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A Report to the Federal Office of Road Safety on the Effect of Visual Impairment on Driving Performance

Author(s)

Joanne M Wood and Rod Troutbeck

Performing Organisation (Name and Address)

Centre for Eye Research and
Physical Infrastructure Centre
Queensland University of Technology
2 George St
BRISBANE QLD 4000

Sponsor

Federal Office of Road Safety
GPO Box 594
CANBERRA ACT 2601

Available from

Federal Office of Road Safety
GPO Box 594
CANBERRA ACT 2601

Abstract

This study investigates how visual impairment affects driving performance and whether this can be predicted by visual testing in a clinic. Visual impairment (cataracts, visual field restriction and monocular vision) was simulated for a group of young normal subjects. Driving performance was assessed (on a closed road circuit) by measuring peripheral awareness, manoeuvring, reversing, reaction times, speed estimation, road positioning and time to complete the course. Subjects completed a questionnaire of their own perception of their driving performance under conditions of visual impairment. Visual function was assessed by measurement using a visual search and localisation measure, a divided attention reaction time measure, and measurement of visual acuity for low contrast letters, using the Pelli-Robson charts. Simulated cataracts cause the greatest detriment to driving performance followed by binocular visual field restriction, even though drivers would have passed the vision test employed by the driving licence Authorities. The monocular condition did not significantly affect driving performance for any of the driving tasks assessed. Visual impairment significantly reduced visual search ability and increased reaction time. Visual impairment also increased low contrast visual acuity. There is a strong indication that these visual tests would assist in the appropriate licensing of drivers.

Keywords

Vision, Driving, Visual Testing, Driving licence testing

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**A Report to the
Federal Office of Road Safety
on the**

**THE EFFECT OF VISUAL IMPAIRMENT
ON DRIVING PERFORMANCE**

Joanne M Wood* and Rod Troutbeck#

***Centre for Eye Research
#Physical Infrastructure Centre
Queensland University of Technology
2 George Street
Brisbane Q4000**

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Summary

In modern society, driving is important for participation in many daily activities and may be regarded as an essential component for maintenance of independence. To deny a person the right to drive imposes a significant limitation on that person, and for the elderly will often be the first compromise to their autonomy. The community is aging. Long term projections estimate a 100% increase in people aged 65 years and over. The incidence of visual impairment increases with age, thus over the next decade the number of persons with visual impairment applying for license renewal will increase. This is important as it has been suggested that vision comprises the major sensory input for driving. How the changing characteristics of the driving population, particularly visual characteristics, will affect road systems is as yet unknown.

The aim of the study was to investigate how visual impairment affects driving performance and whether this can be predicted by visual testing in a clinic.

Field Testing

Visual impairment was simulated for a group of young normal subjects. The subjects wore goggles designed to simulate the effects of cataracts, visual field restriction and monocular vision. Given an imposed visual impairment, driving performance could only be assessed on a closed road circuit. Driving performance was assessed by measuring peripheral awareness, manoeuvring, reversing, reaction times, speed estimation, road positioning and time to complete the course. Subjects completed a questionnaire of their own perception of their driving performance under conditions of visual impairment. Ongoing studies of a group of subjects with true visual impairment are being used to validate the field based results for simulated visual impairment.

Clinical Vision Testing

Visual function was assessed by measurement using two recently developed types of functional visual field tests. The first is a visual search and localisation measure developed at QUT based on a system used at western Kentucky University in the late 1980. The second is a divided attention and reaction time measure and was developed by the research team at the Centre for Eye Research at QUT. The final measurement was the assessment of visual acuity for low contrast letters using the Pelli-Robson charts.

than subjects in whom simulated cataracts had been imposed, however, the number of errors made was greater. When the number of errors and the driving time were combined to give a driving score the results for the subjects with true cataracts and those with simulations were comparable. Larger numbers of visually impaired subjects will be tested as part of an ongoing project.

Reproducibility of the driving measures

To evaluate the reproducibility and variability of the assessment of driving performance, the measures which were common between the present study and that previously undertaken on the same driving course (Wood and Troutbeck 1992) were compared. These are given for baseline and monocular vision for the two groups (Table 6), as the visual field restrictions in the two studies were not comparable. A two tailed t-test confirmed that these scores were not significantly different between groups. In the previous study visual fields were restricted to a horizontal extent of 40° and 80° to investigate the extreme effects of field restriction on driving performance, whilst in the present study the horizontal field extent was 90°. The cataract

Driving scores	True visual impairment			Simulated visual impairment	
	2	3	4	Baseline	Cataract
Peripheral score	40	22	24	9.8 (2.5)	17 (3.9)
Peripheral reaction time	10	9.6	10	6.3 (4.4)	6.4 (4.3)
Central reaction time	8.4	2.5	1.3	2.6 (3.6)	3.3 (3.8)
Speed estimation	80	70	65	66.7 (9.8)	62.5 (9.4)
Driving time	278	246	240	247.8 (20.7)	354.5 (108.5)
Driving score	478	356	360	297.0 (15.0)	434.5 (123.8)

Table 7: Driving scores for three old subjects with true cataracts compared to results from old normal subjects

simulation has not been previously evaluated.

Questionnaire-based assessment

A multiple ANOVA using the statistical program SAS demonstrated significant differences between self assessed driving performance for all of the nine questions (Table 7). In general subjects rated their performance with the cataract simulation as being worse and that for baseline as being best. Subjects noted that when driving into the sun, the cataract simulation made a very significant impact on their driving performance and made it very difficult for them to drive safely.

Visual Performance

Visual acuity

Binocular visual acuity was decreased under conditions of simulated visual impairment, particularly for the cataract simulation, but was always better than the visual requirement of 6/12 for driving eligibility. Thus drivers with significant visual impairment, arising from depression of peripheral sensitivity or overall decrease of contrast and increase in glare sensitivity, could still pass the driver licence test.

Driving scores	True visual impairment	Simulated visual impairment	
		Baseline	Field restriction
Peripheral score	25.0	8.8 (2.9)	11.0 (5.2)
Peripheral reaction time	7.6	2.6 (2.8)	8.2 (3.3)
Central reaction time	5.4	1.2 (1.3)	5.5 (3.9)
Speed estimation	65.0	66.8 (8.3)	32.6 (7.7)
Driving time	269.0	242.6 (11.6)	269 (17.5)
Driving score	394.0	286.6 (22.6)	324.0 (31.3)

Table 6: Driving scores for a young subject with right homonymous hemianopia compared to young normal scores under conditions of simulated visual impairment

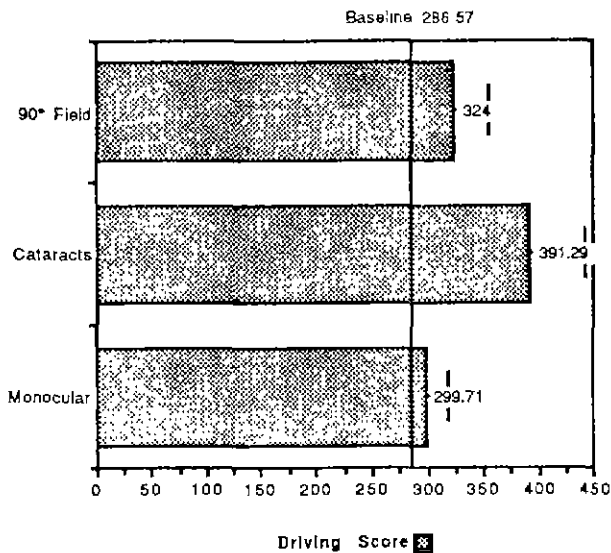


Figure 11 Histogram representing the group mean results for driving score for the three visual impairments relative to baseline (solid vertical line)

Driving score (Figure 11)

When the accuracy of the peripheral awareness task and the time taken to complete the circuit were combined as one score, driving performance for the cataract simulation followed by field restriction had the greatest decrement to driving performance. Monocular vision had no significant effect on driving performance as measured on this closed circuit course.

True visual impairment

The results for the visually impaired subjects were compared with age-matched normal data for simulated visual impairment. Table 4 gives the results for the young subject with visual field restriction compared to the mean results for baseline and simulated visual field restriction for the young normal subjects described previously. Table 5 gives the results for the three older subjects with cataracts together with the mean results from six old normal subjects (age range from 60 to 70 years) for baseline and simulated cataracts collected in a pilot study.

The results from the young subject with true visual field restriction compared well with those from the young subjects with simulated visual impairment. For the simulated condition, subjects drove more slowly and made less errors compared to the subject who had adapted to a field restriction over a period of six months. The time over which visual impairment has developed and the period of adaptation will have an important impact on driving performance and this factor will be further investigated in the ongoing studies.

The results from three patients with true cataracts compared well with the cataract simulations for a group of old normal subjects. As for the young subject with true visual impairment, the older subjects with true cataracts had shorter driving times

	Mean scores			
	n = 9		n = 14	
Driving task	Baseline	Monocular	Baseline	Monocular
Driving time	246.6	261.7	242.6	255.1
Driving score	272.0	305.6	286.6	299.7
Actual speed	67.0	64.3	66.8	64.6
Reversing Time	13.4	16.2	13.4	16.6
Peripheral signs	5.0	8.1	8.8	8.9

Table 4: Comparison between driving scores for the present study and that undertaken previously on the same driving course (Wood and Troutbeck 1992)

Question	Driving Measure	DF	F value	p value
1	Overall driving	3, 54	152.79	< 0.001
2	Anxiety	3, 54	77.54	< 0.001
3	Reaction time	3, 54	35.92	< 0.001
4	Peripheral awareness	3, 54	57.27	< 0.001
5	Road position	3, 54	50.46	< 0.001
6	Reversing	3, 54	44.27	< 0.001
7	Speed estimation	3, 54	28.94	< 0.001
8	Manoeuvring	3, 54	36.55	< 0.001
9	Depth perception	3, 54	34.04	< 0.001

Table 5: Results of the two-way ANOVA for the effect of simulated visual impairment on questionnaire based assessment of driving

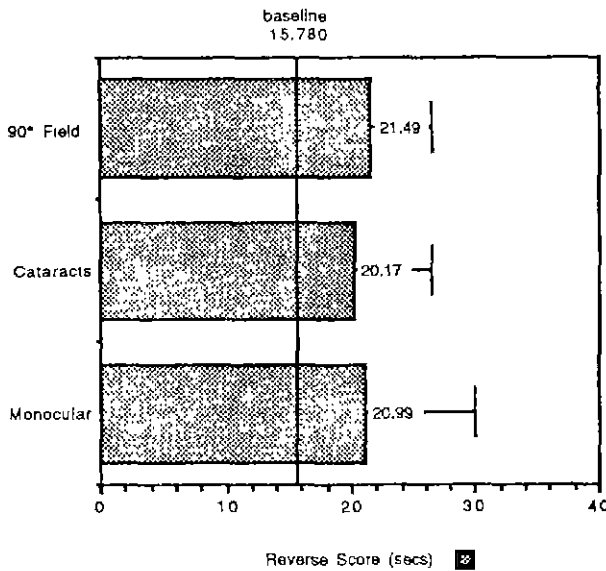


Figure 8 Histogram representing the group mean results for reverse scores for the three visual impairments relative to baseline (solid vertical line)

subjects provided they have a longer period to complete the task. No record of compensatory head movements were made in this study, although qualitative assessment indicated that head movements were more extreme when the fields were restricted as compared to the other visual conditions.

Road position (Figure 9)

Subjects adopted a different road position when driving under conditions of visual impairment compared to baseline. There was a great deal of variation between drivers in the way in which they maintained a constant road position whilst driving along the closed circuit. When monocularity was imposed with the right eye occluded, 12/14 subjects drove to the left (the kerbside of the road) of their baseline position, that is in the direction of the seeing eye.

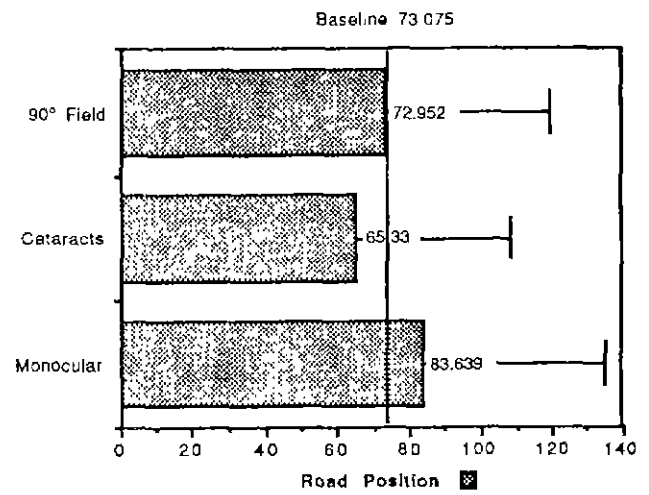


Figure 9 Histogram representing the group mean results for road position scores for the three visual impairments relative to baseline (solid vertical line)

Driving time (Figure 10)

The time to complete the circuit was significantly longer for the cataract condition, followed by visual field restriction and monocularity. This has significant implications for traffic flow and may indicate that persons with cataract and visual field restriction should avoid peak hour traffic where maintenance of a given traffic speed is necessary for constant and efficient traffic flow.

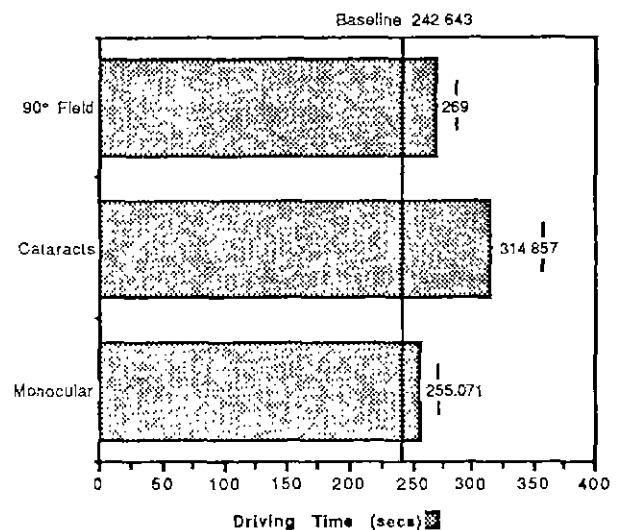


Figure 10 Histogram representing the group mean results for driving time for the three visual impairments relative to baseline (solid vertical line)

the field of view is reduced or under monocular viewing. Similarly, Groeger and Brown (1988) using a laboratory simulation, reported that accuracy of a combined speed and depth estimation task was better for a 40° field than a 10° field, however, they found that sensory information from other modalities such as hearing were important in speed estimation. The fact that peripheral information was not totally excluded for any of the visual impairments employed in this study may explain the lack of a correlation between speed estimation and extent of the binocular field. It is likely that factors, other than the vision (unless it is constricted to totally exclude parafoveal vision), such as the sound and the vibrations of the car engine, contribute to the estimation of speed (Gibson 1954; Evans 1970; Ohta and Komatsu 1991).

Manoeuvring (Figure 7)

Visual impairment resulted in subjects driving more slowly through the line of cones which were designed to simulate roads with cars parked on either side or narrow gaps in car parks. The number of cones touched or knocked over during the manoeuvring task was not, however, significantly increased for visual impairment. Thus in general subjects responded to visual impairment by driving more slowly rather than making more errors. This has significant implications for the visually impaired in that if they are given sufficient time they will make no more errors in these types of tasks than a normal person.

The finding of no significant difference between the

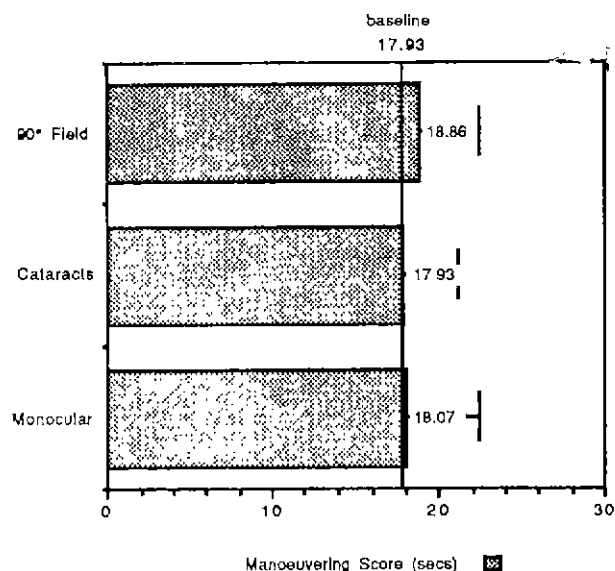


Figure 7 Histogram representing the group mean results for actual speed manoeuvring score for the three visual impairments relative to baseline (solid vertical line)

number of manoeuvring errors made between baseline and monocular vision is interesting as it suggests that the binocular cues in depth perception such as stereopsis and convergence are not essential for manoeuvring through a narrow set of cones. It is likely that monocular cues such as hue, alignment and size are more important in manoeuvring through obstacles within this range. In support of this, it has been reported that one-eyed private pilots land planes better than two-eyed pilots (Lewis et al 1973).

Reversing (Figure 8)

Visual impairment did not significantly affect the accuracy of parking (in terms of straightness and centrality) but as for the manoeuvring task, subjects took significantly longer to reverse into the parking bay under conditions of visual impairment. Thus for tasks such as reversing and manoeuvring, subjects in whom visual impairment has been imposed can perform the tasks as accurately as visually normal

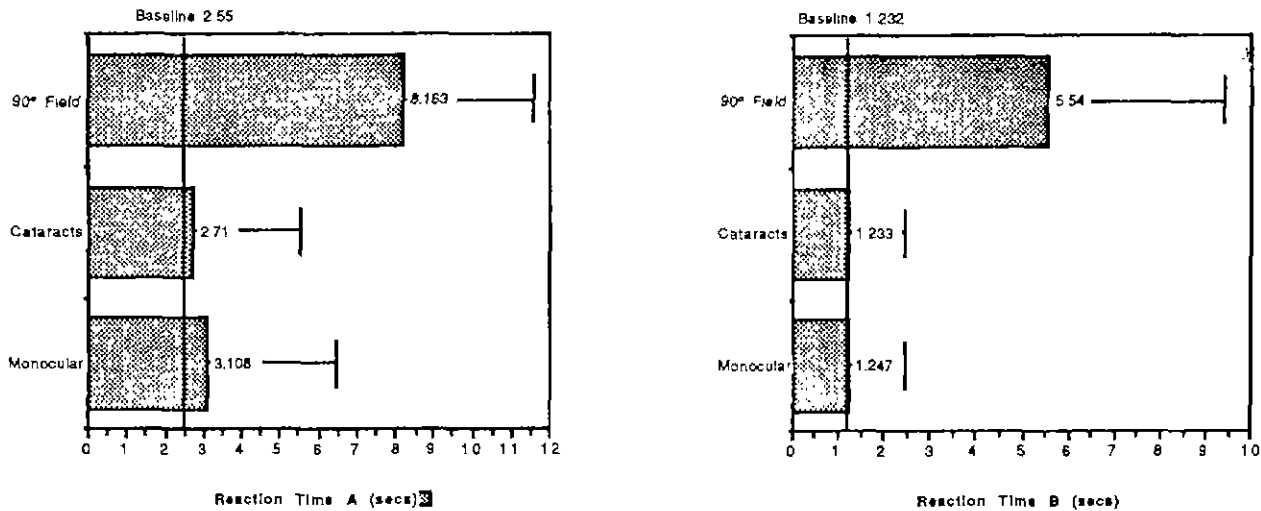


Figure 5 Histogram representing the group mean results for reaction times for a) the LED located centrally on the dashboard b) the LED located peripherally for the three visual impairments relative to baseline (solid vertical line)

cataract condition than for baseline, however these differences were not significant. This finding may have been an artifact of the LED stimuli employed for the reaction time task, which being relatively bright were scattered by the cataract simulation and were therefore rendered more visible than the low contrast objects such as cars or people which are normally encountered in driving. For this reason, the reaction times recorded in this study may have been better than those measured for drivers with cataracts in response to another vehicle or pedestrian appearing suddenly in the field of view.

Speed Estimation (Figure 6)

Subjects tended to drive slower under conditions of simulated visual impairment compared to baseline when requested to drive at a constant speed of 60 kh-1. Subjects commented that they relied upon the sound and vibration of the car in order to judge speed and that they drove slower under visually impaired conditions as they felt less safe. The differences

between conditions was not, however, significant which is contrary to previous studies which suggest that flow patterns generated in the periphery are critical cues for speed estimation (Gordon 1966; Gibson 1968; Brandt et al 1973). This hypothesis is also supported by the findings of road-based studies by Cavallo et al (1986) and Osaka (1988) who reported that subjects underestimate the speed of a distant object when

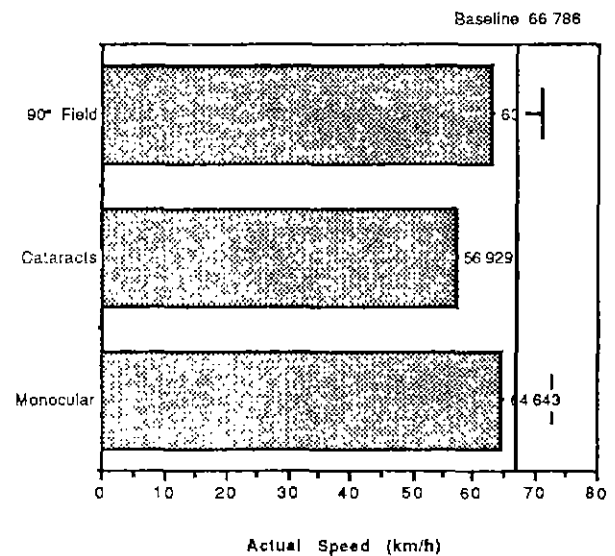


Figure 6 Histogram representing the group mean results for actual speed (estimated to be 60 km/h) for the three visual impairments relative to baseline (solid vertical line)

slower for monocular, visual field restriction and cataracts.

Peripheral Awareness (Figure 4)

The finding that peripheral awareness was reduced for cataracts and visual field restriction implies that drivers with these impairments may not detect peripheral cues, such as other vehicles at intersections or people at the roadside and therefore may not receive the same degree of forewarning as the visually normal driver. This has significant implications for the way in which drivers use road systems in terms of their way-finding ability and their adherence to road rules as dictated by signage. The reduction in peripheral awareness resulting from visual field restriction was also seen to depend upon the horizontal extent of the remaining visual field and the degree of compensatory head movements that the subjects adopted. Monocular vision had no significant effect on peripheral awareness scores.

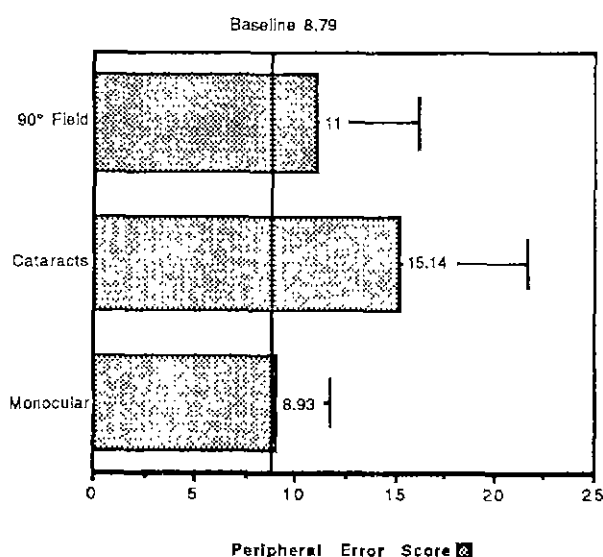


Figure 4 Histogram representing the group mean results for peripheral awareness error scores for the three visual impairments relative to baseline (solid verticle line)

The decrement in peripheral awareness for cataracts and field restriction conditions was most apparent at times of information overload and is supported by the results of a pilot study undertaken on the same driving course (completed as part of a final year student project) which demonstrated that if the information overload is reduced (by decreasing the number of road obstacles and pieces of information per sign) the difference in peripheral awareness between the restricted field and the baseline condition was reduced. There have been a number of studies which have investigated the problems of divided attention and time sharing between a number of visual tasks (Robinson and Desai 1971; Kahneman et al 1973), however, little is known about their contribution to road accidents. This has relevance to suggestions that the visually impaired should be permitted to drive under selected road conditions (Fonda 1989; Bailey and Sheedy 1990).

Reaction times (Figure 5)

Restriction of the binocular visual field had the greatest effect on reaction times. These results concur with those of Lovsund and Hedin (1986) who reported that visual field defects impaired detection capacity for stimuli in the defective area when driving performance was assessed by a simulator. Reaction times were not significantly longer for either the monocular or cataract conditions compared to baseline although there were a range of results across the group. These findings indicates that peripheral vision is important for detecting a change in the visual environment, such as other road users and pedestrians and the initiation of appropriate avoidance action. Reaction times were longer for the

demonstrated that there is a significant learning component in conventional (Wood et al 1987) and functional (Shiffrin and Schneider 1977) visual field testing.

Visual acuity

Binocular visual acuity was measured using a high contrast (90%) chart at the standard working distance of 6 M to give a similar measure of visual performance to that used in driving test centres.

Pelli-Robson letter contrast sensitivity

A measure of low contrast letter sensitivity was determined using the Pelli-Robson letter chart as described by Pelli et al (1988). This comprised eight rows of six uppercase letters of constant size which decreased in contrast from approximately 100% in the upper left hand corner to 0.95 at the lower right. The letters were arranged in groups of three, where contrast was constant within a group, and the

contrast of each group decreased by approximately 0.15 log units. Subjects were required to name the letters and continue until two or more errors were made in a group; nil responses were not permitted and subjects were encouraged to guess as the scoring depends upon a forced choice paradigm. Contrast threshold was determined where each letter counted as 0.05 log unit.

Results & Discussion

Driving Performance

The results demonstrate that imposing visual impairment on young normal subjects significantly affected the manner in which they drive, despite the fact that they fulfilled the visual requirements for driving licensure. A two-way ANOVA undertaken on SAS demonstrated significant differences in driving performance under the four visual conditions for all driving tasks except speed estimation, manoeuvring errors and reversing angle (Table 3). Post hoc analysis showed that these differences were between cataracts and the other visual conditions.

The mean scores for the group for each of the three visual conditions compared to baseline (solid vertical line) for each of the driving tasks, are given in histogram form (Figures 4-11). Poorest performance was recorded for subjects with the simulated cataract condition, followed by visual field restriction, monocular vision and then baseline for the peripheral awareness, driving time, manoeuvring and reversing measures. Reaction times were longest (worse performance) for visual field restriction. In the speed estimation task, subjects drove faster than the required 60 km/h for baseline, driving progressively

Driving Task	DF	F value	p value
Manoeuvring time	3, 54	11.42	< 0.001
Manoeuvring errors	3, 54	1.00	NS
Manoeuvring score	3, 54	2.96	< 0.05
Reversing time	3, 54	17.68	< 0.001
Reversing angle	3, 54	0.94	NS
Reverse score	3, 54	5.96	< 0.005
Speed estimation	3, 54	4.31	NS
Peripheral reaction time	3, 54	15.20	< 0.001
Central reaction time	3, 54	20.60	< 0.001
Peripheral awareness	3, 54	19.13	< 0.001
Driving time	3, 54	22.55	< 0.001
Driving score	3, 54	32.95	< 0.001
Road position	3, 54	8.68	< 0.001

Table 3: Results of the two-way ANOVA for the effect of simulated visual impairment on driving scores

peripheral task. The easier level comprised presentation of the peripheral faces in the absence of any distractor boxes. For the more difficult condition, the peripheral targets had to be located from within an array of 47 distractor boxes. The peripheral response for any of the conditions was only recorded if the subject gave a correct response for the central task. To be tested at each of the 24 peripheral locations the subjects thus had to undertake a minimum of 24 trials for any given condition.

For a given trial, four consecutive displays were presented on the computer screen. The first display was of the central outline box which directed the observers attention centrally. This was followed by the appearance of the face in both the central and peripheral locations, then a random masking noise and finally a radial spoke pattern which allowed the subject to indicate the location of the cartoon face.

For each of the four visual conditions, subjects were tested at the low and high levels of central and peripheral demand. The results were given as the total number of errors and as a percentage of the total number of trials.

Functional Visual Fields: Divided Attention & Threshold Peripheral Targets

Functional visual fields were also measured whilst the subject performed a concurrent central task throughout the test, representing a divided attention measure. Divided attention tasks have been used in previous studies of driving to examine the effect of alcohol on driving performance (Moskowitz 1974).

The divided attention functional visual field test was undertaken using a standard static automated perimeter (Humphrey Field Analyser) adapted for this purpose. Subjects were required to respond to conventional perimetry spot targets of different contrasts presented in the periphery whilst undertaking a central task which assessed reaction times. A flashing LED was placed in the central fixation aperture of the perimeter bowl and linked up to a control box and a separate response button. The control box determined the pseudorandom extinguishing of the LED and the response button served to reactivate the LED when it flashed off. Subjects were instructed to press the LED response button whenever the LED flashed off in order to maintain constant illumination of the central LED. The response time between the LED flashing off and activation by the response button was recorded as a series of reaction times throughout the test. At the same time perimetric sensitivity was measured at the fovea and at eccentricities of 15°, 30°, 45° and 60° along the superior and inferior meridians and at eccentricities of 15°, 30°, 45°, 60° and 75° along the right and left horizontal meridians for target size III.

All measures were undertaken binocularly. Subjects had two response buttons and were instructed to respond to the peripherally presented spot targets by pressing the perimetry button, whilst maintaining illumination of the central LED target by pressing the LED response button whenever the fixation light flashed off.

Subjects were given a series of practice trials without the goggles prior to recording for both of the functional field tests. This was undertaken to minimise the effect of practice, as it has been

performance. Dynamic visual acuity measures were found to be too difficult to standardise and the results were variable. A battery of tests which included functional visual field testing and low contrast visual acuity was employed. Functional visual field tests were selected as previous studies have reported a correlation between measures of the functional visual field and accident rates (Avolio et al 1986; Sloane et al 1991), where the functional field is defined as that visual field area from which target characteristics can be acquired when eye and head movements are precluded (Sanders 1970). A test of letter contrast sensitivity, which employs low contrast letters was included, as it has been suggested that such tests better reflect the visual environment which comprises low contrast as well as high contrast detail (Carman and Brown 1959).

Functional Visual Field: Useful Field of View

A measure of the functional visual field for peripheral search and localisation, known as the Useful Field of View (UFOV), was determined. Targets were generated on a large computer screen to measure both central and peripheral information processing as described by Sekuler and Ball (1986). The central task provided a stimulus for fixation as well as creating various levels of central demand. The peripheral component was designed to measure localisation of targets in the peripheral field when targets were embedded within a distracting array and when presented in an empty field.

A large screen (Sony, Trinitron) which subtended 56° by 51° at the working distance of 28 cm was

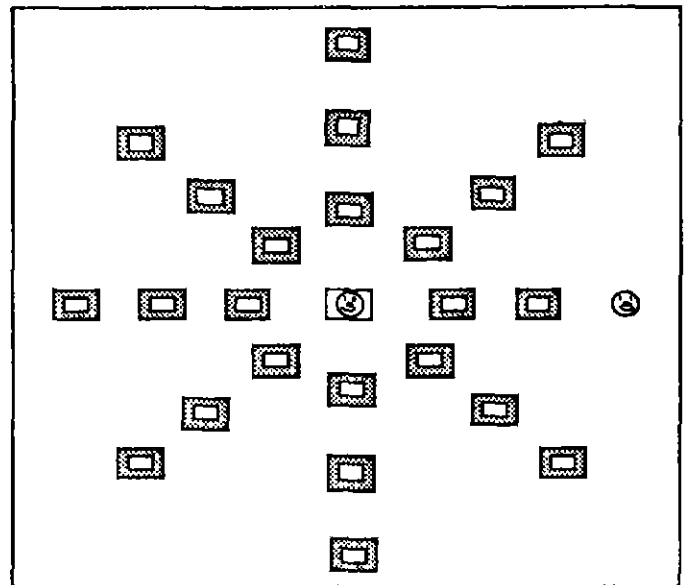


Figure 3. Schematic diagram of the display for measurement of the UFOV functional visual field test

employed for display of the targets. Targets comprised cartoon faces (selected as these are simple to explain to subjects) which were either smiling or frowning and subtended 4° by 3.5° . Cartoon faces were presented centrally and in a given peripheral location for a duration of 90ms (Figure 3). There were two levels of difficulty for the central task. For the easier, or low demand condition, the central cartoon face was either present or absent, and subjects simply had to report on the presence of the face as a yes/no response. For the more difficult, or high demand condition, two faces appeared centrally (either both smiling, both frowning or one smiling and one frowning) and the subject had to report whether the faces were the same or different. In the peripheral task, the cartoon faces appeared predictably but equally often at 24 different locations along 8 radial directions at eccentricities of 8° , 17° and 26° . The distractor stimuli comprise outline boxes of the same size and luminance as the cartoon faces. Two levels of difficulty were available for the

Driving runs

Subjects were required to drive around the circuit six times (each circuit took between 3 and 5 minutes to complete). The first run was in a clockwise direction, followed by a run where the car was driven around in the opposite or anticlockwise direction. These two runs were to familiarise the subjects with the car and the driving skills to be tested and were undertaken without the goggles in place. The subjects were allowed to practice all of the driving tests except for the peripheral awareness task (as we wished to minimise the degree of learning of the signs). The following four runs were undertaken in alternate clockwise and anti-clockwise directions for each of the four visual conditions. The order of visual conditions for each subject was predetermined using a random number generator. For a given subject the order of visual conditions was the same for both the driving and visual performance measures. All of the driving assessments were

undertaken between 4.00 pm and 6.00 pm (during daylight saving) to standardise illumination conditions as much as possible.

Questionnaire-based Assessment

Following completion of the driving assessment each subject was given a questionnaire to determine self assessment of driving performance under the four visual conditions. The questionnaire comprised nine questions are given in Table 2 and were designed to obtain a subjective rating of degrees of driving difficulty induced by visual impairment.

Assessment of Visual Function

A battery of tests of visual function were employed in order to determine which tests best predicts driving performance. Pilot studies demonstrated no relationship between tests of ocular motor balance, depth perception and colour vision and driving

DRIVING PERFORMANCE QUESTIONNAIRE	
Subject _____	Date _____
1 Rank each of the following conditions in the order that they impaired your overall driving performance. (10 for most effect and 1 for least effect, with the lowest/s above the desired value) Cataract (C), Field Restriction (FR), Monocular (M), Baseline (B)	1 2 3 4 5 6 7 8 9 10
2 Rank each of the following conditions in the order that they increased your anxiety with regard to driving in the experiment. (10 for most effect and 1 for least effect) Cataract (C), Field Restriction (FR), Monocular (M), Baseline (B)	1 2 3 4 5 6 7 8 9 10
3 Rank each of the following conditions in the order that they impaired your ability to see the LCDs light up in the car. (10 for most effect and 1 for least effect) Cataract (C), Field Restriction (FR), Monocular (M), Baseline (B)	1 2 3 4 5 6 7 8 9 10
4 Rank each of the following conditions in the order that they impaired your ability to see and read the signs on the road-way. (10 for most effect and 1 for least effect) Cataract (C), Field Restriction (FR), Monocular (M), Baseline (B)	1 2 3 4 5 6 7 8 9 10
5 Rank each of the following conditions in the order that they impaired your driving performance when cornering. (10 for most effect and 1 for least effect) Cataract (C), Field Restriction (FR), Monocular (M), Baseline (B)	1 2 3 4 5 6 7 8 9 10
6 Rank each of the following conditions in the order that they impaired your driving performance when reversing. (10 for most effect and 1 for least effect) Cataract (C), Field Restriction (FR), Monocular (M), Baseline (B)	1 2 3 4 5 6 7 8 9 10
7 Rank each of the following conditions in the order that they impaired your ability to maintain a constant set speed. (10 for most effect and 1 for least effect) Cataract (C), Field Restriction (FR), Monocular (M), Baseline (B)	1 2 3 4 5 6 7 8 9 10
8 Rank each of the following conditions in the order that they impaired your driving performance when manoeuvring through the cones. (10 for most effect and 1 for least effect) Cataract (C), Field Restriction (FR), Monocular (M), Baseline (B)	1 2 3 4 5 6 7 8 9 10
9 Rank each of the following conditions in the order that they impaired your ability to judge distances. (10 for most effect and 1 for least effect) Cataract (C), Field Restriction (FR), Monocular (M), Baseline (B)	1 2 3 4 5 6 7 8 9 10
10 Rank each of the following conditions in the order that they impaired your ability to avoid obstacles. (10 for most effect and 1 for least effect) Cataract (C), Field Restriction (FR), Monocular (M), Baseline (B)	1 2 3 4 5 6 7 8 9 10

Table 2: Questionnaire for the self assessment of driving performance

Road position

The road position of the car throughout each run was recorded by a video camera positioned within the car and directed backwards. The resulting videotapes were analysed by taking measures of position of the car relative to the markings at the edge of the road at three right hand corners, three left hand corners and three straight stretches of the course. Five measures were made at each location giving a total of 45 measures for each run.

Driving Time

The time to complete the course excluding the manoeuvring and reversing tasks was recorded for each subject.

Driving Score

This was calculated to assess the compensations for visual disability made either by taking longer to complete the course or by making more errors, or a combination of both. Each error on the peripheral awareness tasks was given an arbitrary time penalty of 5 s and added to the total driving time to derive a total score. Though this is termed the overall score it does not account for manoeuvring or reversing skills.

Manoeuvring

Subjects were required to drive through a series of cones which were positioned on a wide flat section of the course (Fig 2). A number of different arrangements of cones were trialled to determine the optimum arrangement whereby the level of difficulty

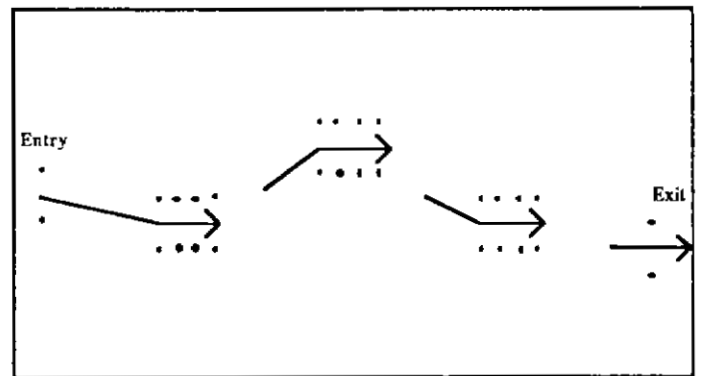


Figure 2: Schematic diagram of the arrangement of traffic cones for the manoeuvring task.

was great enough to avoid a ceiling effect and could be easily reproduced from week to week of the study. Subjects were instructed to drive as quickly as possible through the manoeuvring course without touching any of the cones. Each cone touched or knocked over was recorded by an examiner external to the car and given as an error score. Time taken to complete the manoeuvring task was also recorded. A manoeuvring score was calculated as the time taken to complete the task with a 1s penalty for each error.

Reversing

Subjects were required to reverse into a standard parking bay as quickly and accurately as possible. The distance of the outer edge of each of the tyres to the inside border of the white lines delineating the parking bay were measured to calculate the straightness of park (expressed as an angle) and centrality of parking within the bay. Time taken to complete the reversing task was also recorded. A reversing score which took into account both speed and accuracy of reversing was calculated as time in seconds with a 1s penalty for accuracy.

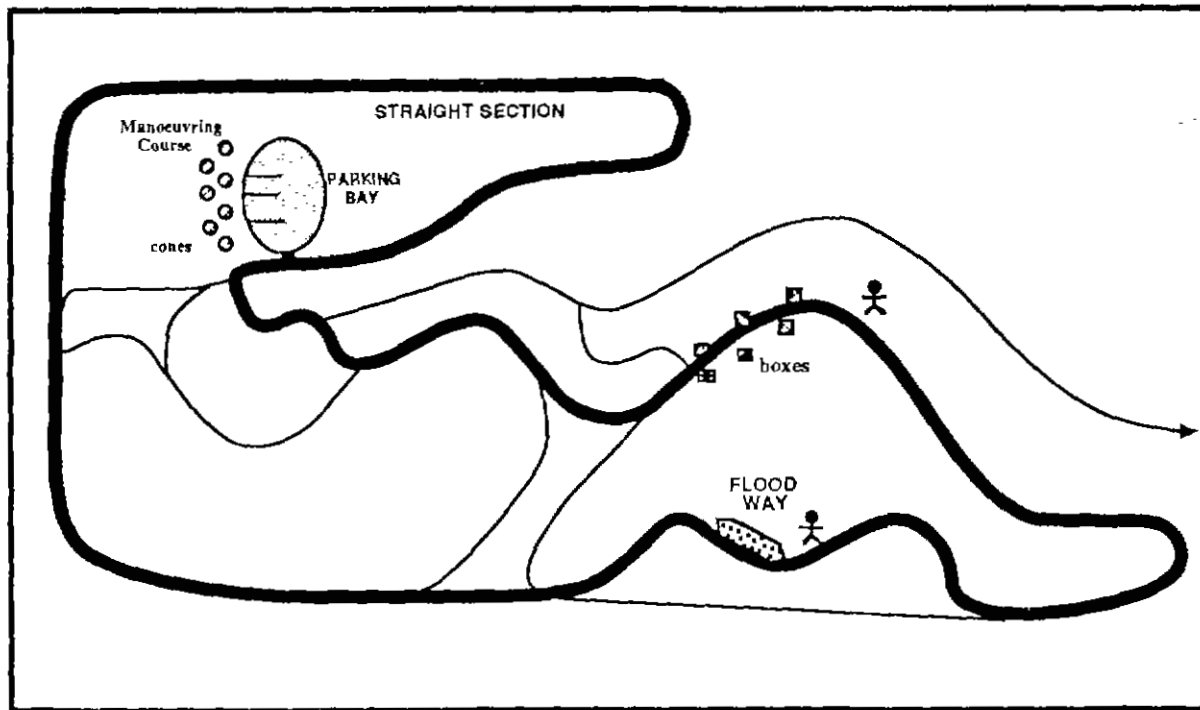


Figure 1 Schematic representation of the driving course at the Police Advanced Driver Training Centre at Mt Cotton, Queensland.

measured included peripheral awareness, manoeuvring, reversing, reaction times, speed estimation, road position and time to complete the circuit.

Peripheral awareness

Subjects were required to report and identify any road signs or people seen as they drove around the circuit. This included 19 standard road signs, six of which contained two extra pieces of information which were changed between runs to minimise familiarity effects. Two people were positioned the roadside whose positions were changed between runs.

Reaction times

Two LEDs were located within the car interior and linked to a timing mechanism connected to the brake

pedal and a control box which the examiner operated. One LED was positioned on the dashboard and the other at 30° temporal to the left eye. Each LED was illuminated twice on each run, with the order and timing of LED presentation randomised to avoid familiarity effects. On illumination of the LED the driver was required to lightly press the brake pedal as quickly as possible and the reaction time automatically recorded.

Speed estimation

Subjects were instructed to drive at 60 km/h along a straight flat stretch of the circuit, with the view of the speedometer obscured. The mean speed driven during this section was recorded. During the two practice runs, the speedometer was visible to the drivers, to familiarise them with the task and the 'feel' of the car travelling at that speed.

simulated using frosted lenses. Peripheral field restriction was simulated by placing pinholes of 6.5 mm in diameter into the swimming goggles, which resulted in binocular visual fields of a horizontal extent of approximately 90°. The position of the pinholes relative to the pupil centre of each subject was individually adjusted to avoid diplopia. Each subject was also advised to report to the examiner if they noticed diplopia at any time during either the driving or visual performance measures. Monocular vision was simulated by a standard eye patch placed before the right eye beneath the swimming goggles. This effectively reduced the horizontal extent of the visual field from 150° with the baseline swimming goggles in place to 105°, with the physiological blindspot at 15° eccentricity on the left temporal side. For the baseline condition the subjects wore the swimming goggles without any field condition. The baseline goggles did not restrict the field of vision, as was demonstrated by measuring binocular visual fields with and without the goggles.

Visually Impaired Subjects

Twenty subjects with true visual impairment have been recruited for inclusion in the study and four have participated so far. A summary of the subject characteristics are given in Table 1. Written informed

consent was obtained from each participant after the nature and purpose of the study had been fully explained, with the option to withdraw from the study at any time. All subjects had distance visual acuity of 6/12 or better and were holders of a current drivers license.

Research Vehicle

The car employed for these studies was specially adapted for this purpose. A car with automatic transmission was selected in preference to a car with manual control to increase the number of subject eligible for participation in the study. The car was instrumented to record its location and to assess various aspects of driving performance. It also had two light emitting diodes (LED) one mounted on the windscreen and one on the dashboard to provide the stimulus for the reaction time task. These were linked up to the brake pedal so an accurate measure of the time between onset of the LED and braking could be made. A video camera was mounted in the back of the car in order to monitor road position on the driving course.

Assessment of driving performance in the field

Driving performance was assessed on a closed road circuit at the Police Advanced Driver Training Centre in Queensland, Australia which comprises a closed bitumen road containing hills, bends, straight stretches and standard road signs (Fig 1). The nature of the visual impairments necessitated that, in the interests of safety, the circuit was free of other road vehicles. The aspects of driving performance

Subject	DOB	Visual acuity	Condition
1	17/11/67	R 6/6; L 6/6	R homonymous hemianopia
2	31/07/21	R 6/8.5; L 6/6	R > L lens opacities
3	29/01/21	R 6/9; L 6/6	R > L lens opacities
4	20/11/17	R 6/6+2; 6/5	R > L lens opacities

Table 1: Characteristics of the visually impaired subjects

is the attribute that is most commonly screened, however, there is no compelling evidence that visual acuity as opposed to other visual functions better predicts driving performance. Indeed, a number of investigators have advocated that full visual fields, as opposed to good central static vision are more important to driving performance (Buyck et al 1988; Fonda 1989).

The aims of this study were to determine which types of visual impairment cause the greatest detriment to driving and to identify those tests of visual function which can best predict driving performance. This was undertaken in two stages. In the first, the effect of simulated visual impairment on the driving and visual performance of normal subjects was measured. In this way factors other than vision, known to have an influence on driving performance, such as experience and higher level of risk taking would be constant for all visual conditions. In the second stage, driving and visual performance were measured for subjects with true visual impairment.

Subjects & Methods

Normal Subjects

Twenty normal subjects were recruited for participation in the study, of these, fourteen subjects satisfied the inclusion criteria and completed all sections of the study. The age range of the subjects was from 19 years to 37 years (mean age 23.6 years; SD 4.5 years). Written informed consent was obtained from each participant after the nature and purpose of the study had been fully explained, with the option to withdraw from the study at any time. All subjects were in good ocular health and had

distance visual acuity of 6/6 or better and were holders of a current drivers licence.

Simulations

Three simulations of visual impairment including monocular vision, cataracts and peripheral field restriction were employed together with a baseline condition. Cataracts were selected as they are one of the most commonly occurring causes of visual impairment in elderly populations (Podger et al 1983). Peripheral field restrictions were selected on the premise that they are most commonly cited as resulting in impaired driving performance (Kite and King 1961; Keeney 1968; Liesmaa 1973) and monocularity, as this condition excludes drivers from operating passenger and heavy goods vehicles in many countries such as Australia (Department of Transport 1992). Pilot studies demonstrated that simulation of central loss was impossible without the assistance of sophisticated projection equipment. Clear lenses with an opaque central spot were suspended in the goggles but were unsuccessful because subjects could easily look around the central spot by moving their eyes. In an attempt to avoid this problem contact lenses with a black pigmented area located centrally were employed but this was also unsuccessful because the central spot could not be made sufficiently opaque to reduce central vision.

The visual impairments were suspended before the eyes in modified swimming goggles. The goggles were secured by a strip of velcro material which permitted easy removal of the goggles at any time. The reduction in contrast and increase in glare sensitivity experienced by cataract patients was

Introduction

In modern society, driving is important for participation in many daily activities and may be regarded as an essential component for maintenance of independence (Interrante 1986). This has particular relevance for those living in rural areas of Australia, where public transport is limited. To deny a person the right to drive imposes a significant limitation on that person, and for the elderly will often be the first compromise to their autonomy.

Since vision has been estimated to comprise up to 90% of the sensory input for driving (Hills 1980), it is generally believed that visual impairment reduces driving performance. Most visual impairment arises subsequent to eye disease. Since the prevalence of eye disease increases significantly with age, the problem of the visually impaired is likely to become a major concern for Australia in the future. Long term projections estimate a 95% increase in people aged between 50-64 years from 2.2 million in 1984 to 4.3 million in 2021, and a projected 100% increase in people aged 65 years and over from 1.6 million in 1984 to between 3.4 and 3.5 million in 2021 (Australian Bureau of Statistics 1988). Over the next decade the number of persons with visual impairment applying for license renewal will thus significantly increase.

If visual criteria are used to determine driving eligibility there should be strong evidence that those who fail to meet the given vision standard do have poorer driving performance leading to an unacceptably high risk of accidents. Although there is some evidence to support this, there have also

been a large number of studies which have failed to show any direct relationship between vision and driving performance. Correlations have been demonstrated between visual acuity (Burg 1967; 1968), visual fields (Keeney and Garvey 1981; Johnson and Keltner 1983; Cavallo et al 1986; Lovsund and Hedin 1986; Groeger and Brown 1988; Osaka 1988; Wood and Troutbeck 1992), motion perception (Henderson and Burg 1974) and driving performance. Conversely, other studies have reported little or no relationship between visual acuity (Buyck et al 1988; Fonda 1989), visual fields (Council and Allen 1974; Cole 1979) and driving performance. The inconsistencies in these findings may have arisen from the relatively small numbers of subjects studied and the crudity of the vision tests in many of the studies. Additionally, with the exception of the study of Wood and Troutbeck (1992), driving performance was assessed by laboratory simulation or by accident rates. The former may bear little relationship to actual driving conditions and the latter can only be an index of driving ability as many accidents remain unreported and those drivers involved in accident statistics may not necessarily be 'at fault'.

The cost of vision screening can only be justified if it leads to significant changes in the visual characteristics and safety of the driving population in a manner that will reduce accident rates or enhance traffic efficiency. There are many characteristics of vision, which are impaired in eye disease, that could be considered as requirements for a driving license. These include measures of central static visual acuity, dynamic visual acuity, visual fields, colour vision and contrast sensitivity. Central visual acuity

Findings

Simulated cataract caused the greatest detriment to driving performance followed by binocular visual field restriction, even though drivers would have passed the vision test employed by the driving license authorities. The monocular condition did not significantly affect driving performance for any of the driving tasks assessed.

Visual impairment significantly reduced visual search ability and increased reaction time as measured by the functional visual field tests. Visual impairment also decreased low contrast visual acuity.

A good correlation was demonstrated between aspects of driving performance and vision. There was also a high correlation between visual impairment and these tests of visual function. There is a strong indication that these visual tests would assist in the appropriate licensing of drivers.

The population is expected to develop an increased frequency of visual impairment, thus the results will be most relevant to road design and road traffic safety. There is a need for more definitive research on the inter-relationship between visual performance and the performance of the road system. The results from this study provide a basis for further investigations which will include large numbers of elderly subjects, both those with visual impairment resulting from eye disease, as well as those with simulated visual impairment.

Low Demand

Visual Condition	Number of Errors			
	0°	8°	17°	26°
Baseline	0.07 (0.27)	0.07 (0.27)	0.14 (0.36)	0.71 (0.61)
Monocular	0.36 (0.63)	0.00 (0.00)	0.07 (0.26)	0.71 (0.47)
Cataracts	0.36 (0.63)	0.00 (0.00)	0.36 (0.63)	1.29 (1.27)
Field Restriction	0.14 (0.36)	0.07 (0.27)	2.57 (2.88)	5.93 (2.34)

High Demand

Condition	Number of Errors			
	0°	8°	17°	26°
Baseline	2.36 (2.98)	0.21 (0.58)	0.57 (0.85)	2.86 (1.75)
Monocular	2.29 (3.22)	0.21 (0.58)	1.07 (0.83)	3.43 (1.70)
Cataracts	4.50 (4.00)	0.50 (0.94)	1.57 (1.45)	4.93 (1.59)
Field Restriction	2.14 (1.75)	0.43 (0.51)	3.14 (2.88)	6.57 (1.60)

Table 8: Error scores for the radial localisation functional field test as a function of eccentricity.

conditions for the low and high levels of central and peripheral demand. In general the number of peripheral errors was highest for the field restriction, followed by cataracts, with the results for monocular and baseline conditions being indistinguishable from one another. The number of errors was larger when the level of demand was higher particularly in the periphery, except for field restriction where the number of peripheral errors was relatively constant regardless of whether peripheral distractors were present or absent.

Functional Visual Field: Useful Field of View

The group mean number of errors for the UFOV are given in Table 8 for low and high demand levels respectively for each of the visual conditions and as error rates in Figures 12a and 12b for the low and high demand conditions respectively. The number of errors increased with eccentricity for all visual

The data for the UFOV were summarised into a central and peripheral score by taking the error rate for the foveal task as central and the sum of the errors at 8°, 17° and 26° as the total peripheral error score. A two-way ANOVA demonstrated that the differences in error scores between the four visual conditions were significant for the peripheral score with (df 3, 54; $F = 8.66$; $p < 0.001$) and without (df 3, 54; $F = 49.75$; $p < 0.001$) distractors and high demand central (df 3, 54; $F = 6.84$; $p < 0.001$) scores. There were no significant differences between visual conditions for the central score when the level of difficulty was low.

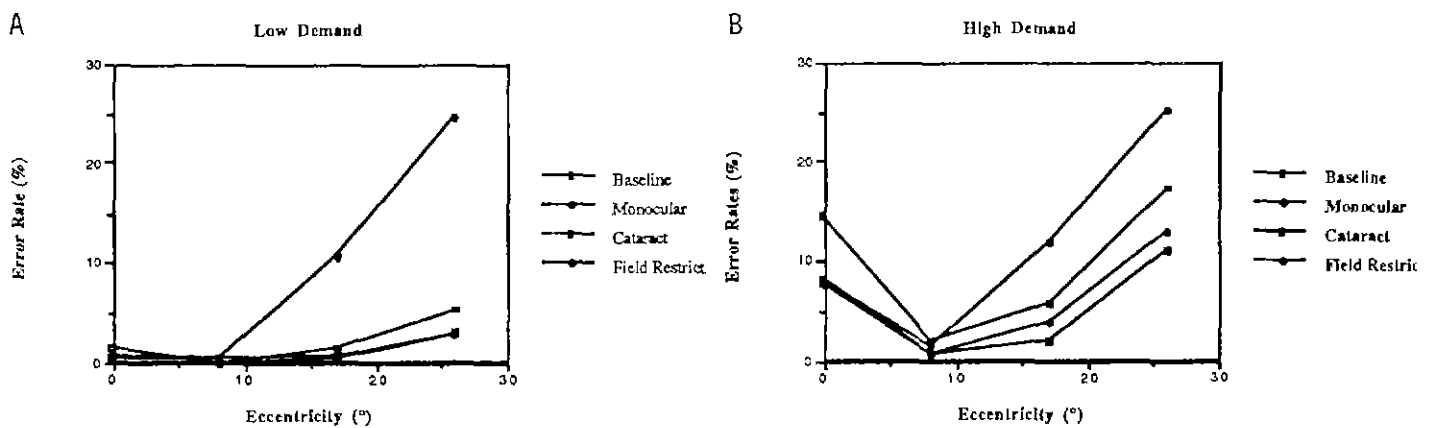


Figure 12 Group mean error rates for the UFOV functional visual field at different eccentricities for a) low demand and b) high demand conditions for the four visual conditions

The fact that the differences between visual conditions were greatest when the UFOV was measured under conditions of high demand concurs with previous reports which suggested that the difference in UFOV scores between young and elderly observers was also greater when the task is set at a high level of central and peripheral demand (Sekuler and Ball 1986). Indeed, it has been suggested that the age-related decline in the extent of the UFOV, demonstrated both in the presence of distractors (Ceralla 1985; Walker et al 1992) and with secondary central tasks (Ball et al 1987), reflect the problems experienced by older adults with visual distractors in real life situations such as locating a familiar face in a crowd or trying to read a street sign surrounded by other street signs (Kosnik et al 1988). This was also supported by our finding that the correlations between driving performance and UFOV scores were higher for the high demand condition. The finding that visual impairment results in a decrease in driving performance and an increase in the number of errors on the UFOV under high demand is also supported by Sloane et al (1991) who reported a significant correlation between UFOV scores and accident rates in elderly drivers. Thus the UFOV, measured for a complex central task and peripheral targets embedded within a distractor array, more closely relates to driving which comprises a divided attention task involving localisation of relevant targets within cluttered environments.

The importance of considering both the central and peripheral errors on the UFOV task for prediction of driving was illustrated for field restriction, which

resulted in reduced driving performance and a significant increase in peripheral UFOV errors but had little impact on the central scores. Field restriction was also the only condition for which the peripheral errors were not increased when distractors were introduced. This arose because of a ceiling effect, where subjects with field restriction made almost the maximum number of peripheral errors in the absence of distractors and thus the addition of distractors could not increase number of errors even though subjects indicated that the presence of the distractors increased the difficulty of the task.

The fact that subjects performed more poorly on the localisation task under simulated cataract conditions indicates that contrast has an important role in this task. Sekuler and Ball (1986) using a similar test protocol reported that lens induced blur resulted in mistakes being made on the central task, where subjects had to report whether the face was smiling or frowning, but no decrement in the peripheral localisation scores. Change in contrast as opposed to refractive blur thus compromised the localisation task to a greater extent.

Condition	Group Mean Data	
	Reaction Time (s)	Mean Sensivity (dB)
Baseline	0.60 (0.13)	26.98 (1.14)
Monocular	0.73 (0.26)	19.53 (1.43)
Cataracts	0.64 (0.22)	15.69 (1.74)
Field Restriction	0.60 (0.17)	7.60 (2.34)

Table 9. Group mean reaction times and sensitivity for the divided attention functional visual field test for the four visual conditions

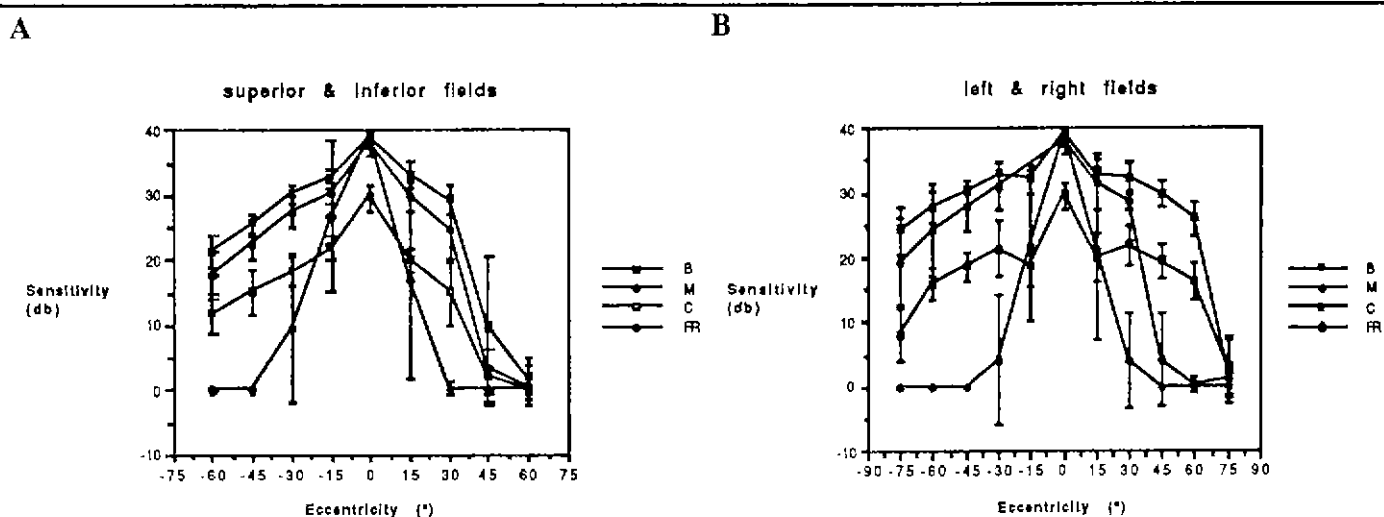


Figure 13 Group mean sensitivity measured for the divided attention functional visual field test at different eccentricities along the a) vertical and b) horizontal meridians for the four visual conditions

Functional Visual Fields: Divided Attention & Threshold Peripheral Targets

The group mean differential light sensitivity measured along the horizontal and vertical meridians of the visual field for each of the four visual conditions are given in Figures 13a and 13b respectively. Group mean reaction times and visual field sensitivity for each of the four visual conditions are given in Table 9. Reaction time for each field test was recorded as the average reaction time measured throughout a given field test, this ranged from between 46 and 86 responses dependent upon the examination and subject (the longer the examination the higher the number of reaction time measures). Average visual field sensitivity for all 19 measured locations was calculated for each examination and given as a mean sensitivity. A two-way ANOVA demonstrated significant differences between visual conditions and mean reaction times (df 3, 54; F 425.31; $p < 0.001$) and mean perimetric sensitivity (df 3, 54; F 425.31; $p < 0.001$). Binocular sensitivity was significantly higher in the inferior field relative to the superior at 30°, 45° and 60° ($p < 0.05$) and in the left field relative to the right at 75° ($p < 0.05$).

The finding that simulated cataracts reduced sensitivity uniformly across the field is in accord with previous reports on the effect of true cataracts on visual fields measured with the static perimeters such as the HFA (Wood et al 1989). Restriction of the visual fields using the simulating goggles limited the horizontal extent of the binocular divided attention field to around 90°, whilst monocularly reduced the horizontal extent of the visual fields but had little impact of the level of sensitivity across the field.

Central reaction times measured during assessment of peripheral sensitivity were significantly affected by visual condition, being worse (increased reaction times) for the monocular condition. The reason for this is unclear, but may arise because the probability of detecting a stimulus is higher if viewed with two eyes rather than one, due to the phenomenon of binocular summation. For visual field sensitivity, binocular summation has a magnitude of $\sqrt{2}$ (Wood et al 1991). The finding that central reaction times for the restricted field and baseline conditions were not significantly different is not unexpected. Fewer peripheral targets were visible for the restricted fields

condition which reduced the extent of the divided attention task, allowing the subject to concentrate more on the central task. For cataracts, as for the reaction time task in the driving assessment, the relatively bright LED targets were scattered thus artificially enhancing their visibility.

Pelli-Robson letter contrast sensitivity

Simulated visual impairment significantly decreased letter contrast sensitivity as measured with the Pelli-Robson chart, where cataracts had the greatest effect and monocular vision the least. Two-way ANOVA demonstrated that visual impairment significantly reduced the scores for the Pelli-Robson chart (df, 3, 54; 19.674; $p < 0.001$). Post hoc analysis showed that these differences were significant between the cataract condition and all other visual conditions tested.

The sensitivity of the Pelli-Robson scores to the cataract simulation is in accord with previous studies which have demonstrated that tests employing low contrast letters differentiate better between patients with cataracts and age-matched normal subjects than tests of high contrast acuity (Elliot et al 1991). Good correlations were demonstrated between the overall driving score and Pelli-Robson letter acuity and thus this test may offer promise as a predictor of driving performance.

Correlation between driving performance & visual function

The relationship between driving performance and visual function was examined by using correlation

analysis. Significant correlations were demonstrated between driving score and letter contrast sensitivity ($p < 0.05$) and the UFOV at the high demand condition ($p < 0.2$). No correlation was found between the other driving scores and visual function. The divided attention visual fields did not reflect changes in driving performance as well as the high demand UFOV task, but exhibited similar correlations to the UFOV for low demand conditions. This is likely to arise because in these tests the peripheral targets are presented against an empty field, whereas in the driving situation, relevant targets appear against a background of clutter or irrelevant objects.

Monocular vision

The results regarding the minimal effect of monocular vision on driving are contrary to previous studies which report that monocular drivers are involved in, and cause more accidents than age-matched normal drivers. Kite and King (1961) found a seven fold increase in intersection crashes and pedestrian injuries for monocular drivers, and Liesmaa (1973) observed that there were three times as many monocular drivers in a group considered to be driving dangerously compared to a group whose driving was considered to be safe. Keeney (1968) reported that the incidence of monocular vision in a population of drivers cited for multiple driving violations was as high as 8%. Monocular blindness on the right side (as simulated in this study) has been also reported to have more serious consequences for driving than that on the left (Keeney 1968). Conversely, Johnson and Keltner (1983) reported

that there were no significant difference in the accident and conviction rates for drivers with monocular visual field loss as compared to a normal control group. More confidence may be placed upon the latter study since it used accurate and reliable methods of visual field assessment, unlike many of the earlier studies. The results of our study, demonstrated that monocular drivers are not significantly worse than visually normal drivers for any of the driving tasks investigated. Further, since it is acknowledged that artificial deterioration of the visual field (without adaptation) would be more traumatic than visual restriction from birth or when adapted to over a period of time, we suggest that the results reported here represent the worse possible detriment to driving capacity arising from monocular vision.

Binocular visual field restriction

Constriction of the binocular visual field to a diameter of 90° reduced many aspects of driving performance, resulting in slower and more inaccurate driving performance. It was not until the field was restricted to smaller than 40° , however, as demonstrated in a previous study (Wood and Troutbeck 1992), that any of the aspects of driving were depressed to a significant level as compared to baseline. This concurs with the findings of Fishman et al (1981), who compared the driving records of a group of retinitis pigmentosa patients to those of age-matched normals. They reported no differences between the two groups, apart from a subgroup of five female subjects who had abnormally high and unexplained accident rates. Indeed, Burg (1967) in reported that there was no increase in accident rate

with constriction of the visual field and Council & Allen (1974) found no difference in accident rates between patients with binocular visual fields smaller than 140° and those with visual fields larger than 160° .

Cataracts

Reduction of contrast levels and increase in glare sensitivity induced by the cataract simulations resulted in the greatest decrement in driving performance, despite the fact that all subjects satisfied the visual requirements for a driving licence. In support of these findings for cataract simulations, the three subjects with true cataracts tested so far had poorer driving performance as compared to the age-matched normal controls. The decrease in driving performance recorded for simulated and true cataracts was greatest when subjects were driving into the sun, particularly in the late afternoon. These results have very important implications in terms of road safety, since all elderly people have some degree of cataract as part of the age-related process, yet the cataract must be relatively advanced to reduce visual acuity below the level required for eligibility for driving. These studies are supported by the fact that one of the most common complaints of the elderly in general and particularly those with cataracts, are poor vision for night-time driving and being almost blinded by sunlight (Nadler et al 1982; Cooper 1990). Whether patients with cataracts have higher accident rates, or whether accidents occur more frequently at times of increased glare, such as in the late afternoon, has yet to be investigated.

The results of this study provide evidence that visual impairment has a direct impact on driving performance. Interestingly, for many of the driving measures subjects compensated for artificial visual impairment by driving more slowly rather than making more errors. The impact of including the visually impaired on the roads may therefore to reduce traffic flow, but possibly not incur a greater number of accidents and may explain why little correlation has been found between visual restriction and accident rates.

Clearly, imposition of visual restrictions without adaptation is an artificial situation and would produce a greater impairment to performance than for a person whose visual impairment has developed slowly and to which they will have adapted to some extent. The study was conducted in this way without adaptation to examine the worse possible effect that visual impairment could impose on driving performance and to isolate the effect of visual restriction on driving performance in the absence of contaminating factors. The results from the subjects with true visual impairment did, however, support the findings for the subjects with simulated visual impairment, where driving performance was significantly worse than that of age-matched normal drivers, even though all the participants had a current driving license.

It is likely that each patient compensates for visual impairment in an individual manner which may or may not result in a detriment to road safety, or alternatively limits driving frequency to a level commensurate with their perception of their own driving ability. Indeed, Retchin et al (1988) found

that in a population of elderly subjects, there was a significant correlation between the extent of the horizontal peripheral field and the frequency of driving; subjects with restriction of the horizontal peripheral field tended to drive only infrequently. A possible solution to the problem of determining whether a person applying for reregistration for driver license is eligible may be to assess performance on a selection of visual tasks. This would provide an index of compensation to visual compromise and its effect on driving performance. Tests of visual function such as low contrast letter sensitivity and the UFOV under high levels of demand may be suitable, as these were shown to better predict driving performance than conventional high contrast visual acuity measures. The fact that these tests are both rapid and easily understood by the subject, indicates their potential for inclusion in such a testing battery.

Alternatively, if it is accepted that the road system should cater for the population of drivers it may considered inappropriate to restrict some users because of a visual impairment which could reasonably be expected to exist in the driving population. Drivers need to be able to see and understand signs and also be able to apply a reasonable level of car control. On the other hand, it would be unreasonable for traffic engineers to expect all drivers to have above average vision and above average driving ability. Traffic engineers tend to cater for drivers with lower levels of performance by:

- increasing the number of signs,
- reducing the demands on drivers,
- reducing the conflicts a driver must resolve,
- increasing the information given to drivers,
- increasing the time between successive conflicts.

If the driving population was to change (as predicted for our aging population) then there may be considerably more drivers with these adverse driving characteristics which would have to be accommodated by changing the road design parameters in this manner.

Conclusions

Visual impairment was shown to compromise certain aspects of driving performance as assessed on a driving course. If the population were to develop an increased frequency of visual impairment, as would be predicted in an aging population, the results will be most relevant to road design and road traffic safety. This indicates a need for more definitive research on the inter-relationship between visual performance and the performance of the road system. The results from this study provide a basis for further investigations which will include larger numbers of subjects from all age groups, both those with visual impairment resulting from eye disease, as well as those with simulated visual impairment.

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References

- Australian Bureau of Statistics. Projections of the populations of Australia, States and Territories 1987 to 2031. Catalogue No. 3222.0, 1988.
- Avolio BJ, Kroeck KB, Panek PE. Individual differences in information-processing ability as a predictor of motor vehicle accidents. *Human Factors* 27: 577-588, 1986.
- Bailey IL, Sheedy J. Impaired vision and driving. In: *The International Conference on Low Vision, 1990. Low Vision Ahead II*. Johnston AW, Lawrence M. (eds) pp. 279-281, 1990.
- Ball KK, Beard BL, Miller RL, Roenker DL. Mapping the useful field of view as a function of age. *Gerontologist* 27: 166A, 1987.
- Brandt T, Dichans J, Keonig E. Differential effects of central versus peripheral vision on egocentric and exocentric motion perception. *Exp Brain Res* 16, 476-491, 1973.
- Burg A. The relationship between vision test scores and driving record. General findings. Report No. 67-24. Los Angeles, UCLA, Department of Engineering, 1967.
- Burg A. The relationship between vision test scores and driving record. Additional findings. Report No. 68-27. Los Angeles, UCLA, Department of Engineering, 1968.
- Buyck A, Missotten L, Maes MJ, Van de Voorde H. Assessment of the driving behaviour of visually handicapped persons. In: *Vision in Vehicles II*. Gale AG, Freeman MH, Haslegrave CM, Smith P, Taylor SP (eds) Holland: Elsevier Science Publishers BV, 1988 pp 131-142.
- Carman PD, Brown H. Brightness of fine detail in ground photography. *J Opt Soc Am* 49: 629-636, 1959.
- Cavallo V, Laya O, Laurent M. The estimation of Time-to-Collision as a function of visual stimulation. In: *Vision in Vehicles I*. Gale AG, Freeman MH, Haslegrave CM, Smith P, Taylor SP (eds), Elsevier Science Publishers BV, Holland, 179-183, 1986.
- Ceralla J. Age-related decline in extrafoveal letter perception. *J Geront* 40: 727-736, 1985.
- Cole DG. Follow-up investigation of the visual fields and accident experience among North Carolina drivers. University of North Carolina, Highway Safety Research Center, Chapel Hill, North Carolina, 1979.
- Cooper PJ. Elderly drivers' views of self and driving in relation to the evidence of accident data. *J Saf Res* 21: 103-113, 1990.
- Council FM, Allen JA. A study of the visual fields of North Carolina drivers and their relationship to accidents. Chapel Hill, University of North Carolina, Highway Research Safety Centre, 1974.
- Department of Transport (1992) Personal communication with Driver Licensing Centre, Brisbane.
- Elliott DB, Hurst MA, Weatherill J. Comparing clinical tests of visual loss in cataract patients using a quantification of forward light scatter. *Eye* 5: 601-606, 1991.
- Evans L. Speed estimation from a moving automobile. *Ergonomics* 13: 219-230, 1970.
- Fishman GA, Anderson RJ, Stinson L, Haque A. Driving performance of retinitis pigmentosa patients. *Br J Ophthalmol* 65: 122-126, 1981.
- Fonda G. Legal blindness can be compatible with safe driving. *Ophthalmology* 96: 1457-1459, 1989.
- Gibson JJ. Visual perception of objective and subjective movement. *Psychol Rev* 61: 304-314, 1954.

- Gibson JJ. What gives rise to the perception of motion? *Psychol Rev* 75: 335-346, 1968.
- Gordon DA. Perceptual basis of vehicular guidance. *Public Road* 34: 53-68, 1966.
- Groeger JA, Brown ID. Motion perception is not direct with indirect viewing systems. In: *Vision in Vehicles II*. Gale AG, Freeman MH, Haslegrave CM, Smith P, Taylor SP (eds) Elsevier Science Publishers BV, Holland, 27-34, 1988.
- Hills BL. Vision, mobility and perception in driving. *Perception* 9: 183-216, 1980.
- Hirsch RP, Nadler MP, Miller D. Glare measurement as a predictor of outdoor vision among cataract patients. *Ann Ophthalmol* 16: 965-968, 1984.
- Interrante J. The road to autopia: The automobile and the spatial transformation of American culture, In: Lewis DL, Goldstein L (eds): *The Automobile and American Culture*, Ann Arbor, The University of Michigan Press, 89, 1986.
- Johnson CA, Keltner JL. Incidence of visual field loss in 20,000 eyes and its relationship to driving performance. *Arch Ophthalmol* 101: 371-375, 1983.
- Kahneman D, Ben-Ishai R, Lotan M. Relation of a test of divided attention to road accidents. *J Appl Psychol* 58: 113-115, 1973.
- Keeney AH. Relationship of ocular pathology and driving impairment. *Trans Am Acad Ophthalmol Otolaryngol* 72: 737-740, 1968.
- Keeney AH, Garvey J. The dilemma of the monocular driver. *Am J Ophthalmol* 91: 801-802, 1981.
- Kite CR, King JN A survey of the factors limiting the visual fields of motor vehicle drivers in relation to minimum visual fields and visibility standards. *Br J Physiol Opt* 18: 85-107, 1961.
- Lewis CF, Blakeley WR, Swaroop R, Masters RL, McMurty TC. Landing performance by low-time private pilots after the sudden loss of binocular vision - Cyclops II. *Aerospace Medicine* 44: 1241-1245, 1973.
- Kosnik W, Winslow L, Kline D, Rasinski K, Sekuler R. Visual changes in daily life throughout adulthood. *J Gerontol* 43: 63-70, 1988.
- Liesmaa M. The influence of a drivers vision in relation to his driving. *Optician* 166: 10-13, 1973.
- Lovsund P, Hedin A. Effects on driving performance of visual field defects. In: *Vision in Vehicles I*. Gale AG, Freeman MH, Haslegrave CM, Smith P, Taylor SP (eds): Elsevier Science Publishers BV, Holland, 323-329, 1986.
- Moskowitz H. Effects of alcohol on peripheral vision as a function of attention. *Human Factors* 16: 174-180, 1974.
- Nadler MP, Miller D, LeClaire J. Glare: The problem, the implications, In: Emery JM, Jackson AC (eds): *Current concepts in cataract surgery. Selected Proceedings of the Seventh Biennial Cataract Surgical Congress*. New York, Appleton-Century-Crofts, 263-264, 1982.
- Ohta H, Komatsu H. Speed perception in driving - comparison with TV observation. In: *Vision in Vehicles III*. Gale AG, Freeman MH, Haslegrave CM, Smith P, Taylor SP (eds) Holland: Elsevier Science Publishers BV, 415-426, 1991.
- Osaka N. Speed estimation through restricted visual field during driving in day and night: naso-temporal hemifield differences. In: *Vision in Vehicles II*. Gale AG, Freeman MH, Haslegrave CM, Smith P, Taylor SP. (eds) Elsevier Science Publishers BV, Holland pp. 45-55, 1988.
- Pelli DG, Robson JG, Wilkins AJ. The design of a

- new letter chart measuring contrast sensitivity. *Clin Vis Sci* 2: 187-199, 1988.
- Podgor MJ, Leske MC, Ederer F. Incidence estimates for lens changes, macular changes, open-angle glaucoma and diabetic retinopathy. *Am J Epidemiol* 118: 206-212, 1983.
- Retchin SM, Cox J, Fox M, Irwin L. Performance-based measurements among elderly drivers and nondrivers. *J Am Ger Soc* 36: 813-819, 1988.
- Robinson GH, Desai SD. Control of attention as a function of risk and risk preference. In: *Psychological Aspects of Driver Behavior*, SWOV Institute for Road Safety Research, Versburg, The Netherlands, 1971.
- Sanders AF. Some aspects of the selective process in the functional field of view. *Ergonomics* 13: 101-117, 1970.
- Sekuler R, Ball K. Visual localization: age and practice. *J Opt Soc Am A* 3, 864-867, 1986.
- Shiffrin RM, Schneider W. Controlled and automatic human information processing: II. Perceptual learning, automatic attending, and a general theory. *Psychol Rev* 84: 127-190, 1977.
- Sloane ME, Owsley, C, Ball K. Visual correlates of vehicle accidents in older drivers. In *Non-invasive Assessment of the Visual System, Technical Digest* 1991. Optical Society of America, Washington DC. Vol 1: 50-53, 1991.
- Walker J, Sedney CA, Mast TM. Older drivers and useful field of view in a part-task simulator. Transportation Research Board. 71st meeting, Jan 1992, Washington DC: 1992.
- Wood JM, Troutbeck R. The effect of restriction of the binocular visual field on driving performance. *Ophthal Physiol Optics*, In press.
- Wood JM, Collins MJ, Carkeet A. Regional variations in binocular summation across the visual field. *Ophthal Physiol Opt* 12: 46-51, 1992.
- Wood JM, Wild JM, Hussey MK, Crews SJ. Serial examination of the normal visual field using Octopus automated projection perimetry: evidence for a learning effect. *Acta Ophthalmol* 65: 326-333, 1987.
- Wood JM, Wild JM, Smerdon DL, Crews SJ. Alterations in the shape of the automated perimetric profile arising from cataract. *Graefes Arch Clin Exp Ophthalmol* 227: 157-161, 1989.