Ophthal. Physiol. Opt. 2002 **22** 1–9

The influence of high contrast acuity and normalised low contrast acuity upon self-reported situation avoidance and driving crashes

S. V. Slade[1], M. C. M. Dunne[1] and J. N. V. Miles[2]

[1]Neurosciences Research Institute, School of Life and Health Sciences, Aston University, Birmingham, UK, [2]Applied Vision Research Unit, Derby University, Derby, UK

Abstract

The aim of this study was to determine the cues used to signal avoidance of difficult driving situations and to test the hypothesis that drivers with relatively poor high contrast visual acuity (HCVA) have fewer crashes than drivers with relatively poor normalised low contrast visual acuity (NLCVA). This is because those with poorer HCVA are well aware of their difficulties and avoid dangerous driving situations while those poorer NLCVA are often unaware of the extent of their problem. Age, self-reported situation avoidance and HCVA were collected during a practice based study of 690 drivers. Screening was also carried out on 7254 drivers at various venues, mainly motorway sites, throughout the UK. Age, self-reported situation avoidance and prior crash involvement were recorded and Titmus vision screeners were used to measure HCVA and NLCVA. Situation avoidance increased in reduced visibility conditions and was influenced by age and HCVA. Only half of the drivers used visual cues to signal situation avoidance and most of these drivers used high rather than low contrast cues. A statistical model designed to remove confounding interrelationships between variables showed, for drivers that did not report situation avoidance, that crash involvement decreased for drivers with below average HCVA and increased for those with below average NLCVA. These relationships accounted for less than 1% of the crash variance, so the hypothesis was not strongly supported.

Keywords: contrast sensitivity, crashes, driving, situation avoidance

Introduction

Contrast sensitivity tests vary enormously in complexity (Woods and Wood, 1996). It has been suggested that simple clinical tests may be as useful as complex computerised tests as a means of identifying drivers at risk of having crashes (Shinar and Schieber, 1991). The Pelli–Robson contrast sensitivity test (Pelli *et al*., 1988) is one example (Ball *et al*., 1993; Wood and Troutbeck, 1995). Unfortunately, this chart does not allow the examiner to assess a driver's high contrast visual acuity (HCVA) – a legal requirement for assessing fitness to drive in the UK. Bailey–Lovie charts (Bailey and Lovie, 1976) do, however, assess HCVA at the same time as providing a means of determining normalised low contrast visual acuity (NLCVA).

The NLCVA is the difference in visual acuity recorded for high and low contrast letters (Regan, 1990). It provides an estimate of the descending limb of the contrast sensitivity function (Regan, 1988). It is also sensitive to visual deterioration accompanying eye disease (Regan, 1990). Therefore, its potential use as a clinical test for assessing drivers' vision is further indicated.

An association between relatively poor NLCVA and self-reported driving crashes was demonstrated in an earlier pilot study (Dunne *et al*., 1998). In that study, data was collected on 284 drivers at 29 different locations comprising festivals and shopping centres.

Received: 13 September 2000
Revised form: 16 September 2001
Accepted: 17 September 2001

Correspondence and reprint request to: M. C. M. Dunne.
Tel.: +44 0121 359 3611; fax: +44 0121 333 4220
E-mail address: m.c.m.dunne@aston.ac.uk

A variety of tests were administered using the Ergovision screener (Essilor, France). Two trained teams collected the data. These tests included assessments of visual acuity (static, dynamic, photopic and mesopic), visual fields, glare recovery and oculomotor balance. A NLCVA score was approximated from the Ergovision test results, although this was originally referred to as contrast susceptibility. The NLCVA score was found to be the best predictor of prior crash involvement in drivers under and over 40 years of age. Typically, NLCVA amounted to a reduction of three lines of letters, a little higher than values found by other researchers (Brown and Lovie-Kitchin, 1989; Bailey, 1993; Elliot and Bullimore, 1993). Treating a reduction of four or more lines of letters as test failure, prior crash involvement could be identified with 7.7% sensitivity and 100% specificity for drivers under 40 years of age and with 21.4% sensitivity and 95.7% specificity for those aged 40 years or more. The association between crashes and NLCVA was statistically significant to at least the 95% level for both age groups. No such relationship emerged for HCVA so the following hypothesis was proposed for these findings (Dunne *et al.*, 1998).

Drivers with relatively poor vision may reduce crash risk by avoiding certain driving situations. A driver's awareness of visual deficits may be based on difficulties experienced when observing high contrast objects (e.g. high contrast letters on traffic signs) rather than low contrast objects (e.g. the relatively low contrast features of other road users). The hypothesised dependence of situation avoidance on features akin to the letters of a HCVA chart might then mask any relationship between HCVA and road crashes. This would explain why driving crash rates did not increase with relatively poor HCVA.

Drivers experiencing little additional difficulty seeing low contrast objects (i.e. those with relatively good NLCVA) would be able to apply appropriate amounts of situation avoidance in poor visibility conditions, albeit that situation avoidance will have been based on high contrast vision. On the other hand, drivers experiencing substantial additional difficulty seeing low contrast objects (i.e. those with relatively poor NLCVA) might overestimate their ability to see low contrast hazards. They might then fail to apply appropriate amounts of situation avoidance and thus become more prone to crashes in poor visibility conditions. This would explain the observed relationship between crash rates and NLCVA deficits (Dunne *et al.*, 1998).

This article reports on two studies conducted to test the hypothesis described above. The first study was designed to determine how often situation avoidance was reported under different visibility conditions and whether self-reported situation avoidance was prompted by difficulties experienced seeing high contrast objects, low contrast objects or by non-visual factors. The second study was carried out to determine how self-reported situation avoidance affects relationships between HCVA, NLCVA and self-reported road crash involvement.

Methods

Subjects

The first study was carried out on 690 British drivers (338 males, 352 females) aged 45 ± 15 years (mean ± SD) attending routine eye examinations at one of 56 optometry practices in the West Midlands area. Drivers were offered a reduced eye examination fee as an incentive to take part in the survey.

The second study was carried out on 7254 British drivers (5480 males 1774 females), aged 42 ± 14 years (mean ± S.D.). Five trained teams collected data at 44 sites throughout Britain. These included 32 motorway sites (service stations) and 12 non-motorway sites (festivals and supermarkets).

Questionnaires

Each driver completed a questionnaire designed to gather information about age, gender, situation avoidance and (in the second study) prior crash involvement.

Drivers participating in both studies were asked whether they slowed down or avoided driving if they felt uneasy about their vision in four defined visibility conditions. Visibility conditions included (1) good visibility during daylight hours, (2) poor visibility during daylight hours (i.e. dull or foggy), (3) good visibility during hours of darkness (i.e. good road lighting) and (4) poor visibility during hours of darkness (i.e. poor road lighting, dull or foggy). The responses requested were 'never', 'rarely', 'occasionally' or 'often'. This question was designed to determine how visibility influenced self-reported situation avoidance.

Drivers participating in study 1 were also asked what had prompted concern about their vision. The driver could tick a number of responses including (1) difficulty reading road signs, (2) awareness that passengers have been able to read road signs before the driver, (3) difficulty reading a number plate, (4) difficulty seeing pedestrians, cyclists and other vehicles, (5) professional advice (i.e. optometrist or general practitioner) or (6) other reason. These responses were designed to determine whether self-reported situation avoidance was prompted by difficulty seeing high contrast objects (responses 1–3), low contrast objects (response 4) or by some other factor (responses 5 and 6).

Drivers participating in study 2 were asked whether they had been involved in a crash within the last 5 years, for which they were deemed to be at least partly at fault, and had failed to see a hazard in time under the four visibility conditions described above.

Measurement of HCVA and NLCVA

In study 1, each driver's optometrist recorded the best-corrected binocular distance visual acuity.

In study 2, binocular HCVA and low contrast visual acuity were measured using 11 Titmus vision screeners [supplied by Bollé (UK) Ltd]. Two new test slides were designed for these machines, based upon the well-known high and low contrast LogMAR charts developed by Bailey and Lovie (1976). Both test slides presented Landolt 'C' symbols for which the gap appeared in any one of eight orthogonal or oblique orientations, making this an eight alternative forced choice test. Symbols represented +0.8 to –0.3 LogMAR acuity in 0.1 log unit steps. Pilot studies had indicated that this range was necessary to avoid truncation. The average background luminance was 14 ± 6 cdm^{-2} (mean ± S.D.). The average (mean ± S.D.) percentage contrast (Weber) of the high and low contrast symbols was 99 ± 1% and 9 ± 3%, respectively. Test slides were presented at optical infinity and the test was carried out with spectacles customarily worn for driving, if needed. Measurements were made to threshold by encouraging drivers to guess if they were not certain of the orientation of the smallest symbols on both test slides. High and low contrast LogMAR visual acuities were measured by-letter (Bailey *et al.*, 1991) and NLCVA was calculated by subtracting the high contrast score from the low contrast score.

Statistical analysis

Relationships between variables were tested to the 95% level using non-parametric statistical tests (Kendall's rank correlation and χ^2; Bailey, 1983). Correction for multiple comparisons (Katz, 1997, p. 222) was carried out where appropriate. The percentage of the variance accounted for in each association was also determined where appropriate. Here, coefficients ϕ (for χ^2 tests) or τ (for Kendall's rank correlations) were squared and multiplied by 100 (Katz, 1997, pp. 81–96). A multiple group structural equation model was also constructed using LISREL 8.12a (Scientific Software Inc., Chicago, IL, USA). This statistical model was designed to remove the confounding effects of interrelationships between all of the variables measured in this study. This type of analysis is appropriate for large sample ordinal data (Kaplan, 1991).

Declaration

All methods followed the tenets of the Declaration of Helsinki.

Results

Measure of self-reported situation avoidance

Table 1 shows the frequency with which drivers reported situation avoidance under the four visibility conditions. The analyses presented in this article were initially carried out separately for each visibility condition and for each level of situation avoidance frequency (i.e. never, rarely, occasionally or often). However, the results of these separate analyses lead to the same conclusions as repeated analyses carried out on pooled data. Therefore, for the sake of brevity, results of only the pooled analyses are presented in this article. Here, self-reported situation avoidance was dichotomised. For analyses depicted in *Tables 2–4*, under each visibility condition, drivers who responded with 'never' were treated as those that did not practise situation avoidance while the remainder (whose responses were 'rarely', 'occasionally' or 'often') were treated as drivers that did practise situation avoidance. For analyses depicted in *Table 5* and *Figure 1*, responses relating to all four visibility conditions were also pooled. In this case, an avoidance score was assigned to responses relating to each visibility condition; 0 points for 'never', 1 point for 'rarely', 2 points for 'occasionally' and 3 points for

Table 1. Frequency (%) of self-reported situation avoidance under different visibility conditions

		Frequency (%)			
Visibility conditions	**Study**	**Never**	**Rarely**	**Occassionally**	**Often**
Daytime/good visibility	1	71	5	16	8
	2	90	7	2	1
Daytime/poor visibility	1	40	25	29	7
	2	49	27	17	7
Darkness/good visibility	1	43	28	21	8
	2	74	17	7	2
Darkness/poor visibility	1	23	20	40	16
	2	41	19	22	18

Table 2. Percentage of drivers reporting situation avoidance under varying visibility conditions. The degrees of freedom (d.f.), Chi-square (χ^2) probability (*p*) and the percentage of variance (POV = $\phi^2 \times 100$) accounted for in each association are also shown. Statistical significance was achieved at the 95% level if the probability, corrected for multiple comparisons, was less than 0.0083

	Percentage of drivers		Study 1 vs. study 2		
Visibility conditions	**Study 1**	**Study 2**	**d.f.**	χ^2	*p*
Daytime/good visibility	29	10	1	235	<0.0001
Darkness/good visibility	57	29	1	234	<0.0001
Daytime/poor visibility	60	54	1	9	0.0027
Darkness/poor visibility	79	62	1	79	<0.0001
d.f.	3	3			
χ^2	369	5327			
p	<0.0001	<0.0001			
POV	13	18			

Table 3. The influence of age and HCVA on the percentage of drivers, from study 2, reporting self-reported situation avoidance under varying visibility conditions. The degrees of freedom (d.f), Chi-square (χ^2), probability (*p*) and the percentage of variance (POV = $\phi^2 \times 100$) accounted for in each association are also shown. Statistical significance was achieved at the 95% level if the probability, corrected for multiple comparisons, was less than 0.0063

	Daytime		Darkness	
	Good visibility	**Poor visibility**	**Good visibility**	**Poor visibility**
Age (years)				
17–29	9	54	27	62
30–39	11	52	27	59
40–49	9	53	28	62
50–59	9	56	32	64
60–69	9	56	32	64
70+	8	59	34	67
d.f.	5	5	5	5
χ^2	8	22	28	29
p	0.1690	0.0006	<0.0001	<0.0001
POV	0.1	0.3	0.4	0.4
HCVA (Snellen)				
6/5+	9	56	28	62
6/5	10	51	22	56
6/5– to 6/6+	9	49	24	58
6/6	9	56	30	62
6/6– to 9/9+	9	53	29	63
6/9 or worse	12	62	37	70
d.f.	5	5	5	5
χ^2	13	47	69	43
p	0.0266	<0.0001	<0.0001	<0.0001
POV	0.2	0.7	1	0.6

Table 4. Percentage of drivers using various cues to signal self-reported situation avoidance (study 1). Figures do not add up to 100% as drivers often used multiple cues

Cue	**Drivers (%)**
Difficulty seeing high contrast objects	32
(a) Number plate	16
(b) Road signs	14
(c) Passenger able to read road signs before driver	14
Difficulty seeing low contrast objects	8
(d) Pedestrians, cyclists and other vehicles	8
Other factors	55
(e) Professional advice	9
(f) Other reasons	8
Cue not known or does not practice situation avoidance	38

'often'. Pooling the avoidance scores for each visibility condition yielded a summated avoidance score of between 0 and 12 for each driver. Drivers with a summated avoidance score of 0 were treated as those that did not practise situation avoidance while the remainder were treated as drivers that did.

The relationship between visibility and self-reported situation avoidance

Table 2 compares the percentage of drivers practising situation avoidance under various visibility conditions in both studies. Chi-square tests carried out on these results revealed, for both studies, that visibility had a statistically significant influence upon situation avoidance; more drivers reported practising situation avoidance in darkness compared with daytime and in poor visibility compared with good visibility. However, the

Table 5. Correlations (Kendall's) between variables measured in study 2. The percentage of variance (POV $= \tau^2 \times 100$) accounted for by each relationship examined is shown along with the associated probability (p). Negative POV values represent inverse relationships. Statistical significance was achieved at the 95% level if the probability, corrected for multiple comparisons, was less than 0.005

	HCVA	NLCVA	Self-reported situation avoidance	Self-reported crash involvement
Age	5.9%	0.02%	0.2%	−1.1%
	$p < 0.0001$	$p = 0.0556$	$p < 0.0001$	$p < 0.0001$
HCVA		−2.5%	0.4%	−0.4%
		$p < 0.0001$	$p < 0.0001$	$p < 0.0001$
NLCVA			−0.01%	−0.01%
			$p = 0.1615$	$p = 0.2659$
Self-reported situation avoidance				0.001%
				$p = 0.6659$

relationship between visibility and self-reported situation avoidance was not strong as the percentage of variance accounted for in both studies only fell between 13% (study 1) and 18% (study 2). *Table 2* shows visibility conditions ranked in order of increasing impact on situation avoidance and further illustrates that both studies yielded the same rank order. Nevertheless, when χ^2 tests were used to compare the proportion of drivers that practised situation avoidance in each visibility category across both studies, statistically significant differences emerged for all visibility conditions. This is likely to have arisen because of sampling differences arising from both studies. For instance, consistently more drivers reported practising situation avoidance in study 1, where drivers were recruited from optometric practice, compared with study 2, where a more general sample of drivers was examined.

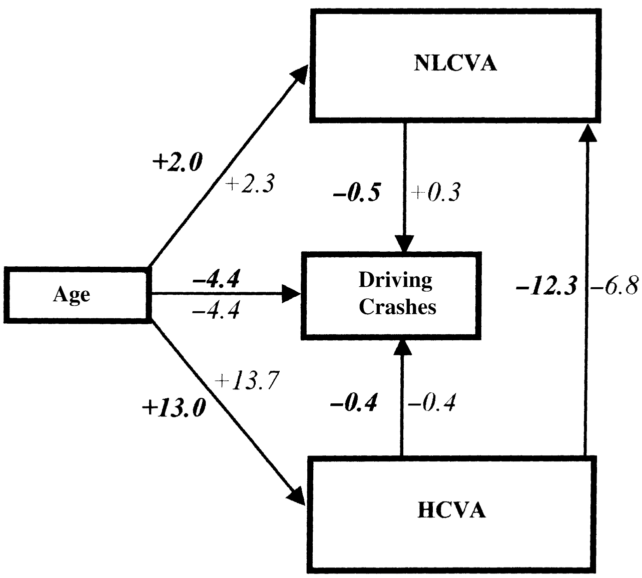

Figure 1. Path diagram arising from a two-group structural equation model applied to the variables measured in study 2. Measured variables are shown in rectangular boxes. Arrows connect variables that exhibit a statistically significant correlation at the 95% level. The direction of the arrow indicates which of the two variables is dependent upon the other. The two numbers that appear on either side of each arrow indicate the percentage of the variance of the dependent variable that is accounted for by the other variable. The sign of the number indicates whether the correlation was direct (+) or inverse (–). Numbers shown in bold relate to drivers that report situation avoidance while those shown in plain text relate to drivers that did not.

The influence of age and HCVA upon the relationship between visibility and self-reported situation avoidance

Table 3 shows the influence of age and HCVA on the percentage of drivers reporting situation avoidance under four visibility conditions. Although this analysis was carried out on the data of both studies, statistically significant effects were only found for the much larger sample of drivers examined in study 2. For this reason, *Table 3* only includes data relating to study 2. To enhance comparison of both studies, drivers were split into five categories of age and HCVA (Snellen); study 2 data, originally expressed in the form of LogMAR scores, were converted to equivalent Snellen fractions (Snellen denominator $= 6 \times$ antilog LogMAR score) for this analysis. *Table 3* shows that self-reported situation avoidance tended to increase with advancing age and declining HCVA. This effect was statistically significant for all but the daylight/good visibility condition. Nevertheless, age and HCVA only accounted for up to 1% of the variance in self-reported situation avoidance, meaning that their influence upon this parameter was only very weak. Further, age and HCVA were interrelated (see *Table 5*). This meant that separation of their individual effects was very difficult using this simple form of analysis. The only clue as to which exerted the stronger influence upon self-reported situation avoidance came from the observation that HCVA accounted for marginally more variance (0.2–1%) than age (0.1–0.4%).

Cues used to signal self-reported situation avoidance

Table 4 shows the percentage of drivers from study 1 that reported using various cues to signal self-reported situation avoidance. Shown in bold is the percentage of drivers that based self-reported situation avoidance on difficulty seeing high contrast objects, difficulty seeing low contrast objects or some other factor. Shown in italics is the percentage of drivers using the cues that fall within each of the above categories. Responses do not add up to 100% as drivers were allowed to check more than one cue. Less than half of the drivers used visual cues to signal self-reported situation avoidance. Of these, more drivers used high contrast cues (32%) than low contrast cues (8%) and this difference was statistically significant ($\chi^2 = 126$, d.f. = 1, $p < 0.0001$). Neither age nor HCVA, split into the categories shown in *Table 3*, exhibited a statistically significant influence upon the cues used to signal situation avoidance.

Measure of self-reported crash involvement

Self reported crash histories were only examined in study 2. Only 8.5% of drivers reported having had a crash in the previous 5 years. Of these, the vast majority (67%) had crashes in good daylight visibility conditions. Relatively few drivers had crashes in poor daylight (15%), good darkness (7%) and poor darkness (9%) visibility conditions. The crash analyses presented in this article were initially carried out separately for each visibility condition and for each level of situation avoidance frequency. However, the results of these separate analyses lead to the same conclusions as repeated analyses carried out on pooled data. Therefore, as for self-reported situation avoidance, results of only the pooled analyses are presented in this article. Here, self-reported crashes taking place in all four visibility conditions were pooled giving a score of 0 (no crashes in any visibility condition) to 4 (at least one crash in each visibility condition). This score was used in the analyses depicted in *Table 5*. The crash data was then dichotomised for the analysis depicted in *Figure 1*. Here, drivers with a crash score of 0 were treated as those that were not crash involved while the remainder were treated as being crash involved.

Relationships between age, HCVA, NLCVA, self-reported situation avoidance and self-reported crash involvement

Table 5 summarises correlations between the variables measured in study 2. Although many of the correlations were statistically significant, each relationship accounted for very little (<6%) of the variance. Table 5 shows that many of the variables were correlated with each other. This made isolation of their individual effects difficult. For example, HCVA and self-reported crash involvement both reduced with age. Therefore, any attempt to examine the correlation between HCVA and self-reported crash involvement, without controlling for the confounding effects of age, would inevitably yield a relationship in which crash involvement falls as HCVA declines – as was actually observed (*Table 5*). There was need for a statistical test that could carry out correlations between any two variables after having controlled for the confounding interrelationships between those two variables and all of the other variables measured. This was achieved using a structural equation model (*Figure 1*).

Figure 1 summarises the path diagram arising from a two-group structural equation model applied to the variables measured in study 2. The two groups comprised of drivers that did or did not report situation avoidance; making use of the dichotomised pooled self-reported situation avoidance data described earlier. In the diagram, each of the measured variables is shown in rectangular boxes. Arrows connect any two variables that exhibit a statistically significant correlation at the 95% level. The direction of the arrow indicates which of the two variables is dependent upon the other. For example, the arrow pointing from Age to HCVA indicates that both variables are correlated and that HCVA is influenced by age but not vice versa. The two numbers that appear on either side of each arrow indicate the percentage of the variance of the dependent variable that is accounted for by the other variable. The sign of the number indicates whether the correlation was direct (+) or inverse (–). Numbers shown in bold relate to drivers that report situation avoidance while those shown in plain text relate to drivers that did not. Preliminary work on this model involved systematic alteration of the connections between each variable in the path diagram. Each variant of the path diagram was then assessed using a χ^2 goodness of fit test. A high, statistically significant, χ^2 value would arise if the model poorly fitted the measured data. Therefore, the desired end point was a model that yielded the smallest and least significant χ^2 value. In the case of the model shown in *Figure 1* ($\chi^2 = 0$, d.f. = 2, $p = 1$) the zero χ^2 value indicated that the model could not be improved upon.

For comparison with the earlier pilot study (Dunne *et al.*, 1998), the NLCVA data measured in the present study were converted to an equivalent by-line (Bailey *et al.*, 1991) score. In agreement with previous results, typical scores amounted to a reduction of three lines of letters. Applying the same test failure cut-off point, prior crash involvement could be identified with 19.9% sensitivity and 80.1% specificity for drivers under 40 years of age and with 14.7% sensitivity and 76.6% specificity for those aged 40 years or more. A statistically significant association between relatively poor NLCVA and increased self-reported crash involvement was only found for drivers of 40 or more years of age ($\chi^2 = 8.34$, d.f. = 1, $p = 0.0039$).

Discussion

The promising results of the earlier pilot study (Dunne *et al.*, 1998) were not replicated in the results of the larger study presented in this article. While NLCVA identified crash involved drivers with about the same sensitivity (14–20%) as the earlier study (8–21%), the specificity of this test (77–80%) was much lower than previously found (96–100%). Further, a statistically significant association between NLCVA and crash involvement was only found for older drivers in the present study while statistically significant associations emerged for older and younger drivers in the earlier study. A number of factors may have contributed to these discrepancies. The pilot study included a higher proportion of crash involved drivers (24%) than the present study (8%). It has been suggested that increasing the proportion of crash involved drivers increases the chance of finding statistically significant associations (Ball *et al*., 1993). The pilot study also included a smaller proportion of males (57%) than the present study (76%). Males tend to under report crash involvement (Ball and Owsley, 1991; Owsley *et al*., 1991). Both factors might, therefore, explain why an association between crashes and NLCVA was found for younger drivers in the pilot study but not the larger study reported in this article. Further support for this notion was provided by separately analysing data collected by the two teams that contributed to the earlier pilot study (Dunne *et al*., 1998). Only one of these teams yielded results that were statistically significant and that team's sample contained twice as many crash involved drivers (34% compared with 17%) and only three-quarters of the proportion of males (47% compared with 64%) included in the other sample.

Despite the lack of strong support for the findings of the pilot study, evidence was sought for individual elements of the hypothesis described in the introduction.

The hypothesis stated that difficulty seeing high contrast objects would signal situation avoidance. Thirty-two percent of drivers reported that situation avoidance was based upon difficulty seeing high contrast objects (*Table 4*). A statistically significant increase in self-reported situation avoidance also occurred as HCVA declined (*Tables 3* and *5*), although HCVA accounted for only 0.1–1% of the variance in situation avoidance. Other researchers have reported that central vision health ratings are associated with avoidance of challenging driving situations (Ball *et al*., 1993).

It was also hypothesised that situation avoidance, driven by difficulties seeing high contrast objects, would mask the intuitive increase of crash involvement in drivers with relatively poor HCVA. Therefore, an increase in crash involvement in drivers with poorer HCVA should have been masked in drivers that practised situation avoidance but evident in those that did not. In actual fact, crash involvement declined in drivers with poorer HCVA regardless of whether situation avoidance was practised or not (*Figure 1*) and HCVA accounted for only 0.4% of crash variance. Other researchers have demonstrated a small increase in state recorded crash involvement with HCVA deficits (Ball and Owsley, 1991; Owsley *et al*., 1991; Ball *et al*., 1993). The findings presented in this paper may have arisen from our dependence on less reliable self-reported crash histories in addition to sampling differences described earlier.

According to the hypothesis, drivers should also be unaware of difficulties seeing low contrast objects. Support for this emerged as only 8% of drivers reported that situation avoidance was based upon on difficulty seeing low contrast objects (*Table 4*). Further, no statistically significant relationship was observed between self-reported situation avoidance and relatively poor NLCVA (Table 5).

The hypothesis added that lack of awareness of low contrast deficits would prevent the practise of appropriate levels of situation avoidance leaving drivers with relatively poor NLCVA prone to crash involvement. This relationship would, of course, be masked for drivers that practised situation avoidance as any level of situation avoidance would inevitably reduce crash risk. The results depicted in *Figure 1* show that the hypothesised increase in crash involvement emerged for drivers that did not practise situation avoidance but that a decrease in crash involvement emerged for drivers that did. In this respect, the hypothesis was supported. It must be pointed out, however, that NLCVA accounted for less that 1% of the variance in crash involvement (*Figure 1*). Therefore, this support was, at best, only very weak.

Several other points of interest that emerged from this study are considered below.

Firstly, NLCVA was inversely related to HCVA (*Table 5* and *Figure 1*). In other words, if HCVA worsens then low contrast visual acuity (LCVA) worsens to a lesser extent. *Table 6* illustrates this effect by showing the relationship between HCVA, LCVA and NLCVA for drivers of 20, 45 and 70 years of age. The intercept and gradient, determined from regressions describing the dependency of LCVA upon HCVA (expressed in LogMAR units), were used to calculate the LCVA (Snellen fractions) for HCVAs of 6/6 and 6/12. The resulting NLCVAs (LogMAR) are also shown. Figures shown in brackets represent LCVAs corresponding to a HCVA of 6/12 that would have arisen for a gradient of 1. All regressions were statistically significant at the 99.99% level and variations in HCVA accounted for between 40 and 62% of the variance of LCVA. Intercepts are equal to the mean NLCVA for each age group. It can thus be seen that the mean NLCVA increases with age, as has already been shown in *Table 5* and *Figure 1*. The expectation was that within a single age group, the difference between HCVA

Table 6. The relationship between HCVA, LCVA and NLCVA in drivers of 20, 45 and 70 years of age. The intercept and gradient (±95% confidence interval), determined from regressions describing the dependency of LCVA upon HCVA (LogMAR), were used to calculate the LCVA (converted to Snellen fractions using: Snellen denominator = 6 × antilog LogMAR) for HCVAs of 6/6 and 6/12. The resulting NLCVAs (LogMAR) are also shown. Figures shown in brackets represent LCVAs corresponding to a HCVA of 6/12 that would have arisen for a gradient of 1

				LCVA		NLCVA	
Age	*n*	Intercept	Gradient	HCVA = 6/6	HCVA = 6/12	HCVA = 6/6	HCVA = 6/12
20	84	0.30 ± 0.02	0.6 ± 0.18	6/12	6/18 (6/24)	0.30	0.18
45	147	0.34 ± 0.02	0.9 ± 0.12	6/13	6/24 (6/26)	0.34	0.31
70	46	0.35 ± 0.04	0.9 ± 0.18	6/13	6/25 (6/27)	0.35	0.32

and LCVA would remain constant and would be equal to the intercepts shown in *Table 6*. In this case, a gradient of 1 would have arisen. However, gradients of less than 1 actually arose so that as HCVA worsens then LCVA worsens to a lesser extent. For drivers of 20 years of age, for example, an HCVA of 6/6 corresponded to a LCVA of 6/12. Note that a HCVA of 6/6 is equivalent to a LogMAR score of 0 meaning that the gradient has no influence upon the resulting LCVA. Had the gradient been 1, as expected, a reduction of HCVA to 6/12 should have give rise to an equal amount of reduction in LCVA to 6/24 (as shown in brackets in Table 6). In actual fact, the gradient was 0.6 so that the LCVA reduced by a lesser extent to 6/18. Consequently, the NLCVAs corresponding to HCVAs of 6/6 and 6/12 fell from 0.30 to 0.18 LogMAR units. Hence, the inverse relationship between HCVA and NLCVA. Interestingly, this effect was more pronounced in pre-presbyopic drivers (20 years of age) compared with those that were either approaching (45 years of age) or were already (70 years of age) presbyopic.

The above effect was not because of truncation, in which a driver's low contrast visual acuity falls below the chart's measurable range, as the charts were designed to avoid this. Drivers that failed to read any of the letters on the low contrast chart were also excluded from the analysis; this occurrence being very rare. Visual acuity was also measured to threshold thus reducing the criterion dependency of the test and the causative role that this may have had. One possibility that is currently being investigated is that the measurements of NLCVA described in this paper, being instrument based (i.e. modified Titmus vision screeners used), may vary from chart based measurements that have been reported by other researchers.

The second point of interest was that a statistically significant inverse correlation arose between age and crash frequency (*Table 5* and *Figure 1*), meaning that older drivers had fewer crashes than younger drivers. Here, age accounted for less than 5% of crash variance so that this relationship was weak. Classical research (Burg, 1971) has shown that older drivers only have poor driving records if crash rate, and not crash frequency, is considered. When crash rate is considered (i.e. crashes per 100 000 miles), crashes appear to occur more often in the youngest and oldest drivers (Burg, 1971). When crash frequency is not considered (i.e. mileage is not accounted for), as in the present study, older drivers appear to have least crashes (Burg, 1971).

In conclusion, the studies presented in this article do not support a strong association between NLCVA and driving crashes or the hypothesis proposed to explain the role situation avoidance might play in this association. Whether or not statistical significance was achieved, all correlations (*Table 5* and *Figure 1*) were too weak to be of practical use in terms of driver vision screening. Reliance was placed upon self-reported measures of situation avoidance and crash histories. As far as situation avoidance is concerned, the authors know of no alternative to self-reported data. Regarding crash history, other researchers have favoured more reliable state records (Burg, 1971; Ball *et al*., 1993). Unfortunately, state records were not available to the authors of this article.

Acknowledgements

The authors gratefully acknowledge the support of Vauxhall Motors Ltd, the Wellcome Trust, Granada Group plc, Bollé (UK) Ltd, PC Hayes of West Midlands police traffic division and all of the optometrists in the West Midlands area who contributed to the surveys carried out in study 1.

References

Bailey, N. T. J. (1983) *Statistical Methods in Biology*, 2nd edn. Hodder and Stoughton, London, pp. 52–66.

Bailey, I. L. (1993) New procedures for detecting early losses in the elderly. *Optom. Vis. Sci.* **70,** 299–305.

Bailey, I. L., Bullimore, M. A., Raasch, T. W. and Taylor, H. R. (1991) Clinical grading and the effects of scaling. *Invest. Ophthalmol. Vis. Sci.* **32,** 422–432.

Bailey, I. L. and Lovie, J. E. (1976) New design principles for visual acuity letter charts. *Am. J. Optom. Physiol. Opt*. **53,** 740–745.

Ball, K. and Owsley, C. (1991) Identifying correlates of crash involvement for the older driver. *Hum. Factors* **33,** 583–595.

Ball, K., Owsley, C., Sloane, M., Roenker, D. and Bruni, J. (1993) Visual attention problems as a predictor of vehicle crashes in older drivers. *Invest. Ophthalmol. Vis. Sci.* **34,** 3110–3123.

Brown, B. and Lovie-Kitchin, J. E. (1989) High and low contrast acuity and clinical contrast sensitivity tested in a normal population. *Optom. Vis. Sci.* **66,** 467–473.

Burg, A. (1971) Vision and driving: a report on research. *Hum. Factors* **13,** 79–87.

Dunne, M. C. M., Styles, D., Wardell, P., Stylianou, L. and Sprakes, R. (1998) Driver vision screening: pilot study. In: *Vision in Vehicles VI* (eds A. G. Gale, I. D. Brown, C. M. Haslegrave and S. P. Taylor), Elsevier, Oxford, pp. 343–352.

Elliott, D. B. and Bullimore, M. A. (1993) Assessing the reliability, discriminative ability and validity of disability glare tests. *Invest. Ophthalmol. Vis. Sci.* **34,** 108–119.

Kaplan, D. (1991) The behaviour of three weighted least squares estimators for structural means analysis with non-normal Likert variables. *Br. J. Math. Stat. Psychol.* **44,** 333–346.

Katz, D. L. (1997) *Epidemiology, Biostatistics and Preventative Medicine Review*. Saunders, London, pp. 81–96, 222.

Owsley, C., Ball, K., Sloane, M. E., Roenker, D. L. and Bruni, J. R. (1991) Visual/cognitive correlates of vehicle crashes in older drivers. *Psychol. Ageing* **6,** 403–415.

Pelli, D. G., Robson, J. G. and Wilkins, A. J. (1988) The design of a new letter chart for measuring contrast sensitivity. *Clin. Vis Sci.* **2,** 187–199.

Regan, D. (1988) Low contrast letter charts and sinewave grating tests in ophthalmological and neurological disorders. *Clin. Vis. Sci.* **2,** 235–250.

Regan, D. (1990) High and low contrast acuity. *Optom Vis Sci.* **67,** 650–653.

Shinar, D. and Schieber, F. (1991) Visual requirements for safety and mobility of older drivers. *Hum. Factors.* **33,** 507–519.

Wood, J. M. and Troutbeck, R. (1995) Elderly drivers and simulated visual impairment. *Optom. Vis. Sci.* **72,** 115–124.

Woods, R. L. and Wood, J. M. (1996) The role of contrast sensitivity charts and contrast letter charts in clinical practice. *Optom. Today* **36,** 19–22.