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Association of lens opacities, intraocular straylight, contrast sensitivity and visual acuity in European drivers

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ABSTRACT.
Purpose: **To study the relationship between lens opacity and intraocular straylight, visual acuity and contrast sensitivity.**
Methods: **We investigated 2422 drivers in five clinics in different European Union (EU) member states aged between 20 and 89 years as part of a European study into the prevalence of visual function disorders in drivers. We measured visual acuity [Early Treatment Diabetic Retinopathy Study (ETDRS) chart], contrast sensitivity (Pelli–Robson chart) and intraocular straylight (computerized straylight meter). Lens opacities were graded with the Lens Opacities Classification System III (LOCS) without pupillary dilation. Participants answered the National Eye Institute Visual Functioning Questionnaire – 25.**
Results: **Intraocular straylight was related more strongly to LOCS score than to both visual acuity and contrast sensitivity. Visual acuity and contrast sensitivity were correlated to each other well, but to intraocular straylight to a much lesser extent. Self-reported visual quality was best related to contrast sensitivity; night driving difficulty was best related to visual acuity.**
Conclusion: **Straylight is found to have added value for visual function assessment in drivers, whereas if visual acuity is known contrast sensitivity has limited added value.**

Key words: cataract – contrast sensitivity – driving – glare – quality of life – quality of vision – straylight – visual acuity

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Introduction

Currently, visual acuity is considered the primary visual function for the evaluation of drivers. Although the importance of contrast sensitivity and glare sensitivity is recognized (Adamsons et al. 1992; Elliott & Bullimore 1993; Deutsche Ophthalmologische Gesellschaft 1999; Mantyjarvi & Tuppurainen 1999), application is being hampered by the absence of an adequate measurement method, the absence of well-evaluated cut-off values and lack of knowledge of prevalence of impairments in the (driving) population. Earlier studies showed that visual acuity, contrast sensitivity and glare sensitivity are risk factors for self-reported visual function impairment (Rubin et al. 1994, 2001; Stifter et al. 2006).

Recently, a technique for glare measurement has been developed using a computerized straylight meter, according to the Compensation Comparison principle (Franssen et al. 2006). Measured intraocular straylight (IOSL) is the known cause of disability glare (Vos 1984; van den Berg 1986; Elliott

1993). It increases with age in the healthy eye, and more so with ocular conditions such as cataract and other disturbances to the optical media (Vos 1984; Elliott 1993; van den Berg 1995; van den Berg et al. 2007). A review of current techniques to measure disability glare in ophthalmological practice is given by Aslam (Aslam et al. 2007).

In an earlier study (van Rijn et al. 2002), straylight has been appreciated as a visual function that has 'added value', being affected independently of visual acuity and contrast sensitivity in a clinical population. As yet it is unclear to what extent straylight measurements also provide additional information about visual function in the population of elderly drivers. Such population data are a prerequisite for the introduction of straylight measurements for driver testing. It must provide so much additional information that the application of this test is warranted. To resolve the problem of lack of prevalence knowledge, a study was conducted among automobile drivers in Europe (van den Berg et al. 2005). This was the first study in which the new computerized straylight meter was applied in a large population. The data from this study were used to evaluate straylight effects with ageing and lens extraction (van den Berg et al. 2007). In the current evaluation, we focused on how objective straylight measurements relate to subjective lens opacity grading [Lens Opacities Classification System III (LOCS)], visual acuity, contrast sensitivity and self-reported impairments of visual function. Since this population study was carried out, the computerized straylight meter has been made into a commercial product by Oculus GmbH.

Materials and Methods

The methods for inclusion of participants, measurement of visual function and analysis of data of the European study on elderly European drivers are reported elsewhere (van den Berg et al. 2005). In this article, we report only those elements of the methods that are relevant for the current analysis.

The 2422 participants were recruited among the general population in a wide area around the five participating clinics: the Vrije Universiteit Medical Centre in Amsterdam; the Universitätsklinik für Augenheilkunde und Optometrie in Salzburg; the Universitäts-Augenklinik in Tübingen; the Centro de Oftalmología Barraquer in Barcelona; and the Universitair Ziekenhuis Antwerpen. Participants had to belong to the relevant age category and be in the possession of a valid class 1 driving licence. Participants had to consider themselves an 'active driver', according to their own judgement. We intended to recruit an equal number of individuals in the following age groups: 20–30 years (n = 211), 45–54 years (n = 652), 55–64 years (n = 688), 65–74 years (n = 529) and ≥ 75 years (n = 342). The study was approved by an ethics committee (Tübingen, Germany) and conforms to the provisions of the Declaration of Helsinki.

Best-corrected visual acuity (BCVA) was measured with the Early Treatment Diabetic Retinopathy Study (ETDRS) chart on a logMAR scale (Ferris et al. 1982; Arditi & Cagenello 1993). Participants wore autorefraction values that were fine-tuned by an optometrist, such that BCVAs were obtained. Driving visual acuity was measured with the same ETDRS chart and the correction used by the participants during driving. Contrast sensitivity was measured using the Pelli–Robson chart and expressed as log [percent contrast] (log[c]) (Pelli et al. 1988; Rubin 1988; Elliott et al. 1990b). Participants were placed at 1.5 m distance from the screen and wore a trial frame with their best-corrected values, with a near addition of +0.5 for individuals above 40 years of age. IOSL was measured using a computerized straylight meter, adapted from the conventional straylight meter for the purpose of general application. A ring-shaped straylight source is directed into the eye at a frequency of 8 Hz. The resultant retinal straylight in the fovea is compared to a reference light in counter phase. Retinal straylight is quantified by matching the scattered light with the reference light. Major modifications consist of the application of a forced-choice strategy and statistical analysis of the results to assess measurement reliability. Values were expressed as log [straylight parameter] (log[s]) (van den Berg 1995). Note that higher straylight values indicate a higher sensitivity to glare and thus a more compromised visual function. This method has been described in detail in another report (Franssen et al. 2006). The method is now available commercially (C-Quant; Oculus GmbH, Wetzlar, Germany).

All participants had a brief medical and ophthalmological history taken by an ophthalmologist, as well as examination of the anterior (slit-lamp) and posterior segment, without pupillary dilation. Participants answered the National Eye Institute Visual Functioning Questionnaire – 25 (NEI-VFQ-25) (Mangione et al. 2001; Owen et al. 2006), which was used in the self-administered format. The NEI-VFQ-25 consists of a base set of 25 vision-targeted questions representing 11 vision-related constructs, plus an additional single-item general health rating question. It includes three driving-related questions with one about night driving ('how much difficulty do you have driving at night?'). The answers were treated and evaluated according to the NEI-VFQ-25 manual version 2000 (http://www.nei.nih.gov). We used the general calculated mean scores (VFQ mean) and the scores of the night driving question (VFQ night driving) in our analysis.

Participants underwent grading of lens opacification (cataract) according to the LOCS lens classification system (Chylack et al. 1993) of cortical opacity (C), nuclear opacity (NO), nuclear colour (NC) and posterior subcapsular opacity (P). LOCS classifications had to be performed without pupillary dilation because the drivers came to the clinics with their car for the tests. Because of the large scale of the study, the exams were performed by non-medical personnel. Furthermore, pupillary dilation was not necessary for the purpose of the main study into prevalence of impairments of visual function in elderly European drivers. This limits the value of cortical and posterior subcapsular cataract assessment (see Discussion). A mean LOCS value was calculated as the mean of the NC, NO, C and P judgement, which was divided by four and used in our data analysis.

Data were analysed for all age groups together. To avoid possible autocorrelations of data, one randomly selected eye per individual was included in the analysis. Pseudophacic eyes (107) and eyes with missing LOCS data (144) were excluded, resulting in 2171 eyes for the data analysis.

Multiple regression was applied for LOCS as a function of BCVA, contrast sensitivity and IOSL and for VFQ mean and VFQ night driving as function of driving visual acuity, contrast sensitivity and IOSL. We used the standardized partial regression coefficient beta as indicator of relative importance of the various variables X in determining Y in multiple regression analysis (Zar 1999). The significance level and confidence coefficients (CIs) were set to 0.5 and 0.95, respectively.

Results

We found a mean of 0.91 log[s] IOSL in the youngest age group (20–30 years). IOSL increases with increasing age, reaching 1.40 log[s] in the oldest age group (75 years and over). A graphical representation and a derived formula of IOSL as a function of age is published elsewhere (van den Berg et al. 2007).

IOSL also increased with increasing LOCS score (Fig. 1A). Mean IOSL for the lowest LOCS score (0.1) was 0.99 log[s] (CI ± 0.03) and for the highest LOCS score (> 0.75) was 1.44 log[s] (CI ± 0.05). BCVA and contrast sensitivity worsened slightly with increasing LOCS score (Fig. 1C, E). To investigate which visual function was best related to the LOCS score, we performed a multiple regression analysis of all eyes. Results showed that all three visual functions (BCVA, contrast sensitivity and IOSL) were

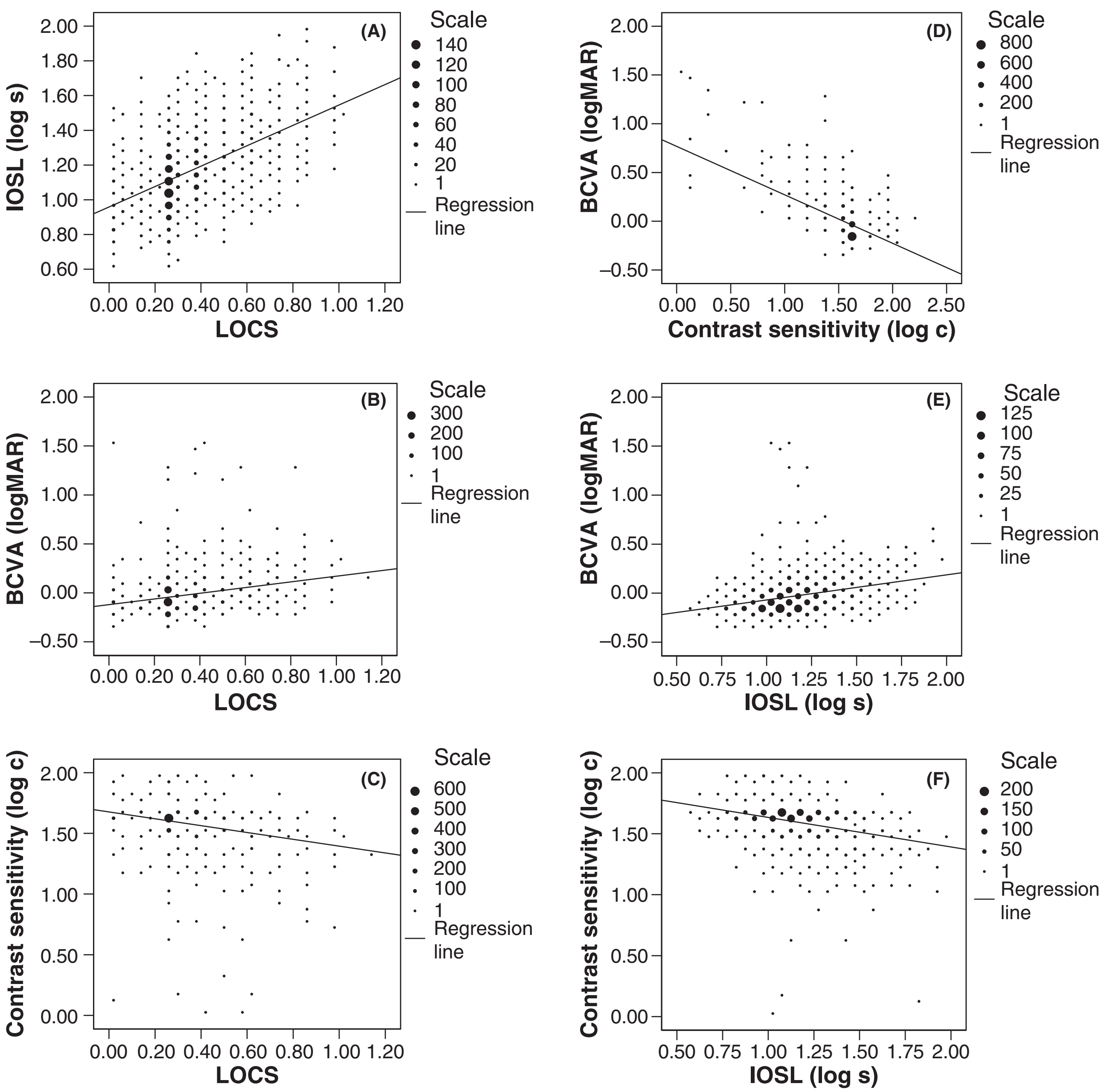

Fig. 1. Intraocular straylight (IOSL), best-corrected visual acuity (BCVA) and contrast sensitivity as a function of subjective lens opacity grading [Lens Opacities Classification System III (LOCS)]. Individual data points are grouped into bins of different dot size that indicate the number of points in the bin (scale). Linear regression equations are: IOSL (log[s]) = 0.5861 × mean LOCS + 0.959; BCVA (logMAR) = 0.2916 × mean LOCS − 0.1217; contrast sensitivity (log[c]) = −0.2812 × mean LOCS + 1.6764.

independently related to the LOCS score (all p-values < 0.05) (Table 1, LOCS). IOSL was related most strongly, as is reflected by the highest absolute value of the standardized partial regression coefficient beta: 0.44. The values for BCVA and contrast sensitivity were 0.13 and −0.07, respectively (Table 1, LOCS). Single linear regression of IOSL as a function of LOCS score also gave the best coefficient of determination: R^2 = 0.27. The coefficient of determination for BCVA and contrast sensitivity as a function of LOCS score was R^2 = 0.10 in both cases (Fig. 1C, E). All three single linear regressions were significant (p < 0.001).

We found that BCVA and contrast sensitivity worsened slightly with increasing IOSL, whereas high contrast sensitivity was related to good BCVA (Fig. 1B, D, F). Correlation analysis between BCVA, contrast sensitivity and IOSL showed that all three possible pairs were correlated to each other (all p-values < 0.05) (Table 2). Best coefficient of determination had the linear regression of BCVA as function of contrast sensitivity (R^2 = 0.27). The coefficient of determination for BCVA and contrast sensitivity as function of IOSL was R^2 = 0.12 in both cases (Fig. 1D, F). All three single linear regressions were significant (p < 0.001).

To investigate which visual function was best related to the NEI-VFQ-25 score, we performed another multiple regression analysis. Because these difficulties were obviously experienced during habitual spectacle correction, we included driving visual acuity rather than BCVA in this analysis (notably, the results involving BCVA were similar). The overall NEI-VFQ-25 scores (Table 1, VFQ mean), as well as the NEI-VFQ-25 night driving question (Table 1, VFQ night driving), were independently related to all three visual functions (all p-values < 0.05). The overall score was best related to contrast sensitivity and the night driving score to driving visual acuity (highest absolute standardized coefficient beta).

Figure 2 shows graphically the relation between self-reported night driving difficulty and measured IOSL values. The highest two categories have large uncertainty because of low numbers of cases (37 and 12, respectively) compared to the lower three categories (1002, 979 and 319 cases, respectively). Corresponding to the significant correlation value, mean IOSL values increased with increased reported difficulty; 'no' difficulty corresponded to a mean IOSL value of 1.14 log[s] and 'extreme' difficulty to 1.20 log[s]. One-way-analysis of variance (anova) demonstrated that IOSL was significantly different across the groups with different night driving difficulties (F = 6.080 and p < 0.001). Post-hoc orthogonal comparison showed a significant difference between 'no' difficulty and 'little' difficulty (p = 0.002), but no significant difference between 'little' and 'moderate' night driving difficulty (p = 0.182). We found a similar relationship for contrast sensitivity and BCVA with night driving difficulty.

Table 1. Results of multiple linear regression with independent variable: subjective lens opacity grading [Lens Opacities Classification System III (LOCS)] (upper part), overall National Eye Institute Visual Functioning Questionnaire – 25 (NEI-VFQ-25) scores (middle part) and night-driving-related questions of the NEI-VFQ-25 (lower part).

	Unstandardized coefficients (B)	Unstandardized coefficients (SE)	Standardized coefficients (Beta)	Test statistics (*t*)	Significance level (p)
LOCS					
Constant	0.0376	0.0526		0.7150	0.4747
BCVA (logMAR)	0.1640	0.0275	0.1345	5.9602	< 0.0001
Contrast sensitivity (log[c])	−0.0900	0.0270	−0.0746	−3.3336	0.0009
IOSL (log[s])	0.3903	0.0191	0.4426	20.4650	< 0.0001
VFQ mean					
Constant	71.3198	2.9054		24.5474	< 0.0001
Driving VA (logMAR)	−2.9611	1.1606	−0.0597	−2.5514	0.0108
Contrast sensitivity (log[c])	9.3130	1.5166	0.1434	6.1408	< 0.0001
IOSL (log[s])	−2.9463	0.9260	−0.0760	−3.1817	0.0015
VFQ night driving					
Constant	71.4307	6.8104		10.4884	< 0.0001
Driving VA (logMAR)	−13.4406	3.5200	−0.0958	−3.8184	0.0001
Contrast sensitivity (log[c])	9.4674	3.4998	0.0675	2.7051	0.0069
IOSL (log[s])	−5.2331	2.4052	−0.0531	−2.1757	0.0297

SE, standard error; BCVA, best-corrected visual acuity; IOSL, intraocular straylight.

Table 2. Results of correlation analysis between best-corrected visual acuity (BCVA), contrast sensitivity and intraocular straylight (IOSL).

		IOSL (log[s])	BCVA (logMAR)	Contrast sensitivity (log[c])
Pearson correlation	IOSL (log[s])	1.000	0.356	−0.339
	BCVA (logMAR)	0.356	1.000	−0.443
	Contrast sensitivity (log[c])	−0.339	−0.443	1.000
Significance (one-tailed)	IOSL (log[s])	–	< 0.001	< 0.001
	BCVA (logMAR)	< 0.001	–	< 0.001
	Contrast sensitivity (log[c])	< 0.001	< 0.001	–

Discussion

We have found a mean of 0.9 log[s] IOSL in the youngest age group (20–30 years), which can be considered baseline. IOSL for the lowest LOCS score (0.1) was about 1.0 log[s] and with a LOCS score for mild cataract (> 0.75), IOSL was about 1.4 log[s] (Fig. 1A). This corresponds to a more than threefold increase of IOSL. Earlier studies (de Waard et al. 1992) with a predecessor of the computerized straylight meter used in the present study showed similar results comparing forward scattered light (straylight meter) with backward scattered light evaluation (LOCS or Lens Opacity Meter of Interzeag, Switzerland). However, most other previous studies estimate the effect of cataract on glare sensitivity by comparing visual acuity, contrast sensitivity or

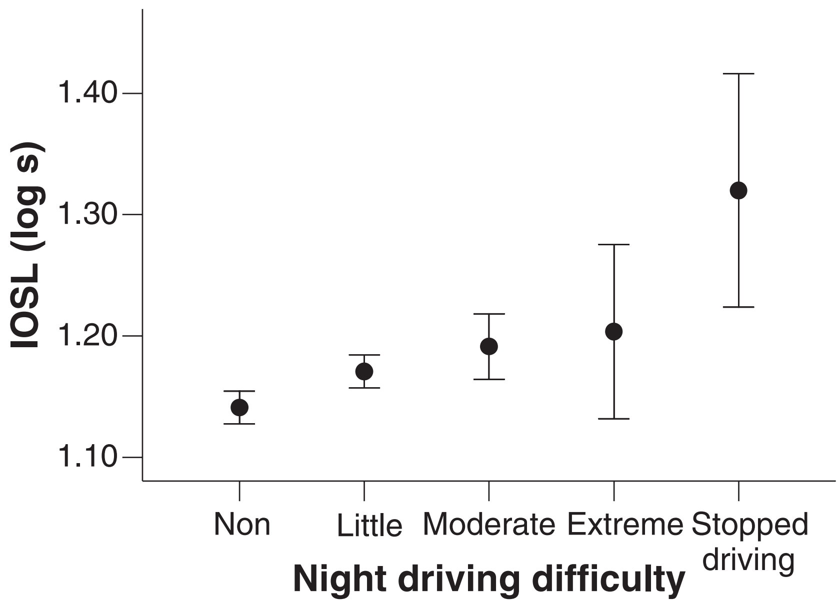

Fig. 2. Mean of intraocular straylight with 95% confidence interval grouped for the different answers to the National Eye Institute Visual Functioning Questionnaire – 25 (NEI-VFQ-25) night driving question.

contrast acuity with and without a glare source (Elliott et al. 1989, 1990a; Adamsons et al. 1992; Whitaker et al. 1993; Stifter et al. 2006). We have measured IOSL that causes disability glare and compared it to visual acuity and contrast sensitivity.

Our results demonstrate that IOSL was much better related to LOCS than both visual acuity and contrast sensitivity (Table 1, LOCS and Fig. 1A, C, E). Stifter et al. (2006) found a low correlation between individual LOCS scores and the Visual Functioning Questionnaire VF-14. Only the LOCS score on posterior subcapsular opacity gave a high correlation. This finding is consistent with the results by de Waard et al. (1992) and may suggest that our conclusion that LOCS scores compare best with IOSL may also depend on the type of cataract involved. An article addressing this question is currently under preparation.

Because of the scale of the study, it was impossible to dilate the pupil during the examinations. Therefore, we may have underestimated cortical and posterior subcapsular opacities, because these are fairly difficult to judge without pupillary dilation. In contrast, nuclear opacities can be judged easily, even with narrow pupils. We think that this does not affect the validity of our conclusions, because cortical and subcapsular opacities are known to cause light scatter and glare sensitivity, more so than nuclear opacities. If we had underestimated cortical and subcapsular contributions, our conclusion that straylight measurements are best related to early cataracts would have been even stronger.

From correlation analysis, we found that IOSL is a vision impairment not directly related to visual acuity and contrast sensitivity (Table 2 and Fig. 2). This study includes more than 2000 participants, strengthening and generalizing the earlier finding mentioned in the Introduction that straylight measurement has 'added value' (van Rijn et al. 2002). This earlier study was based on 93 participants and glare sensitivity was assessed with the Mesotest II (Oculus GmbH, Wetzlar, Germany) and the Nyktotest 300 (with 502 test disc; Rodenstock GmbH, Ottobrun, Germany). The case for contrast sensitivity is different to that for straylight data. If visual acuity is known, contrast sensitivity has limited added value. This independence of straylight and visual acuity may be understood from the underlying processes that govern both aspects of visual function. For a discussion of this notion, see van den Berg et al. (2007).

Rubin et al. (2001) found that visual acuity alone is not sufficient to assess the visual disability of a person and concluded that additional vision measures are required to understand the impact of vision loss on everyday life. Our results support this assertion; we found such important increases in straylight in a relatively healthy population of active automobile drivers.

Although IOSL is very well related to LOCS, this does not translate as strongly into self-reported difficulties during general activities and during night driving. There was a significant difference between 'no' difficulty and 'little' difficulty, but not between 'little' and 'moderate' night driving difficulty. For self-reported difficulties, the role of visual acuity and contrast sensitivity are more important than IOSL (Table 1, VFQ mean and VFQ night driving). However, the absolute values of the standardized partial regression coefficient beta are relatively low for all three vision parameters, ranging from 0.05 to 0.14 compared to a maximum value of one. This finding confirms an earlier report regarding the overstated role of visual acuity in the subjective feeling about visual capacity (van Rijn et al. 2002). In general, questionnaires are hampered with the noise of subjective interpretations. A gold standard for actual visual capacity in relation to driving would be needed.

In other studies, the discrepancy between objective impairment and subjective disability is remarkable. For visual acuity, the relation between impairments and unsafe driving behaviour (accidents, traffic violations) is rather weak (Hills & Burg 1977; Keeffe et al. 2002). A recent study on the role of visual impairments in traffic accidents in elderly drivers (Rubin et al. 2007) showed that glare sensitivity and visual field loss were significant predictors of crash involvement. Acuity, contrast sensitivity and stereo acuity were not associated with crashes.

Another reason for the relatively weak relationship between IOSL (glare sensitivity) and self-reported driving difficulties may be the following. We speculate that difficulties caused by impairments of contrast sensitivity and glare sensitivity are condition-dependent. This may affect the important issue of compensatory driving behaviour. It has been speculated that people realize that they have an impairment and adjust their driving accordingly (avoid driving at night, speed adjustment, etc). A recent study on night driving self-restriction showed an important gender difference: men's night-driving cessation was associated with contrast sensitivity and depression, whereas women's night-driving cessation was associated with low-contrast acuity in glare as well as age (Brabyn et al. 2005).

If drivers do not experience difficulties regarding glare, they may not adjust their driving strategy. This may translate into a stronger relation with traffic accidents (Rubin et al. 2007). However, data on the relation of elevated IOSL values and traffic accidents are still scarce, presumably because of the absence of an adequate measurement technique. Because an objective technique for IOSL measurement (C-Quant) is now available commercially, the role of glare sensitivity in traffic safety may gain importance in the future.

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