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Mesopic contrast sensitivity in the presence or absence of glare in a large driver population

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Human subjects and informed consent: The authors confirm that the research followed the tenets of the Declaration of Helsinki that informed consent was obtained from the subjects after explanation of the nature of the study. The research was approved by the Clinical Research Ethics Committee of the Hospital Clínico San Carlos (Madrid).

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Abstract *Background:* To evaluate mesopic contrast sensitivity in conditions of glare and no glare in a vehicle driver population, and to explore the effects of age, habitual spectacle correction, photopic visual acuity and driving exposure. *Methods:* A cross-sectional study was performed on 297 drivers stratified by age into six groups. The mesopic contrast sensitivity was measured in the absence or presence of glare using the Mesotest II (Oculus, Germany) in each subject both with habitual and best spectacle correction. A questionnaire on the subject's driving habits was completed. *Results:* There were no significant differences between contrast sensitivity measured with habitual or best spectacle correction. In conditions of no glare, the mesopic contrast sensitivity gradually got worse from 51 to 60 years onwards, and from 41 to 50 years onwards in the presence of glare. In both conditions, the total decrease in contrast sensitivity was 0.3 log units. The with-glare and without-glare mesopic contrast sensitivity improved as photopic visual acuity increased. Forty-five per cent of drivers who reported difficulties in driving at night were unable to perform any of the tests with glare, compared to 20% without glare. However, the effect of driving habits on contrast sensitivity was only significant in the oldest age group. *Conclusions:* The mesopic contrast sensitivity and glare sensitivity seem to be stable until the age of 50 years, from which point they start to decline at a rate of 0.1 log contrast sensitivity loss per decade. Drivers with poor visual acuity and/or older drivers who avoided night driving presented worse mesopic contrast sensitivity and greater glare sensitivity.

Keywords Mesopic contrast sensitivity · Glare disability · Vehicle driver · Age

Introduction

The sense of vision provides the vehicle driver with most of the information needed to perform well. During night hours, in adverse weather conditions of rain or fog, visual information is reduced, contour discrimination gets worse and the risk of glare increases. Under these circumstances, visual acuity plays a less important role than the ability to recognize weak contrasts [18].

Older drivers are the population group that complain most about night driving difficulties above all because of glare [18, 28]. Furthermore, the exponential increase in subjects undergoing refractive surgery has increased complaints of night vision disturbances [9] due to enhanced wavefront aberrations [17], associated with the larger pupil sizes.

Given that a substantial proportion of road accidents occur at night, certain tests have been designed to assess relevant features of vision ranging from acuity at low light levels to glare resistance and recovery. These measures appear to be of some significance and show some correlation with accidents [4, 14], with poor motion perception on the road at night [1] and with perceived driving disability [23]. Using the recommendation set by the German Ophthalmologic Society (DOG) for driving a car at night [11], the Mesotest II, mesopic contrast sensitivity and glare sensitivity were described to diminish with age [25] and after photorefractive keratectomy for myopia [16, 26].

As highlighted by Fan-Paul et al. [9], the terms glare and disability glare are often confused in the literature. Glare is the physical term referring to a light source and disability glare is a reduction in visual acuity or contrast sensitivity due to a nearby glare source and is the result of forward intraocular light scattering. Bearing in mind that sensitivity to glare rises as scattering in the cornea or lens increases, disability glare increases with age even in people with perfectly healthy eyes or patients with corneal edema, cataracts or contact lenses [6]. Most current glare testers measure glare at photopic levels only, those that evaluate the glare effect in conditions similar to those found in night driving being limited to only a few tests.

Given the scarce amount of data available on mesopic vision in large populations, the aims of this study were to: (1) evaluate spatial contrast sensitivity and glare sensitivity at low light levels in a large Spanish vehicle driver population and establish variation with age; (2) explore differences in everyday visual performance capacity in terms of the mesopic contrast sensitivity measured using habitual distance correction and best spectacle correction; and (3) establish the effect of photopic visual acuity and driving exposure on this mesopic contrast sensitivity in conditions of both no glare and glare. This objectives were achieved using the Mesotest II.

Materials and methods

A cross-sectional study was performed on 297 volunteer vehicle drivers stratified into six age groups recruited from the driver population of Madrid, Spain. The guidelines of the Declaration of Helsinki were followed, and the procedures applied were approved by the Clinical Research Ethics Committee of the Hospital Clínico San Carlos (Madrid). All subjects gave their consent to participate after the nature of the study had been explained to them.

The drivers enrolled in the study were required to fulfill Spain's minimum driving requirements. This includes checking visual (visual acuity equal or greater than 0.5), hearing, motor, medical and psychological functions every 10 years, or every 1 or 2 years in the case of elderly or disabled subjects. Given our interest in knowing the subjects' everyday visual performance capabilities no evaluation was made of the status of the media. The age bands established and the total number of subjects in each age group were: 21–30 (58); 31–40 (56); 41–50 (53); 51–60 (48); 61–70 (49); >70 (33).

The experimental protocol involved a single visit to the Clinic of the School of Optometry, Complutense University, Madrid by each subject. Detailed objective and subjective tests were performed to establish the subjects' refractive errors and provide them with the best optical correction when needed. Refraction and binocular distance visual acuity were determined under photopic conditions (85 candela per square meter, cd/m^2). During the time of adaptation to the dark for the subsequent test, each subject was asked about his/her driving habits including whether they: (1) were habitual drivers defined as driving at least 6 days a week, and (2) avoided night driving. The information obtained was used to complete a questionnaire for each subject.

The mesopic contrast sensitivity in the presence or absence of glare was measured using the Mesotest II or Mesoptometer II (Oculus, Germany), as described by others [16, 26]. These variables reflect mesopic function and are therefore used in Germany as recommendations to determine night-driving ability. The subject was allowed to dark adapt for at least 5 min before the examination; no differences were noted between adaptation times of 5 min or 15 min [21]. We conducted the tests binocularly. First the subject was tested with habitual optical distance correction to establish everyday visual performance. The tests were then repeated with best spectacle correction if necessary.

The Mesotest is a compact instrument that avoids instrument myopia. The viewing screen of the test panel is seen through an optical system at a distance of 5 m from the eye. During the examination, the subject views a Landolt ring of decimal visual acuity of 0.1 (20/200). Background luminance is 0.032±0.003 cd/m^2 without glare and 0.10±0.01 cd/m^2 with glare, corresponding to the brightness of traffic at twilight or at night. The contrast of the target with respect to its background can be decreased in steps each corresponding to a factor of 0.10 log contrast sensitivity units (Table 1). Given that contrast sensitivity is the reciprocal value of the contrast threshold, this value was converted to log contrast sensitivity for statistical analysis [3]. Lower levels of contrast in this low mesopic conditions would be difficult to discriminate even in young people [16]. The most important setting was the 1:5 contrast level, which is the critical level for driving a car at night according to the recommendations of the German Ophthalmic Society (DOG) [11].

The target was displayed in a random position. If the subject identified the Landolt ring in three of five different positions (60% criterion), the next lower contrast level was tested. Upon completion of the test, glare source at a visual angle of 3° was introduced and the above procedure repeated. Subjects were asked to keep fixation on the optotype and to avoid direct fixation on the glare source. The glare illumination is set at 0.35±0.03 lux on the pupil.

Disability glare was defined as the difference in contrast sensitivity in the absence and presence of a glare source and was expressed as log contrast units lost with glare.

Statistical analysis was performed using Statgraphics, version 5.0 software. The non-parametric Kruskal–Wallis test was used to compare data between the age groups. This analysis was based on a non-normal distribution of the data. The level of statistical significance was set at $p<0.05$.

Table 1 Contrast levels of the optotypes. Weber contrast = $(L_f - L_o)/L_f$

Ratio L_o/L_f	Contrast threshold	Contrast sensitivity	Log contrast sensitivity
1:23	0.95	1.052	0.02
1:5	0.8	1.250	0.1
1:2.7	0.63	1.587	0.2
1:2	0.50	2	0.3

Results

Mesopic contrast sensitivity was similar whether determined with best spectacle or usual distance correction according to the sign and signed rank tests, even when the subjects were stratified by age. Hence, thereafter, contrast sensitivity was only evaluated in terms of variables corresponding to best spectacle correction.

Figure 1 shows median log contrast sensitivity in the absence and presence of glare for each age group. The vertical lines through the data points represent the 25th and 75th quartiles. Median without-glare contrast sensitivity decreased 0.3 log units between the oldest and the youngest age groups. With glare the diminution was greater than 0.3 log units. When the Kruskal–Wallis test was used to test the null hypothesis that the medians of the contrast sensitivity for each of the six age group levels were the same, a statistically significant difference was detected among medians at the 95% confidence level for the variables without glare ($p<0.01$) and with glare ($p<0.01$). The without-glare contrast sensitivity median decreased gradually from the 51–60 year group onwards, the first three age groups being homogenous (Fig. 1a). In conditions of glare, the decrease started at the earlier age of 41–50 years, and median values reached zero for subjects older than 70 years, of whom 75% could not discriminate any contrast (Fig. 1b). In both conditions, the decline was approximately 0.1 log contrast sensitivity per decade from 50 years onwards.

When the effect of age on median log contrast sensitivity was analyzed in subjects with a visual acuity of at least 20/20, our preceding findings were confirmed in both conditions of no glare and glare ($p<0.01$).

Table 2 shows the percentage of subjects in each age group not fulfilling the contrast limit of 1:5 recommended by the German Ophthalmologic Society (DOG) for night driving. 20.54% of the entire sample did not fulfill this limit in conditions of no glare, and 41.8% in the presence of glare.

The effect of age on disability glare was analyzed by examining the difference in the without-glare and with-glare contrast sensitivity expressed as log contrast units lost in glare. A statistically significant difference was shown among the difference of the medians (Kruskal–Wallis, $p<0.01$). Median disability glare values indicated that less than a 0.1 log contrast unit was lost by subjects in the two youngest age groups. A loss of 0.1 log contrast units was the median value obtained in the remaining groups, but there was an increase in the percentage of drivers who lost between 0.2 or more log contrast units with age. Furthermore, few subjects of the total sample showed better contrast discrimination with glare than without glare and some subjects in the older age group lost no log contrast units since they were unable to discriminate any contrast in the presence or absence of glare.

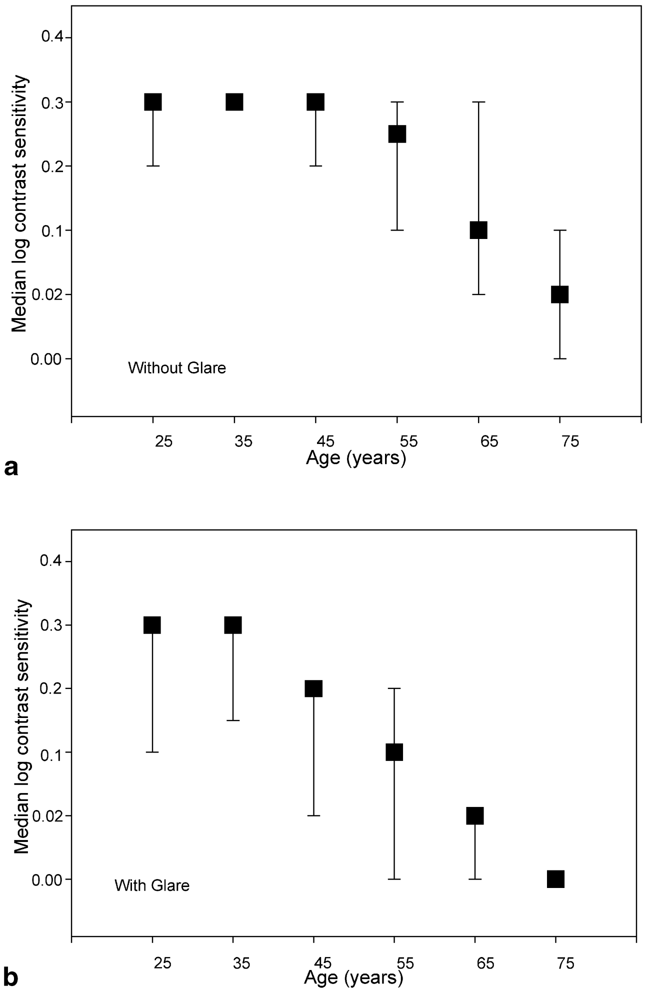
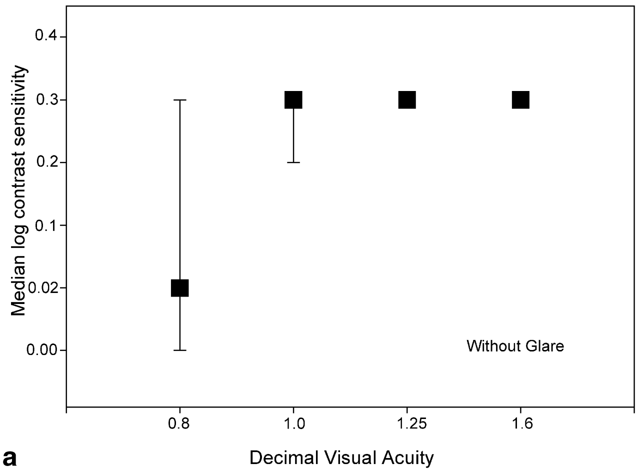


Fig. 1 Mesopic contrast sensitivity medians across age groups. **a** No glare. **b** Glare. *Vertical lines* indicate upper and lower quartiles

Table 2 Percentage of subjects in each age group not fulfilling the contrast limit of 1:5 (0.1 log contrast sensitivity) recommended by the German Ophthalmologic Society (DOG)

Age	No glare	Glare
21–30	8.6	13.8
31–40	8.9	14.3
41–50	13.2	28.3
51–60	16.7	47.9
61–70	30.6	75.5
>70	63.6	93.9
Total sample	20.5	41.1

Next, to avoid the influence of age, the effect of visual acuity on median log contrast sensitivity was analyzed in the two youngest age groups, since these groups were homogenous without and with glare. This analysis indicated that the mesopic median log contrast sensitivity was enhanced with increasing photopic visual acuity in the absence ($p<0.01$) or presence ($p<0.01$) of glare. Figure 2



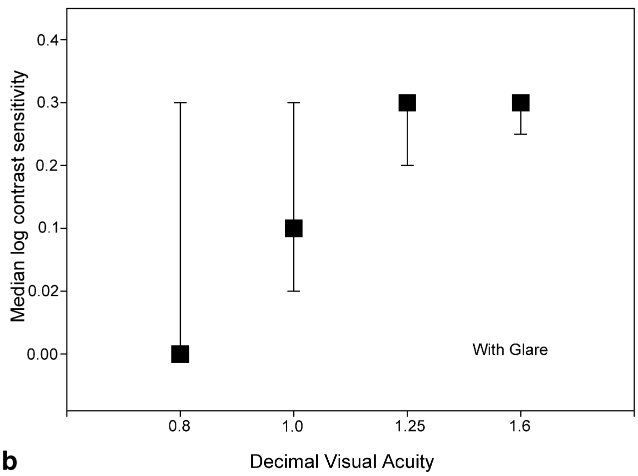


Fig. 2 Mesopic contrast sensitivity median by photopic visual acuity. **a** No glare. **b** Glare. *Vertical lines* indicate the upper and lower quartiles

Table 3 Driving habits expressed as the percentage of people in each age group. *p*-values were determined using the χ^2-test

Age	Habitual driving		Night driving avoided	
	Yes (%)	No (%)	No (%)	Yes (%)
21–30	63.79	36.21	81.03	18.97
31–40	92.86	7.14	73.21	26.79
41–50	71.70	28.3	58.49	41.51
51–60	81.25	18.75	70.83	29.17
61–70	38.78	61.22	34.69	65.31
>70	27.27	72.73	21.21	78.79
p-values	p=0.0001		p=0.0001	

Table 4 Mesopic log contrast sensitivity without glare according to driving habits. Values expressed as the percentage of people in each driving habit group and contrast sensitivity category. *p*-values were determined using the χ^2-test

Without glare	Habitual driving		Night driving avoided	
Log contrast sensitivity	Yes (%)	No (%)	Yes (%)	No (%)
0	7.7	17.5	20	5.1
0.02	8.2	11.6	12.5	7.3
0.1	9.3	10.7	12.5	7.9
0.2	16.5	15.5	15	16.9
0.3	58.3	44.7	40	62.7
p-values	*p* ns		p<0.01	

Table 5 Mesopic log contrast sensitivity with glare according to driving habits. Values expressed as the percentage of people in each driving habit group and contrast sensitivity category. *p*-values were determined using the χ^2-test

With glare	Habitual driving		Night driving avoided	
Log contrast sensitivity	Yes (%)	No (%)	Yes (%)	No (%)
0	20.1	38.8	45	14.1
0.02	12.4	18.5	15.8	13.6
0.1	13.4	9.7	10	13.6
0.2	20.1	10.7	10	21.5
0.3	34	22.3	19.2	37.3
p-values	p<0.01		p<0.01	

shows mesopic contrast sensitivity as a function of visual acuity. Without glare, median contrast sensitivity increased by 0.3 log units between the lowest and highest visual acuity group and more than 0.3 log units with glare.

The results of the survey on driving habits are shown in Table 3. Subjects were classified according to their replies with regard to their driving habits. A smaller percentage of subjects drove habitually and a larger percentage expressed difficulty in night driving in the 61–70 and >70 year age groups. The remaining groups scarcely differed in their answers to these two questions.

Log contrast sensitivity distribution according to driving habits is shown in Table 4 without glare and Table 5 with glare. In the absence of glare, contrast sensitivity showed no variation as a function of the variable habitual driving. However, when the subjects were stratified according to whether they avoided night driving or not, contrast sensitivity did vary significantly (p<0.01). It should be highlighted that 20% of subjects who had difficulty in driving at night were unable to discriminate contrast, compared to 5% who claimed they did not mind driving in the dark. In the presence of glare, significantly different contrast sensitivities were recorded depending on driving habits (p<0.01), most marked differences being related to avoiding night driving (contrast not distinguished in 45% of subjects who avoided night driving vs 14% of subjects who drove at night).

Next, to avoid the influence of age, the effect of driving habits on contrast sensitivity was analyzed in each age group. In this analysis, significant differences (p<0.01) were observed only in the oldest age group.

Discussion

Our findings indicate that mesopic contrast sensitivity both in the presence or absence of glare decreases significantly with age. While it has been clearly established that photopic contrast sensitivity diminishes in normal, healthy aging eyes [7, 8, 20], the literature lacks data on changes in mesopic contrast sensitivity throughout adulthood. In particular, there are very few reports of large population studies.

Bearing in mind that all our subjects satisfied the legal visual requirements for driving, no significant differences in the mesopic contrast sensitivity were detected whether measured with habitual or best spectacle correction. The without-glare median contrast sensitivity decreased gradually 0.3 log units (Fig. 1) from 51 to 60 years onwards, whereas with-glare contrast sensitivity started to decline at an earlier age (41–50 years) and the diminution was greater than 0.3 log units. This finding is consistent with those described by Scharwey et al. [25], who found that mesopic contrast acuity and glare sensitivity, measured using the Mesotest II, deteriorated in an age-dependent way in 117 healthy subjects. We are in agreement with Harrison et al. [12] who found no significant differences in the sensitivity increment in the absence or presence of glare as a function of age across the middle years (21–50 years) in ophthalmologically normal subjects using sine-wave gratings to measure the mesopic contrast sensitivity at four low spatial frequencies. We also observed homogenous results in the middle age groups (21–50 years) of our population.

The age-related changes observed in the mesopic contrast sensitivity are in line with the findings of Sloane et al. [27] who reported a loss in contrast sensitivity at low luminance using sinusoidal gratings in a group of elderly subjects with respect to a young group. In photopic luminance conditions, the decline in contrast sensitivity is also greatest at older ages, as noted by Haegerstrom et al. [10] and Rubin et al. [24]. In this last study performed on 2,500 subjects between the ages of 65 and 85 years, a 0.1 decrease in log Pelli-Robson contrast sensitivity (low spatial frequency) per decade was observed. A similar decline per decade was observed in our study from 50 years onwards in mesopic conditions.

Consistent with the decline in contrast sensitivity noted here in elderly subjects, reports in the literature on aging indicate that even in the absence of ocular disease there are normal age-related changes in visual function. With age, the lens becomes yellower and less transparent, the pupil becomes smaller, less able to dilate in conditions of low light, and the integrity of the macular pigment and neural pathways is altered. These changes lead to decreased light sensitivity, increased glare sensitivity, reduced visual acuity, and prolonged dark adaptation [29]. Because driving is a visually highly demanding task, it has been suggested that the higher accident rate among the elderly, who indeed are the fastest growing sector of the driving population, may in part be attributable to age-related changes in vision.

Scharwey et al. [25] found that nearly 40% of persons over the age of 60 did not fulfill the Mesotest contrast limit of 1:5 recommended by the German Ophthalmologic Society (DOG) for night driving and showed reduced night driving ability. We found that 20.54% of our series of 279 subjects did not fulfill the DOG criteria in conditions of no glare and observed a rise in this proportion to 41.8% when measurements were made in the presence of glare. With increasing age, it was noted that the percentage of people in each age group who could not discriminate the contrast limit of 1:5 increased (Table 2). We basically agree with the proposal by Rassow [21], that testing contrast sensitivity in conditions of no glare or glare at a higher luminance level would reduce the number of people unable to reach the contrast limit of 1:5. Rassow argues that the luminance of today's vehicle headlights is significantly higher than the background luminance of the mesopic instrument. Furthermore, it appears that typical current UK road lighting levels (about 1 cd/m^2) are too high for significant night myopia to develop among drivers [2, 5]. Night myopia is largely due to changes in accommodation in the youthful eye, these being absent after the age of about 50 [15].

It is clear that glare can have an effect on the contrast sensitivity. Our results indicate that disability glare is enhanced in the elderly. Most of our subjects under 50 years of age lost less than 0.1 log contrast unit in glare, while in subjects older than 50 years, a large proportion lost between 0.2 and more log contrast units. Effectively, most subjects in the oldest age group failed to discriminate contrast with glare. Further, in some subjects of varying age, no contrasts log units were lost at all or even better contrast was discriminated with glare than without. These results might be explained by the pupillary miosis induced by glare possibly having a pinhole effect in some persons and offset any loss in contrast sensitivity due to blur in glare conditions. This would be the effect of artificially reducing disability glare [6].

Our findings suggest that mesopic contrast sensitivity improves as photopic visual acuity increases. This indicates that the same occurs in mesopic as in photopic conditions, in which there is high correlation between Pelli-Robson chart contrast sensitivity (low spatial frequency) and high contrast visual acuity [10, 24]. However, there are no data available concerning the effect of visual acuity on mesopic contrast sensitivity, this point thus needs further investigation to verify our results. Moreover, given that the values in Fig. 2 only represent 50% of the population, we cannot say that visual acuity was a good predictor of mesopic vision in every case.

Our questionnaire results indicated that older drivers who did not drive daily were more likely to avoid night driving. Visual difficulties in the elderly are generally exacerbated under night-time driving conditions, in part, due to the age-related decrease in visual performance, arising from reduced contrast sensitivity and increased glare sensitivity. Despite vision problems in the older driver, the risk of traffic accidents among Spanish drivers is significantly higher in the 18–24 year old range [22]. Twilight and night driving, driving in urban areas, and driving on weekends and national holidays have also been associated, though not significantly, with a slightly higher accident risk. Owsley et al. [19] found that subjects who reported driving less than 7 days per week were 30% less likely to have incurred a crash compared with those who reported driving daily.

Although, it is well-known that older drivers restrict their driving under poor visibility conditions, the relation between driving self-restriction and the mesopic contrast sensitivity was only recently studied [23]. In our study, subjects who did not drive daily and avoided night driving showed worse mesopic contrast sensitivity in glare-free conditions or those of glare. Specifically 60.8% of drivers who reported difficulties in driving at night were unable to reach the DOG contrast limit 1:5 with glare, compared to 32.5% without glare. However, the driving habits effect on contrast sensitivity was only statistically significant in the oldest age group. The studies of Lachenmayr et al. [14] have shown that reduced mesopic vision and increased sensitivity to glare are accompanied by an increased risk of night-time accidents. 11.4% of drivers involved in accidents (mean 56.3 years) did not reach the DOG contrast limit 1:5 in the absence of glare, and 17.2% failed to do so in the presence of glare. In comparison, in a control group of accident-free drivers of comparable age, 4% did not reach this critical limit in conditions of no glare and 7.6% in those of glare. This gives some indication of the impact of mesopic contrast on night driving, as measured by us and others. In Spain, accident records do not include personal data, so we could not compare our correlations.

The use of a vehicle-licensing sight test under night-time driving conditions has been strongly advocated. The results of this study provide mesopic contrast sensitivity data without and with glare on a large population covering all ages. These data could help establish reference values to evaluate, for instance, patients with cataracts or those who complain of reduced night vision after corneal refractive surgery. Further, considering that mesopic contrast sensitivity and glare sensitivity seem to remain fairly stable until the age of 50 years when both variables start to decline, the importance of regular check-ups including tests of visual functions such as mesopic vision and sensitivity to glare, currently not required by traffic laws, will become more evident over the next few decades as the driving population ages. This becomes particularly relevant if we consider that elderly drivers tend to continue to drive for as long as possible [13].

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