the best. The users filled up a questionnaire evaluating the general vision for everyday activities and a specific questionnaire related to vision when driving.

Statistical analysis

Registered data from the different lenses was compared to assess the visual performance of each lens design. A design of randomized complete block test was used to determine differences in satisfaction rates. The level of significance and the statistical power were set at $p < 0.05$ and 0.8, respectively. All statistical tests were performed using Statgraphics Centurion XVI.II® (StatPoint Technologies Inc., USA).

Results and Discussion

Sample characteristics

Sample was comprised of 56 subjects, 26 of them were under 45 years of age and tested single vision lenses. The remaining 30 participants over 45 years tested progressive power lenses (PPL).

Tolerance to negative defocus

No statistical differences were found for VAm when the user was wearing their best-corrected prescription or when inducing a negative defocus of -0.25D (Table 1). However, results showed that 17% of patients improved and 19% decreased their VAm when inducing this negative defocus. The remaining participants (64%) showed VAm changes lower than 0.06logMAR when inducing a negative defocus of -0.25D. The resulting segmentation was used in the statistical analysis of the mesopic clear viewing field and subjective user's feedback.

	Total	Under 45 years	Over 45 years
Without defocus	-0.09 ± 0.08	-0.10 ± 0.08	-0.08 ± 0.09
-0.25D defocus	-0.08 ± 0.07	-0.09 ± 0.07	-0.08 ± 0.08

Table 1: *VAm values with/without inducing a negative defocus of -0.25D.*

Mesopic visual acuity

No significant differences between designs were found for VAm for any of the groups (Table 2). No correlations were found between the VAm obtained with the two lens designs and the segmentation of the participants according to their tolerance to defocus (Figure 6).

	Control lens	Test lens	p-value
Total sample			
VAm	-0.06 ± 0.08	-0.05 ± 0.08	> 0.05
VFm	48.53 ± 17.60	60.13 ± 13.54	< 0.01*
GRt	26.83 ± 15.14	22.44 ± 8.82	0.01*
Group 1 (under 45 years) - Testing SV lenses			
VAm	-0.08 ± 0.08	-0.04 ± 0.07	> 0.05
VFm	58.81 ± 16.20	63.37 ± 11.38	< 0.01*
GRt	21.67 ± 6.78	19.98 ± 6.17	> 0.05
Group 2 (over 45 years) - Testing PPL lenses			
VAm	-0.05 ± 0.08	-0.07 ± 0.08	> 0.05
VFm	44.45 ± 18.27	56.75 ± 14.81	< 0.01*
GRt	31.34 ± 18.79	24.59 ± 10.26	0.01*

Table 2: *Differences between lenses in mesopic visual function for total sample, subjects under 45 years and subjects over 45 years.*

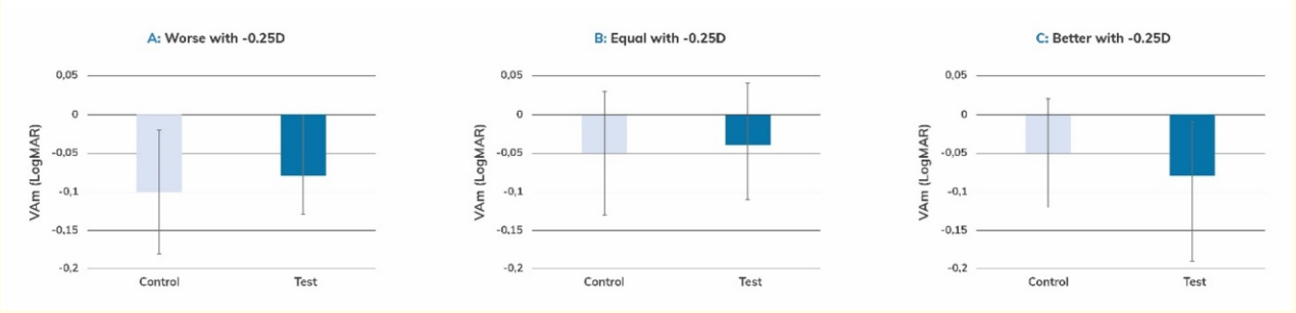

Figure 6: *Mesopic visual acuity for control and test lenses according to tolerance to negative defocus.*

Mesopic clear viewing field

For both age groups, VFm was significantly wider with the lenses specifically designed for night driving (Table 2). In comparison with the control lens, the VFm provided by these lenses was 18.6% wider in people under 45 testing SV lenses and 28.7% wider in people over 45 years testing PPLs. There was improvement of VFm for the three subgroups with different tolerance to defocus (Figure 7).

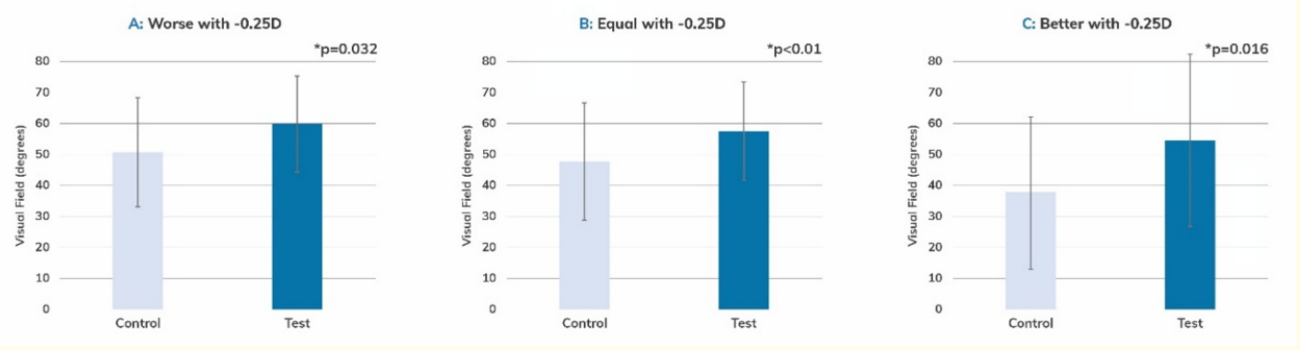

Figure 7: *Mesopic undistorted viewing field for control and test lenses according to tolerance to negative defocus.*

Glare recovery time

A lower GRt after flash was observed when using the special design, mainly due to the group of people over 45 (Table 2). This group of patients decreased their GRt 22% in comparison with the control lenses. No significant differences were observed between designs for the group of younger people. When analyzing changes of glare recovery time according to defocus tolerance, it was observed a better performance of the test lens in subgroup 2, those people whose VAm did not change with -0.25D (Figure 8).

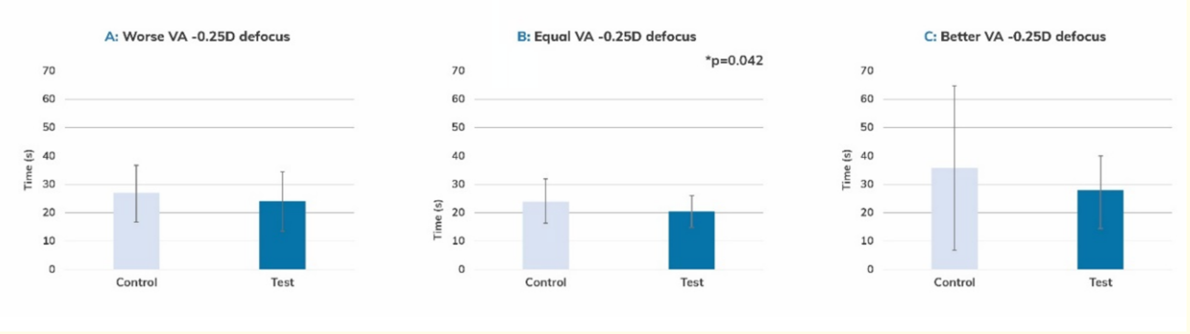

Figure 8: *Glare recovery time for control and test lenses according to tolerance to negative defocus.*

Subjective user's feedback

Results showed that lenses specially designed to optimize night vision provided significantly better satisfaction than standard lenses for driving but also for general use (Figure 9). This difference was mainly due to those patients in subgroups 1 and 2. No statistical differences were found between lens designs in the subjects in subgroup 3 (Figure 10).

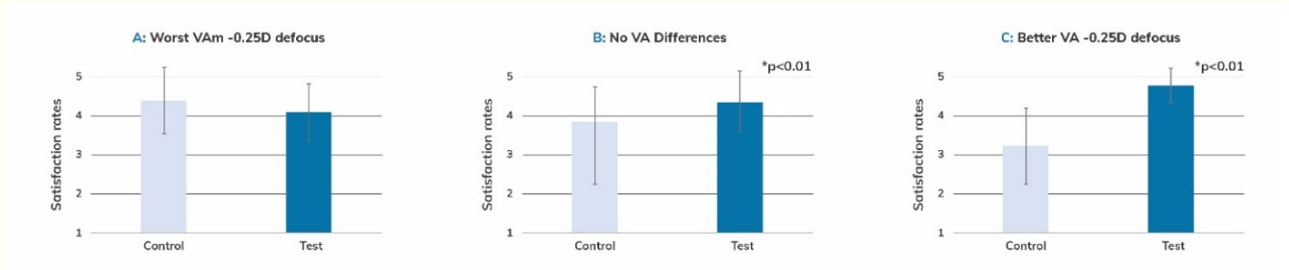

Figure 9: *Satisfaction rates for general use and driving specific vision using the control and test lenses.*

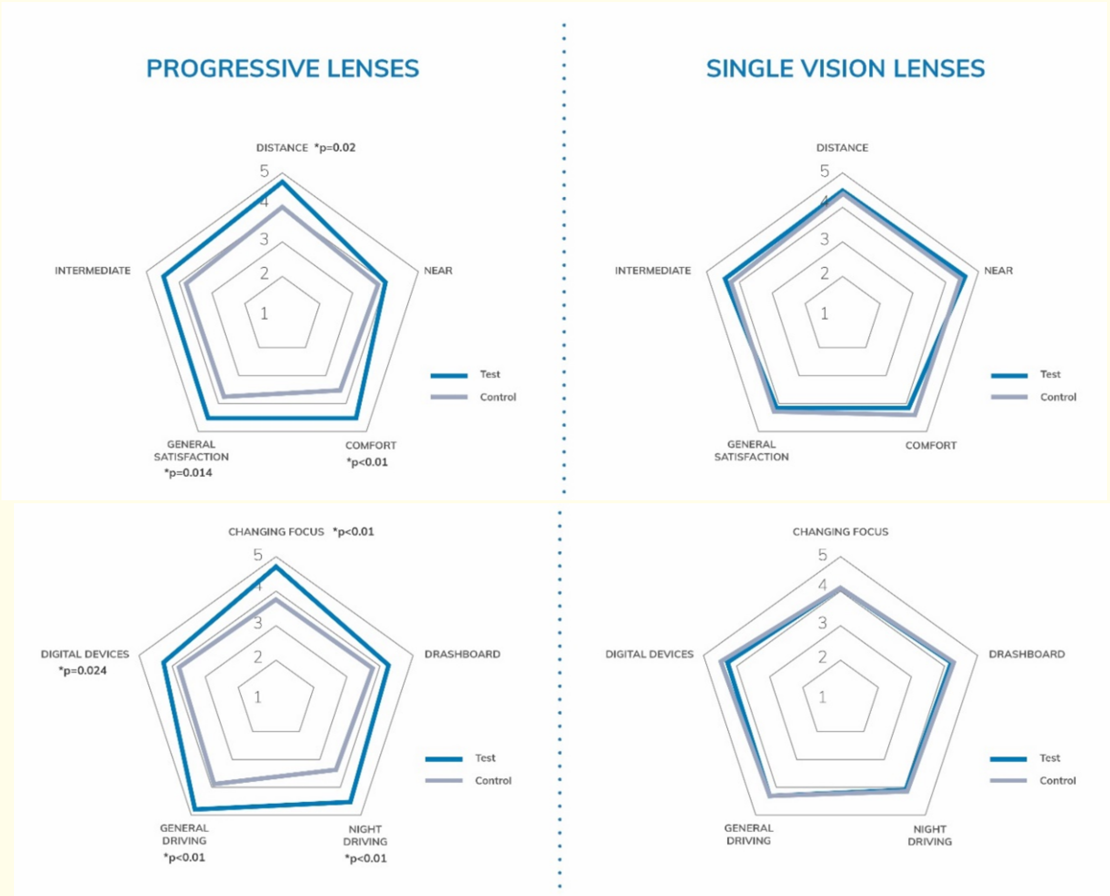

Figure 10: *Satisfaction rates for general use and driving specific vision for control and test lenses according to tolerance to negative defocus.*

Discussion

In this study we have tested a new design proposal intended to improve visual quality when driving at night. These lenses have been designed with a power distribution that improves the distance viewing field and a modification of the standard progression profile of the lens that provides a slight negative defocus in a small region just above the pupil. The lenses also incorporate a new AR coating along with a filter for short wavelengths. Results of this study demonstrate that, in comparison with a control lens, the proposed lenses provide a 34% wider distance viewing field in mesopic illumination conditions, 22% decrease of recovering time after a dazzle and better satisfaction. However, mesopic visual acuity was not affected using the proposed lenses.

Driving is a complex task in which many different factors interact: roads, environment, vehicles and drivers. Driving requires the highest focus from the driver to evaluate and interpret the environment around, and vision is the most important tool for driving. Vision directly affects the driving performance and, consequently, road safety. In addition, during night-time driving, the environment presents challenging visual conditions for drivers. At night, detection of low-contrast or bad illuminated objects is harder, and that implies longer reaction times and, consequently, longer braking times and stopping distances [10,11]. Studies have shown that approximately one-third of drivers over 45 years report night-time driving difficulties [5-7] and these problems increase with age. In fact, it has been reported that visual factors significantly contribute to the elevated risk of fatal crashes at night, which are 2 - 4 times greater than in the daytime [5]. Crash database analyses have demonstrated that poor visibility at night, rather than increased fatigue and alcohol, is the main reason for the elevated pedestrian fatality rate at night, which is 7 times bigger than in the daytime [12]. According to Gruber [13] poor visibility in low-light conditions is associated with pedestrian and bicyclist collisions and with diminished road sign recognition. Poor lighting decreases the distance to read traffic signs and consequently less time is available to react upon their information. Finally, reduced visual acuity leads to a shorter recognition distance and thus to a reduced time for an adequate reaction.

On another hand, a well-known factor contributing to the deficiency of the visual function when driving in low illumination conditions is night myopia. This condition is mainly characterized by the increase of the defocus under mesopic vision. In this sense, several studies have tried to evaluate the influence of night myopia in the driving performance. The study carried out by Cohen [14] showed a positive relationship between night myopia over -0,75 D and the accident rate during night in professional drivers.

Results of this study do not show differences in mesopic visual acuity, the most common clinical procedure used to measure visual function by eye care professionals. Visual acuity is a measurement of the ability of the eye to differentiate shapes and details of objects at a given distance, but, our visual environment when driving consists of much more than just the simplified way in which we typically assess vision with letters or numbers on a standard eye chart. So, to assess the visual function under mesopic conditions we have followed the indications of the European Working Group for Vision. In the conclusions to these indications they explicitly mention that the most important visual function parameters in order of relevance for save driving are, in addition to VA, contrast sensitivity, the visual field, and sensitivity to glare [15]. So, in our study, we have measured the viewing field using a low contrast optotype and the glare recovery time. In addition, to assess the visual function under mesopic conditions, the testing cabinet was adapted up to similar levels to the real ones in night driving. Both parameters showed differences between the control and the test lens indicating that the new lens improved these aspects of mesopic visual function.

Also, to confirm the advantages of this kind of lenses, participants filled a questionnaire to register the subjective feedback of the participants when using both pair of lenses. Results of this survey confirms the benefits of this lenses showing better satisfaction rates with the proposed lenses.

It is worth mentioning that the advantages of the proposed lenses were more remarkable in the group of people over 45 years of age that were wearing PPLs. Studies have shown that age produce a range of declines in sensory, cognitive, and motor skills performance [16] and that wearing different presbyopic vision corrections can affect real-world measures of driving performance at night. In the study of Chu [17] it was analyzed the impact of different vision corrections in presbyopic people when driving, concluding that spectacle corrections performed better than contact lens corrections. Specifically, for the PPLs users, it was reported that they present more peripheral distortion and blur compared with the other groups under daytime and night-time conditions. This result is likely due to the geometry of the PPL in which there is a gradual power change from the distance to the near area of the lens, which induces unwanted distortion through the lower lens periphery. So, it is essential to design lenses, as the one proposed in this study, that minimize these lateral aberrations and improve driving performance.

Conclusion

The new lens-design concept characterized by inducing a slight negative defocus above the fitting cross and incorporating a special coating, improved mesopic visual function. These lenses provided wider undistorted distance visual field, lower glare recovery time and higher user satisfaction in general, and specifically at driving.

Acknowledgements

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Conflict of Interest

We as main authors certify that all authors have seen and approved the manuscript being submitted. We warrant that the article is the Authors' original work. We warrant that the article has not received prior publication and is not under consideration for publication elsewhere. On behalf of all Co-Authors, the corresponding Author shall bear full responsibility for the submission. All authors agree that author list is correct in its content and order and that no modification to the author list can be made without the formal approval of the Editor-in-Chief, and all authors accept that the Editor-in-Chief's decisions over acceptance or rejection.

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