

ELDERLY DRIVERS AND VISUAL IMPAIRMENT

Joanne M Wood\* and Rod Troutbeck#

\*Centre for Eye Research

#Physical infrastructure Centre

A Report to the  
Federal Office of Road Safety  
on the

**ELDERLY DRIVERS AND VISUAL IMPAIRMENT**

Joanne M Wood\* and Rod Troutbeck#

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

June 1993

## SUMMARY

Older drivers comprise the fastest growing sector of the driving population and have been reported to have more traffic convictions and accidents per kilometre driven than any other age group. Although studies have indicated that the skills required for safe driving begin to decline at age 55 years and above, it is not known which particular aspects of driver behaviour contribute to the increased accident involvement of the elderly. The deterioration in vision through both age-related changes and eye disease has been implicated as an important factor because vision comprises the major sensory input for driving.

The aim of this study was to investigate how visual impairment affects the driving performance of elderly drivers and whether these changes can be predicted by vision tests undertaken in the clinic. We also wished to compare the driving and vision performance of the elderly drivers in this study with that measured for young drivers in a previous study (Wood and Troutbeck FORS 1992).

### **Assessment of Driving - Field Studies**

Visual impairment was simulated for a group of elderly normal subjects. The subjects wore goggles designed to simulate the effects of cataracts, visual field restriction and monocular vision. Due to the imposed visual impairments, driving performance could only safely be assessed on a closed road circuit which was free of other road users. Driving performance was assessed by measuring peripheral awareness, manoeuvring, reversing, reaction times, speed estimation, road positioning and time to complete the course. These measures were also undertaken on a group of elderly persons with a range of levels of cataract and compared to a group of elderly normal subjects.

### **Assessment of Driving - Questionnaire studies**

Following completion of the field-based driving assessment, subjects completed a questionnaire of their own perception of their driving performance under the three conditions of visual impairment relative to the baseline condition.

### **Clinical Vision Testing**

Visual performance was assessed by measuring peripheral visual function using two techniques: 1) a conventional perimetric technique with the incorporation of a central task and by 2) measuring functional visual fields where foveal load was variable and the peripheral task included visual search and localisation within a cluttered background, known as the Useful Field of View (UFOV). Central visual function was measured using the Pelli-Robson Letter contrast sensitivity (CS) chart and disability glare.

**Findings**

Visual impairment significantly decreased driving performance, even though all drivers satisfied the visual requirements for driving licensure. Simulated cataracts caused the greatest detriment to driving performance followed by binocular field restriction. The monocular condition did not significantly affect driving performance for any of the driving tasks assessed. Visual impairment significantly decreased the extent of the functional visual fields and reduced low contrast letter acuity. These results were supported by the findings for the subjects with true cataracts, whose driving and visual performance were reduced compared to a group of age-matched normal subjects.

Comparison of the performance of the elderly subjects in this study with a group of young subjects measured previously (Wood and Troutbeck FORS 1992), indicated that the elderly drivers had significantly longer reaction times and poorer performance on the UFOV task than the young subjects.

**Implications**

The results demonstrate that the elderly find it more difficult to find information in a cluttered view than do young drivers, furthermore, those drivers with cataracts find it more difficult again. This has important implications for the design and location of road signs. Drivers are expected to locate signs, read the message and act on the information with only a few car lengths, this is a difficult enough task for any driver, let alone the elderly or those with cataracts.

These changes are exacerbated by the fact that the elderly have slower reaction times. In the study we found that the reaction times of the elderly drivers were significantly longer than for the young drivers and it was calculated that the sight distances would be increased by 2.9s of travel. These distances might mean the difference between seeing and not seeing a child or another car at an intersection. It can thus be seen that the elderly driver is at risk or puts other road users at risk. Tragically, because driver's abilities and performance change gradually, they may not be able to detect that their performance has been significantly degraded until an incident occurs or until they are advised. Simple traffic engineering measures for improving driving performance are also discussed.

## INTRODUCTION

The community is aging; long term projections estimate a 100% increase in people aged 65 years and over by 2021 (ABS 1988). This new generation of elderly persons consider driving a right rather than a privilege and are likely continue to drive well into old age resulting in a significant increase in the number of older road users. This is of importance as older drivers have more traffic convictions and accidents per kilometre driven than any other age group (Keltner and Johnson 1987) and are involved in a disproportionate number of accidents involving intersections, right turns, failure to yield, stop signs and inattention and are more frequently cited as being at fault (eg. Waller 1988). Road users of 60 years or more have nearly a one and a half times greater chance of being killed in a road accident than adults aged 30 to 59 years and on a per capita basis (fatalities/10,000 population), the older group has a fatality rate of 17 per 10,000 population compared to 12 per 10,000 for the younger group in 1989 (ABS 1992). This highlights road users aged 60 years and above as a high risk group in terms of road safety.

A number of studies have investigated specific aspects of driving performance in old subjects and these have suggested that elderly drivers have slower reaction times (Korteling 1990), less accurate platoon car following (Korteling 1990) and poorer merging behaviour at junctions (Wolffelaar et al 1991) than young drivers. However, there are a number of methodological problems associated with these studies. Most have been undertaken using laboratory simulations of driving or at isolated road sites which do not represent the complexity of the driving task. Other studies have derived self-reported information on elderly drivers by questionnaire-based measures and show that elderly drivers have problems with a number of driving tasks including changing lanes, intersections, night-time driving, other vehicles appearing unexpectedly, and reading signs (Kosnik et al 1990; Kline et al 1992).

Since driving is a highly visual task, it has been suggested that the increased accident rate of the elderly may arise, in part, from age-related changes in vision. These include loss of elasticity, yellowing and loss of transparency of the crystalline lens through the development of light scatter. At the same time the pupil becomes smaller and loses its ability to dilate in dim light. These changes are exacerbated by changes in macular pigment and the neural pathways producing increases in glare sensitivity and decreases in light sensitivity, visual acuity and dark adaptation. In addition, the incidence of visual impairment arising from eye disease increases significantly in elderly populations, with cataracts, macular degeneration and glaucoma representing the leading causes of visual impairment in elderly populations (Podgor et al 1983).

Eligibility for driving is restricted by a visual requirement of binocular visual acuity of 6/12 or better which must be satisfied on an annual basis and accompanied by medical certification of

good general health after the age of 70 or 75 years in all Australian States except Victoria and the Northern Territory (FORS 1990). Though some studies support a relationship between vision and driving there is no strong evidence to suggest that increased accident rates result from reduced vision. Modest correlations have been demonstrated between accident rates and visual measures such as binocular visual acuity under normal (eg. Hofstetter 1976) and dim (eg. Shinar 1977) illumination, dynamic acuity (eg. Burg 1967;), motion detection thresholds (Henderson and Burg 1974) and binocular visual fields (eg. Johnson and Keltner 1983) whilst other studies have reported little or no correlation between accident rates and visual acuity (eg. Buyck et al 1988) or visual fields (eg. Cole 1979). There are a number of reasons for the inconsistency of these findings. These include the use of self-reported accident frequency as a measure of driving performance and the selection of independent variables consisting of tests of visual sensory function such as visual acuity and visual field sensitivity which do not reflect the complexity of the driving task.

Alternatively, it may be that the increase in elderly drivers will not compromise road safety, since aging drivers are commonly believed to reduce their driving frequency. However, Jette and Branch (1992) in a recent longitudinal study demonstrated that older drivers continue to drive as long as possible and resist change to their preferred mode of travel. Self regulation could be more efficient if older drivers were made aware of some of their abilities which were impaired and relevant to driving performance. Owsley et al (1991) found that drivers who had been informed by their eye care specialist of eye problems such as cataracts, tended to avoid difficult driving situations, however those individuals with a similar level of visual impairment who had not been informed, did not appear to modify driving behaviour. Thus being informed of a visual impairment can be a persuasive means to achieve self-regulation, highlighting the need for studies to determine the effect of visual impairment on driving performance.

In previous studies, supported by Federal Office of Road Safety (FORS) Seeding Grants for 1991-1992, we investigated the relationship between vision and driving in young drivers (Wood and Troutbeck FORS 1992). In these studies we measured the effect of simulated visual impairment on the driving performance of normal subjects, so that factors other than vision known to have an influence on driving performance, such as experience and higher level of risk taking, were constant for all conditions. We also overcame some of the problems of previous research by assessing driving performance on a closed road circuit. The results of these studies indicated that simulated cataracts followed by simulated visual field restriction significantly reduced driving performance, despite the fact that all subjects satisfied the visual requirements for driving. The decrement in driving performance with simulated cataract was greatest when the subjects were driving into the sun, particularly in the late afternoon. Drivers with simulated

monocular vision were not significantly worse than for the baseline condition in agreement with recent studies on monocular drivers (Edwards and Schachat 1991; McKnight et al 1991).

The implications of these findings with regard to elderly drivers are far reaching because the elderly have some degree of cataract (opacification of the crystalline lens) as part of the normal age-related process. The degree of cataract must be quite severe, however, to reduce visual acuity below that required to satisfy driving license standards.

The overall aims of our studies is to test the hypothesis that age-related changes in visual function contribute to the alleged decrement in driving performance in elderly drivers. In this project the specific aim was to determine which types of visual impairment cause the greatest detriment to driving in the elderly and identify those tests of visual function which can best predict driving performance. In the first stage, the effect of simulated visual impairment on the driving and visual performance of elderly 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 arising from cataracts. In the third stage, we compared the driving and visual performance of the elderly drivers to that of the young drivers reported in a previous study (Wood and Troutbeck FORS 1992).

## SUBJECTS

### *Stage 1: Normal Subjects - simulated visual impairment*

Twenty normal elderly subjects were recruited for participation in the study, of mean age 64.5 years, (SD 5.2 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 license.

### *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).

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 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 empty 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.

### *Stage 2: Visually Impaired Subjects*

Twenty elderly subjects with varying degrees of cataract were recruited for inclusion in the study, however, two persons were unable to complete all parts of the study. A summary of the subject characteristics are given in Table 1.

Subject	Age	Sex	Ocular characteristics
1	71	F	Lenticular opacities R & L
2	75	M	Small lenticular opacities R > L
3	71	M	Cortical lenticular opacities R & L
4	65	F	Slight lenticular haze R & L
5	71	F	R wedge-shaped lenticular opacities; L cortical lenticular opacities
6	78	M	Lenticular dot opacities L > R
7	61	M	R lenticular haze; L post subcapsular lenticular opacities
8	69	M	Nuclear sclerosis R & L
9	65	F	Central spoke lenticular opacities R & L
10	51	M	Nuclear lenticular opacities R & L
11	77	M	Early lenticular opacities R & L
12	69	M	Vitreous opacities L>R
13	65	M	Early media opacities R & L
14	68	F	Early lenticular haze R & L
15	69	M	Early lenticular opacities R & L
16	73	M	Diffuse nuclear sclerosis R & L
17	71	F	Early lenticular opacities R & L
18	66	F	Hazy media R & L

TABLE 1. Characteristics of the subjects with cataracts



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. The degree of cataract was graded using a slitlamp microscope and confirmed by the subjects performance on a low contrast letter chart.

## METHODS

### Assessment of driving performance

#### Field Studies

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 (Figure 1). The nature of the visual impairments necessitated that, in the interests of safety, the circuit was free of other vehicles. The aspects of driving performance measured included peripheral awareness, manoeuvring, reversing, reaction times, speed estimation, road position and time to complete the circuit.



FIGURE 1. Schematic representation of the closed circuit driving course

***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 at 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 on the windscreen 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, whilst the view of the speedometer was obscured from the driver. The mean speed driven during that period 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.

***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 the 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 5s 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. A number of different arrangements of cones were trialled to determine the optimum arrangement whereby the level of difficulty 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 a time in seconds with a 1s penalty for each error.

### ***Car***

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 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.

### ***Procedure***

The normal subjects with simulated visual impairment 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.

The subjects with true visual impairment and the age-matched controls were only required to drive around the circuit twice (each circuit took between 3 and 5 minutes to complete). Both runs were driven in a clockwise direction. The first run was to familiarise the subjects with the car and the driving skills to be tested and 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) and the second was the recorded run.

### **Questionnaire-based assessment**

Following completion of the field-based assessment of driving performance subjects were given a questionnaire to determine their own perception of their driving performance. The questionnaire comprised nine questions on driving performance under the four visual conditions (see Appendix 1). The questions were designed to obtain a subjective rating of the degree of driving difficulty induced by visual impairment. These included both general questions on their overall perception of driving performance for a given condition, as well as for the specific driving tasks that subjects were required to perform during the assessment.

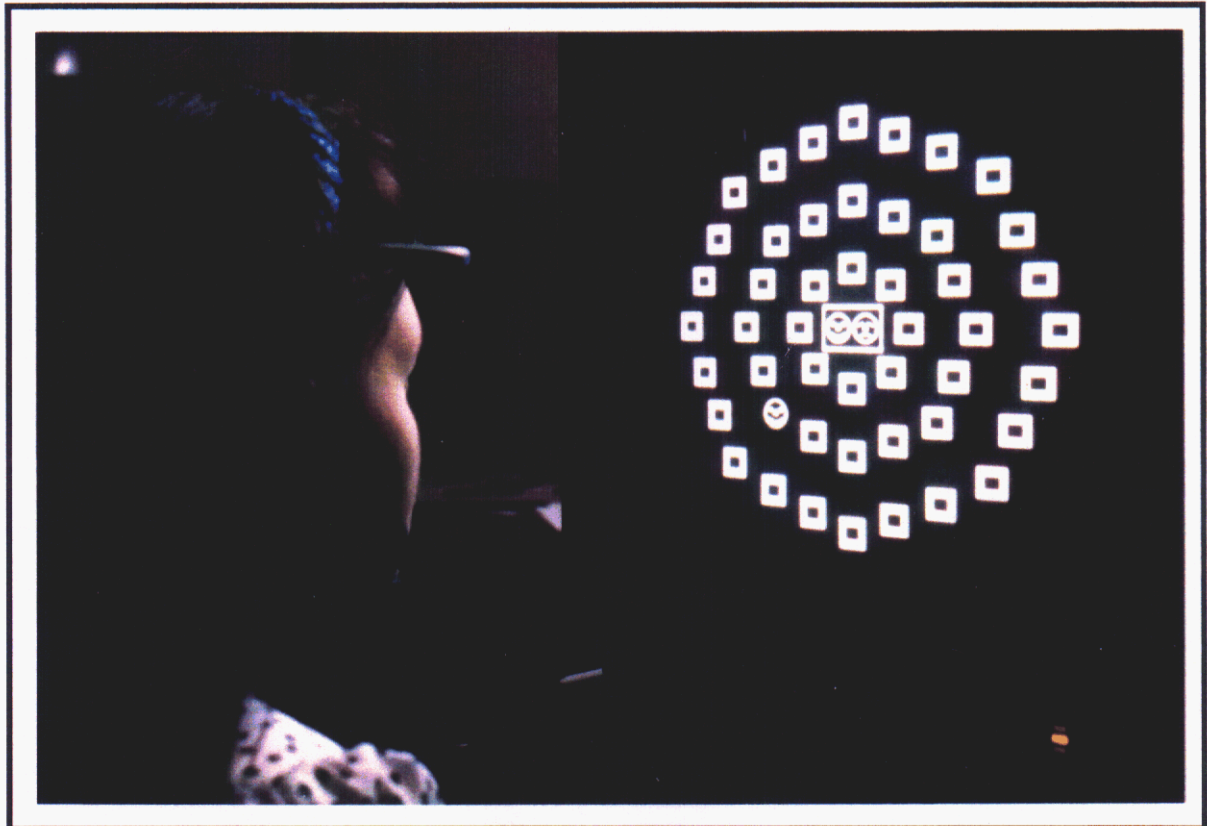
### **Assessment of visual function**

A battery of tests of visual function were employed in order to determine which tests best predict driving performance. Functional visual field tests were selected as previous studies have demonstrated significant correlations between scores on functional visual field tests involving peripheral search within cluttered arrays and accident rates (Avolio et al 1986; Sloane et al 1991). A test of letter contrast sensitivity, which employs low contrast letters was also 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 (UFOV)***

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 measured localisation of targets in the periphery when targets were either embedded presented against an empty field or within within a distractor array.

A large screen (Sony, Trinitron) which subtended  $56^\circ$  by  $51^\circ$  at the working distance of 28 cm was employed for display of the targets. Targets comprised cartoon faces which were either smiling or frowning and subtended  $4^\circ$  by  $3.5^\circ$ . Cartoon faces were presented centrally and in a given peripheral location for a duration of 90ms (Figure 2).



**FIGURE 2.** The Useful Field of View Test where the subject has to discriminate the central characters and locate the peripheral target within the distractor array.

There were two levels of difficulty for the central task. For the easier, or low demand condition, the central target 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  $8^\circ$ ,  $17^\circ$  and  $26^\circ$ . The distractor stimuli comprise outline boxes of the same size and luminance as the targets. Two levels of difficulty were available for the peripheral task. The easier level comprised presentation of the cartoon face targets 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 condition.

For a given trial, four consecutive displays were presented on the screen. The first display was of the central outline box which directed the observers attention centrally. This was followed by the appearance of the target 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 target. For each of the four visual conditions, subjects were tested at the low and high levels of difficulty. The results were given as the 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 such as this, have been used extensively in previous studies of the effect of alcohol on driving performance (Moskowitz 1974).

The divided attention functional visual field test was undertaken using a standard static automated perimeter, the Humphrey Field Analyser (HFA), which was adapted for this purpose. Subjects were required to respond to the 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 pseudo-random extinguishing of the LED and the response button reactivated 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 field 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.

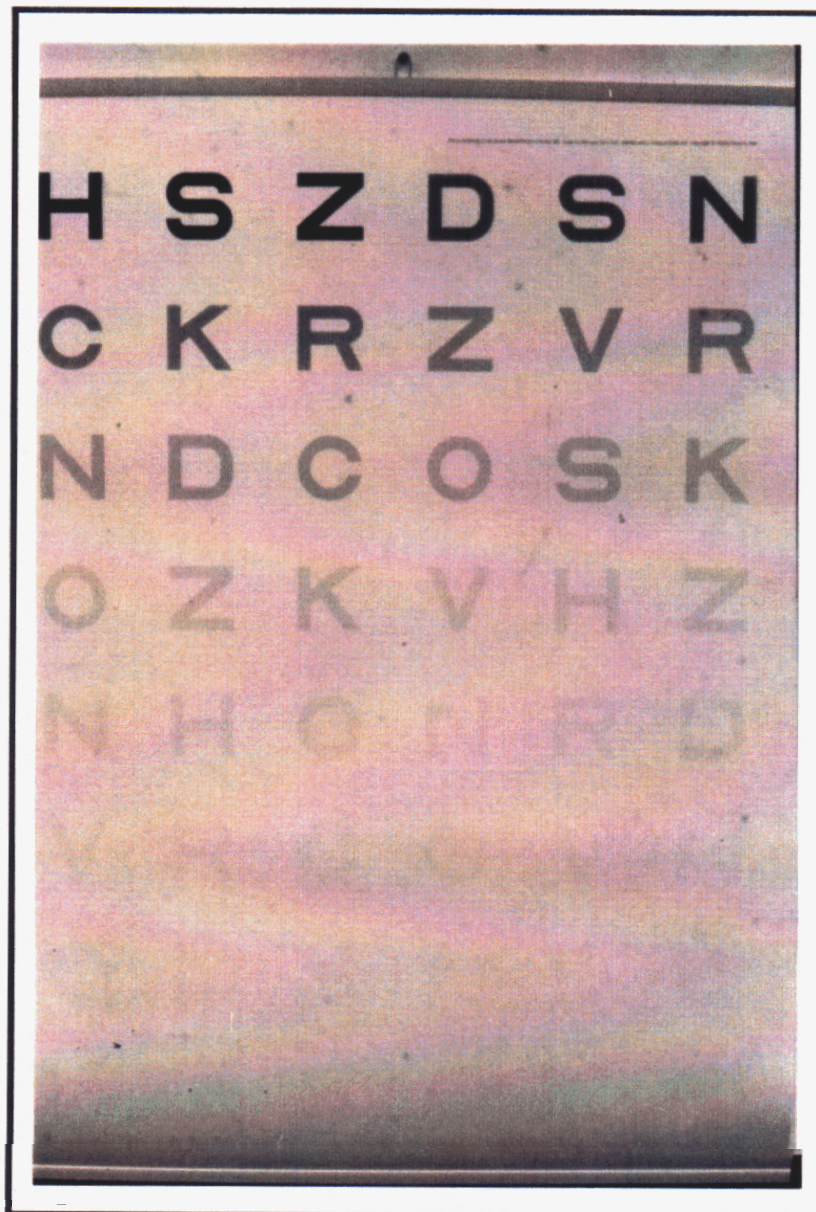
All measures were undertaken binocularly. Subjects had two response buttons (one in each hand) and were instructed to respond to the peripherally presented spot targets by pressing the perimetry button, whilst maintaining illumination of the central LED target by pressing the LED response button whenever the fixation light flashed off. The subjects were instructed that the relative importance of the two tasks was equal and to concentrate on both.



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

*Pelli-Robson letter contrast sensitivity chart*

A measure of low contrast letter sensitivity was determined using the Pelli-Robson letter contrast sensitivity (CS) chart as described by Pelli et al (1988) and shown in Figure 3.



**FIGURE 3.** The Pelli-Robson Letter Contrast Sensitivity Chart

The chart 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.

### *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.

### *Subjects with visual impairment*

For the subjects with true visual impairment and the age-matched control subjects in stage 2, we were able to include a more extensive testing battery of vision and vision-related tests, as subjects only had to complete each test once, whereas the simulation subjects had to complete each test four times (once for each visual condition). We were thus able to include a test of disability glare and a reaction time task, in addition to the other tests.

A test of disability glare was included as it is well established that tests of glare sensitivity more accurately reflect the functional decrement suffered by patients with cataracts than visual acuity measures (Hirsch et al 1984). A laboratory test of reaction times was included since a general slowing of information processing speed (Salthouse 1985) and an increase in reaction times (Korteling 1990) have been reported as part of the normal aging process.

### *Disability glare*

An index of disability glare was derived by taking the difference in visual acuity, measured for the low contrast chart, under the no-glare and glare conditions using the Berkeley Glare test (Bailey and Bullimore 1991). This consisted of a reduced low contrast Bailey-Lovie letter chart (Weber's contrast = 18%) mounted on a triangular opaque panel in the centre of a 30x27 cm opal Plexiglass panel at the medium setting (750cd/m<sup>2</sup>). Low contrast visual acuity was measured at 1 m with and without the glare source. Alternative charts were used to reduce the subject's familiarity with the letters and an adaptation period was provided between glare conditions to ensure that no carry-on effect from one condition to another occurred. Responses were scored as a Visual Acuity Rating (VAR) where VAR = 100 was equivalent to 6/6 visual acuity, with credit being given for each letter seen correctly (one point for each letter seen correctly).



### **Reaction Times**

Simple and forced choice reaction times were measured using a computer-generated laboratory technique. A series of eight outline boxes (the stimuli) was generated on the computer screen with a response panel on the keyboard, which comprised eight button presses each one corresponding to one of the stimulus boxes. On initiation of the program one of the boxes was illuminated at a randomly timed interval. When a given stimulus light was illuminated the subject was required to push any response button as quickly as possible for the simple reaction time task, and for the forced choice reaction time task subjects were required to press the corresponding response button as quickly as possible. For both the simple and the forced choice reaction time tasks the reaction time was automatically recorded in milliseconds by a simple timer device and for the forced choice task, an error rate was also recorded.

## **RESULTS**

### **Driving performance**

#### **Field studies**

The results demonstrate that imposing visual impairment on elderly normal subjects significantly affected their driving performance, despite the fact that they fulfilled the visual requirements for driving licensure. The mean scores for the group for each of the four visual conditions for each of the driving tasks, are given in Table 2.

	Baseline	Monocular	Cataract	Field Restriction
Driving Time	254.75 (7.27)	265.80 (6.37)	368.56 (39.74)	267.72 (6.41)
Driving Score	309.70 (8.91)	324.00 (14.98)	461.12 (47.93)	317.54 (9.53)
Manoeuvring Time	12.40 (0.99)	12.70 (1.25)	13.90 (0.94)	13.40 (1.00)
Manoeuvring Cones	4.20 (0.92)	5.30 (1.10)	5.50 (1.15)	4.70 (1.30)
Manoeuvring Score	16.60 (0.65)	18.00 (1.03)	19.40 (1.02)	18.10 (1.26)
Reversing Time	15.10 (1.75)	16.30 (1.64)	17.90 (1.77)	25.10 (1.98)
Reversing Angle	-1.12 (0.79)	-5.14 (2.19)	0.14 (1.97)	-0.20 (0.49)
Reversing Score	17.17 (1.48)	21.61 (3.25)	21.94 (2.40)	26.38 (2.13)
Peripheral Reaction Time	7.77 (1.20)	7.43 (1.17)	7.84 (1.17)	10.00 (0.00)
Central Reaction Time	4.15 (1.30)	4.43 (1.25)	4.38 (1.32)	6.74 (1.19)
Speed Estimation	68.00 (2.91)	68.50 (2.59)	61.00 (4.46)	64.20 (3.01)
Peripheral Sign Errors	7.59 (0.76)	7.84 (1.59)	15.24 (1.97)	8.36 (1.30)
Peripheral Person Errors	3.40 (1.19)	3.80 (0.88)	3.30 (0.78)	1.60 (0.60)
Peripheral Awareness Score	10.99 (1.23)	11.64 (2.07)	18.51 (1.91)	9.96 (1.02)
Road Position	69.98 (9.25)	95.33 (9.33)	46.97 (12.48)	73.70 (10.38)

**TABLE 2.** Group mean scores and standard errors for each of the visual conditions for the driving tasks.

A series of one way ANOVAs undertaken on SAS demonstrated that these differences in driving performance under the four visual conditions reached significance for all driving tasks except speed estimation and peripheral and central reaction times (Table 3).

Driving Task	DF	F value	p value
Driving time	3, 27	8	< 0.001
Driving score	3, 27	11.75	< 0.001
Manoeuvring time	3, 27	3.21	<0.05
Manoeuvring errors	3, 27	3.06	<0.05
Manoeuvring score	3, 27	2.96	<0.05
Reversing time	3, 27	9.54	< 0.001
Reversing angle	3, 27	3.04	<0.05
Reverse score	3, 27	14.37	< 0.00
Speed estimation	3, 27	1.51	NS
Peripheral reaction time	3, 27	1.82	NS
Central reaction time	3, 27	1.5	NS
Peripheral awareness	3, 27	3.65	< 0.05
Road position	3, 27	117.04	< 0.001

**TABLE 3.** Results of a series of one way ANOVAs for the effect of simulated visual impairment on driving scores.

Post hoc analysis showed that these differences were between cataracts and the other visual conditions, except for the reaction time and reversing tasks where the major differences were between visual field restriction and the other conditions. 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 and manoeuvring measures. In the speed estimation task, subjects drove faster than the required 60 km/h for baseline, driving progressively slower for monocular, visual field restriction and cataracts. In the reaction time task, reaction times were longest for the visual field restriction condition for both the central and peripherally presented LEDs, however, these differences were not significant, and in the reversing task, reversing time was longer for visual field restriction compared to the other conditions.

The results for the subjects with true cataracts were compared to those of the age-matched normal control group and are given in Table 4. This demonstrates that driving performance was poorer for the subjects with true cataracts compared to the age-matched normal controls for a number of the driving measures. Driving performance was significantly reduced in the subjects with cataracts for driving time (df 1, 26; F 10.942; p=0.0028), driving score (df 1, 26; F 6.588; p=0.017), manoeuvring time (df 1, 26; F 3.117; p=0.08) and manoeuvring errors (df 1, 26; F 3.11; p=0.09). Other aspects of driving performance were reduced in the subjects with cataracts compared to the age-matched normal subjects, but the differences did not reach significance.

Driving Task	Visual Condition	
	Cataracts	Age-matched normals
Driving time	284.12 (30.82)	246.64 (19.73)
Driving score	352.37 (50.91)	306.52 (21.85)
Peripheral awareness	13.65 (7.15)	11.97 (4.36)
Manoeuvring time	16.22 (4.42)	13.44 (2.19)
Manoeuvring errors	1.35 (1.35)	2.44 (1.74)
Manoeuvring score	17.5 (4.61)	15.89 (3.48)
Reversing time	21.56 (10.07)	18.78 (10.73)
Reversing angle	-2.40 (5.98)	0.44 (3.65)
Reverse score	24.56 (11.85)	21.72 (11.49)
Speed estimation	64.00 (7.88)	63.89 (8.94)
Peripheral reaction time	8.36 (2.68)	6.40 (3.65)
Central reaction time	5.98 (3.74)	7.22 (2.75)

**TABLE 4.** Group mean results for the driving performance measures for the subjects with cataracts compared to the age-matched control subjects.

### Questionnaire-based assessment

A one way ANOVA demonstrated significant differences in self-reported driving performance between the four conditions when rated by each of the subjects for all of the questions (Table 5).

Question	Driving Measure	F value	p value	Significant differences
1	Overall driving	134.26	0.0001	All sig diff
2	Anxiety	114.26	0.0001	All sig diff
3	Reaction time	11.31	0.0001	1-2, 1-3, 1-4
4	Peripheral awareness	29.98	0.0001	1-2, 1-3, 1-4, 2-3, 3-4
5	Road position	44.79	0.0001	1-2, 1-3, 1-4, 2-3, 3-4
6	Reversing	26.18	0.0001	1-2, 1-3, 1-4, 2-3, 3-4
7	Speed estimation	11.37	0.0001	1-2, 1-3, 1-4, 2-3, 3-4
8	Manoeuvring	37.45	0.0001	1-2, 1-3, 1-4, 2-3, 3-4
9	Depth perception	31.38	0.0001	1-2, 1-3, 1-4, 2-3, 3-4

**TABLE 5.** Results of a series of one way ANOVAs for the effect of simulated visual impairment on questionnaire-based assessment of driving performance.

In general, subjects rated their performance with the cataract simulation as being worse and that for the baseline condition as being the best. The questionnaires also gave subjects the opportunity to make additional comments and most noted that the difficulties with driving with the cataract simulation were exacerbated when driving into the sun.

### Visual performance

The results demonstrate that visual performance was significantly affected by visual impairment despite the fact that performance was not decreased below 6/12 for any of the visual conditions tested and therefore all subjects would have been eligible to drive with these impairments.

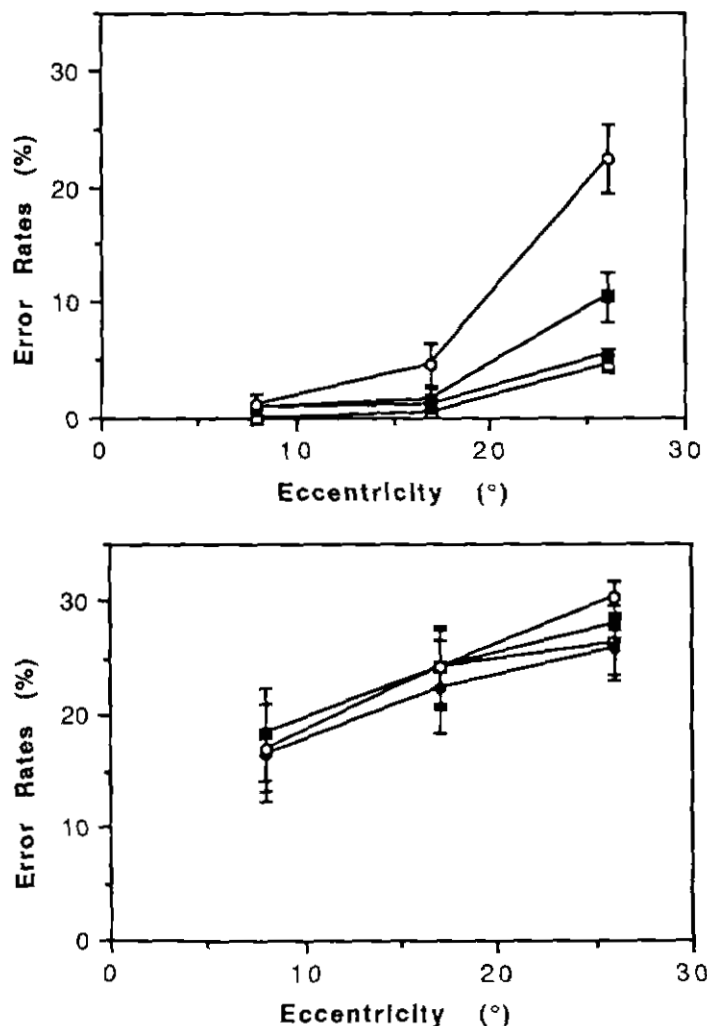
*Useful Field of View*

Performance on the UFOV was scored as the number of errors for each condition; central error scores are given in Table 6 for low and high demand levels for each of the visual conditions.

Error Scores	Baseline	Monocular	Cataract	Field Restriction
Low Demand	0.10 (0.10)	0.10 (0.10)	0.70 (0.21)	0.30 (0.21)
High Demand	4.80 (2.09)	5.70 (2.81)	13.00 (4.00)	7.20 (3.13)

**TABLE 6.** Mean central error scores and standard errors for the UFOV task for the four visual conditions.

The mean number of central errors increased with increasing demand and when measured for the simulated cataract condition. Mean peripheral errors are given as a function of eccentricity in Figure 4 for the low and high demand conditions.



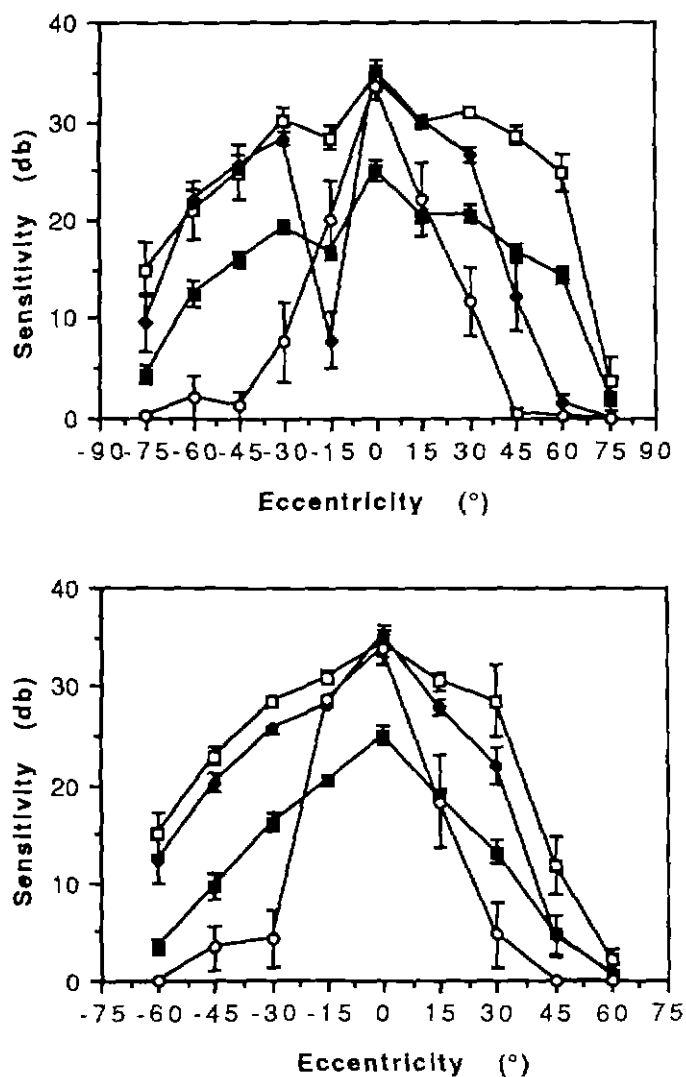
**FIGURE 4.** Group mean peripheral error rates for the UFOV as a function of eccentricity for baseline (open squares), monocular (filled diamonds), cataracts (filled squares) and field restriction (open circles) for low (upper graph) and high (lower graph) levels of demand..

The number of errors increased with eccentricity for all visual conditions for both levels of demand, in general the number of peripheral errors being highest for the field restriction, followed by cataracts, with the results for monocular and baseline being of similar magnitude.

The peripheral data for the UFOV was summarised to produce a single peripheral error score for each of the four conditions. A one way ANOVA demonstrated that the difference in error scores between the four visual conditions was significant for the central error scores under levels of low (df 3, 27;  $F$  3.54;  $p < 0.05$ ) and high (df 3, 27;  $F$  4.89;  $p < 0.01$ ) foveal demand and for the peripheral error scores was significant without distractors (df 3, 27;  $F$  16.54;  $p < 0.001$ ).

#### *Functional Visual Fields: Divided Attention & Threshold Peripheral Targets*

Mean binocular sensitivity measured with the HFA is given in Figure 5.



**FIGURE 5.** Group mean perimetric sensitivity as a function of eccentricity for baseline (open squares), monocular (filled diamonds), cataracts (filled squares) and field restriction (open circles) along the horizontal (upper graph) and vertical (lower graph) meridians.

Group mean reaction times and perimetric sensitivity for each of the four visual conditions are given in Table 7.

Condition	Reaction Time (s)	Summed Sensitivity (dB)
Baseline	0.57 (0.20)	442.20 (53.73)
Monocular	0.50 (0.24)	341.35 (31.47)
Cataracts	0.58 (0.21)	255.5 (31.79)
Field Restriction	0.62 (0.17)	159.25 (52.19)

**TABLE 7.** Group mean reaction times and summed sensitivity for the divided attention functional visual field test for the four visual conditions.

Reaction time was recorded as an average value throughout a given test, where the number of measures ranged from between 46 and 86 dependent upon the examination and subject (the longer the examination the higher the number of measures). Average perimetric sensitivity for all locations was calculated for each examination and given as a summed value. A one way ANOVA demonstrated significant differences between visual conditions and mean perimetric sensitivity (df 3, 27;  $F$  140.73;  $p < 0.001$ ) but no significant difference between mean reaction times.

#### *Subjects with visual impairment*

The group mean scores for the cataract patients and the control subjects are given in Table 8 for high contrast visual acuity, disability glare, Pelli-Robson Letter CS and reaction times

Visual Tasks	Visual Condition	
	Cataracts	Controls
High contrast VA (Snellen equivalent)	92.89 (5.63) (6/7.5-2)	96.8 (7.4) (6/6-4)
Pelli-Robson Letter CS	1.68 (0.11)	1.91 (0.04)
Disability Glare	9.06 (4.15)	6.6 (5.5)
1 Choice Reaction Time (s)	423.53 (98.42)	384.22 (46.57)
4 Choice Reaction Time (s)	772.06 (206.09)	716.44 (143.04)
% correct	69.53 (16.24)	76.89 (12.61)

**TABLE 8.** Group mean scores for the visual performance tests for the subjects with true cataracts and the age-matched control subjects.

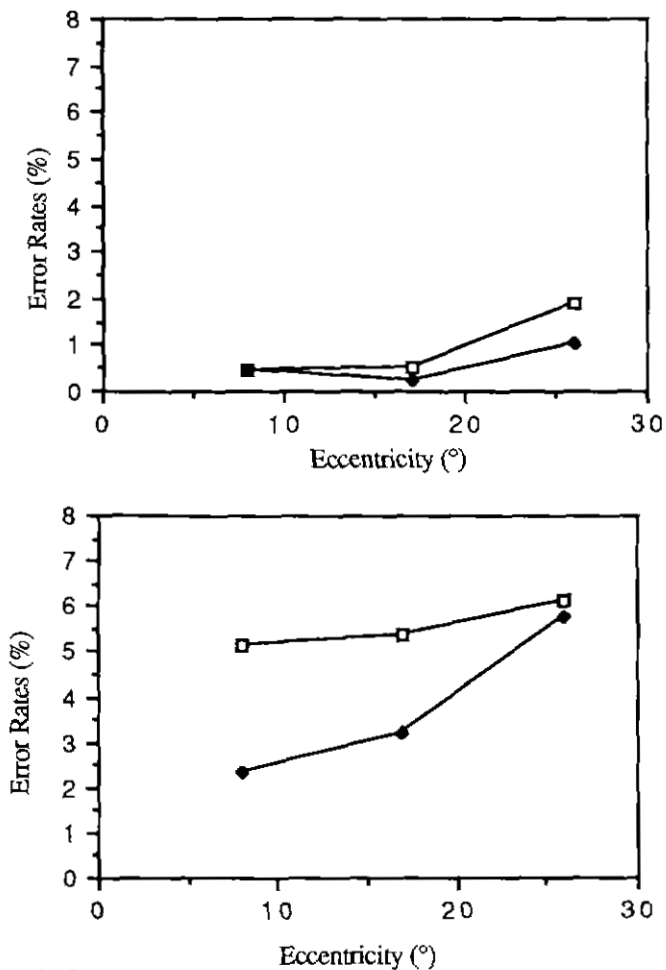
This demonstrates that the visual performance of the subjects with cataracts was poorer than that for the age-matched normal control subjects, even though the differences in high contrast acuity are very small and both groups are within one line of 6/6 (normal visual acuity) and easily satisfy the visual requirements for a driving license. Low contrast letter acuity measured with the Pelli-Robson Letter CS chart was reduced in the cataract subjects and disability glare scores were increased, indicating a higher degree of light scatter and reduction in contrast for these subjects. Reaction times for the simple and forced choice tasks were longer for the subjects with cataracts

and the number of correct responses was reduced compared to the controls. The group mean scores for the UFOV task are given in Table 9.

UFOV task	Visual Condition	
	Cataracts	Controls
<b>Low demand</b>		
Central	0.44 (0.86)	0.44 (0.53)
Peripheral	2.83 (3.28)	1.67 (0.71)
<b>High demand</b>		
Central	7.50 (5.48)	9.56 (12.04)
Peripheral	16.61 (4.73)	11.33 (6.34)

**TABLE 9.** Group mean scores for the UFOV for the subjects with true cataracts and the age-matched controlled subjects

Table 9 demonstrates that the cataract subjects made more errors on the UFOV task and these differences were greater when the level of demand was high. Figure 6 represents the peripheral error scores as a function of eccentricity.



**FIGURE 6.** Group mean error rates for the UFOV as a function of eccentricity for the cataract (open squares) and age-matched control (filled diamonds) subjects.

This shows that the subjects with cataracts made more errors on the UFOV task for both the low and high levels of demand compared to the age-matched control subjects, and that these differences were greater for the high demand condition.

### *Correlation between driving performance and visual function*

The correlation between visual function and three summary measures of driving performance (total driving score, manoeuvring and reversing error scores) are given in Table 10.

Driving measures	Pelli-Robson Letter CS	Divided Attention HFA		UFOV	
		Mean Sensitivity	Reaction Time	Low	High
Driving score	<0.001	<0.01	NS	NS	<0.005
Man score	<0.05	NS	<0.05	NS	NS
Reverse score	NS	NS	NS	NS	NS

**TABLE 10.** Correlation between driving and visual performance scores

Significant correlations were demonstrated between total driving score and Pelli-Robson Letter CS ( $p < 0.001$ ) and the UFOV at the high level of demand ( $p < 0.005$ ). Significant correlations ( $p < 0.05$ ) were also demonstrated between manoeuvring score and Pelli-Robson Letter CS, and between manoeuvring score and Pelli-Robson Letter CS, and between manoeuvring score and reaction time on the HFA test, however, there was no correlation between reversing score and visual function.

### *Comparison of performance between the old and young subjects*

The results for the elderly normal subjects with simulated visual impairment were compared to those measured in a previous study for young subjects (Wood and Troutbeck FORS 1992). In both studies cataracts caused the greatest detriment to driving and vision performance, with the exception of the reaction time test in the driving study where field restriction had the greatest effect.

The driving and vision performance of the elderly drivers was worse than that of the young subjects for all measures. A two way ANOVA, with age and visual impairment as the independent variables, demonstrated that these differences reached significance for central (df 1, 22;  $F 7.89$ ;  $p = 0.01$ ) and peripheral (df 1, 22;  $F 16.67$ ;  $p = 0.0005$ ) reactions times and reversing score (df 1, 22;  $F 11.64$ ;  $p = 0.0025$ ). There were also significant interactions between age and the type of visual impairment for driving score (df 3, 66;  $F 2.63$ ;  $p = 0.0573$ ), road position (df 3, 66;  $F 3.01$ ;  $p = 0.0389$ ), manoeuvring error (df 3, 66;  $F 3.56$ ;  $p = 0.0188$ ), peripheral reaction times (df 3, 66;  $F 2.74$ ;  $p = 0.05$ ) and reversing error (df 3, 66;  $F 5.95$ ;  $p = 0.0012$ ).



The visual performance of the elderly subjects was also worse compared to the young subjects recorded previously (Wood and Troutbeck FORS 1992). A two way ANOVA, with age and visual impairment as the independent variables demonstrated that these differences reached significance for the UFOV task for the high level of demand for central (df 1, 22;  $F$  4.08;  $p=0.0558$ ) and peripheral scores (df 1, 22;  $F$  34.71;  $p=0.0001$ ) and the sum of perimetric sensitivity for the HFA test (df 1, 22;  $F$  5.88;  $p=0.0239$ ). There were also significant interactions between age and visual impairment for the central (df 3, 66;  $F$  2.84;  $p=0.0448$ ) and peripheral scores (df 3, 66;  $F$  4.62;  $p=0.0054$ ) and the sum of perimetric sensitivity for the HFA test (df 3, 66;  $F$  5.61;  $p=0.0017$ ).

## DISCUSSION

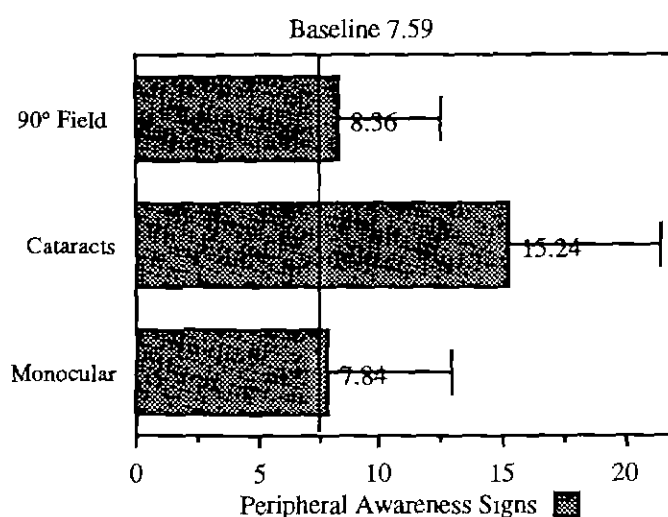
The study demonstrated that imposing simulated visual impairment on elderly drivers compromised driving and vision performance, despite the fact that all subjects satisfied the visual requirements for driving for all of the conditions of testing. These findings were supported by the results for subjects with true visual impairment.

### Driving Performance Measures

#### Field Studies

##### *Peripheral Awareness*

Peripheral awareness was reduced for cataracts (represented in Figure 7) in agreement with previous studies on young drivers (Wood and Troutbeck FORS 1992).

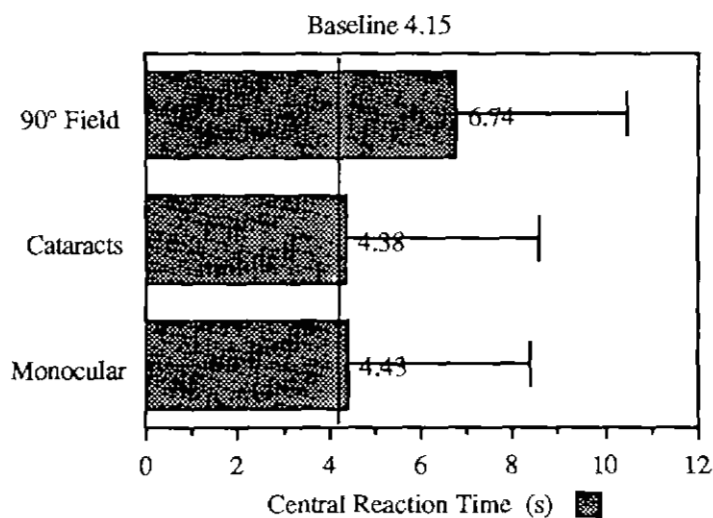


**FIGURE 7.** Histogram representing the group mean results for peripheral awareness for the three visual impairments compared to baseline (solid vertical line).

This finding implies that all drivers with these impairments (regardless of age), may not detect peripheral cues, such as other vehicles at intersections or people at the roadside and 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 when binocular visual fields were restricted to a horizontal extent of  $90^\circ$  was not, however, significantly different from the other visual conditions and was less than that reported in a previous study where horizontal visual fields were restricted to a  $40^\circ$  and  $80^\circ$  (Wood and Troutbeck 1992; Troutbeck and Wood 1993). This suggests that the extent to which peripheral awareness is reduced depends upon the extent of the binocular visual field restriction. Monocular vision had no effect on peripheral awareness scores and this finding is in agreement with that of McKnight et al (1991) who found no differences in the hazard detection and information recognition of monocular drivers compared to those who had binocular vision.

### *Reaction times*

Restriction of the binocular visual field increased reaction times for both the peripherally and centrally presented targets (Figure 8) compared to the other three visual conditions.



**FIGURE 8.** Histogram representing the group mean results for central reaction times for the three visual impairments relative to baseline (solid vertical line).

These differences were not significant, however, as many of the subjects failed to respond to the stimulus over the 10s period over which it was presented and therefore scored the maximum score of 10s. There was thus a ceiling effect in the results, which some of the subjects reached for the baseline condition. Previous studies conducted by our research group have demonstrated that restriction of the binocular field has the greatest effect on reaction times for young normal

subjects (Wood and Troutbeck FORS 1992). This indicates that under these conditions of visual impairment, subjects will have a reduced ability to react to changes in the visual environment, such as the appearance of other road users and pedestrians and will be less able to initiate appropriate avoidance action.

### *Speed Estimation*

Subjects tended to drive slower for the visual field restriction and cataract conditions, compared to baseline and monocular conditions when requested to drive at a constant speed of 60 km/h, however, these results were not significantly different. Subjects commented that they relied upon the sound and vibration of the car in order to judge speed, but that they drove slower under conditions of visual impairment as they felt less safe.

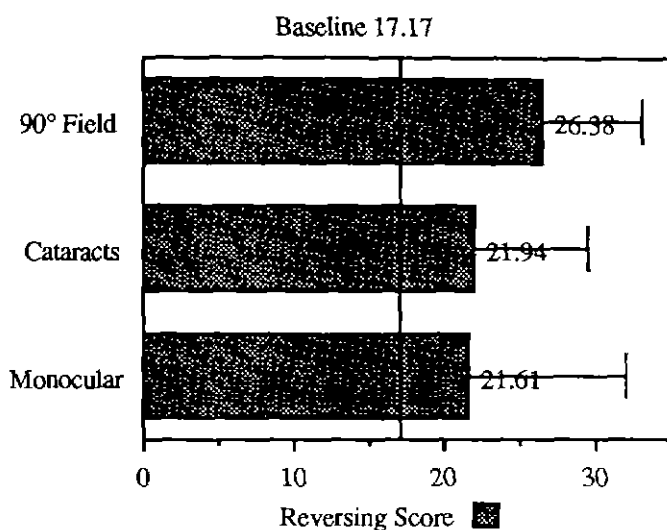
### *Manoeuvring*

Simulated cataracts resulted in the subjects driving more slowly through the line of cones designed to simulate roads with cars parked on either side or narrow gaps in car parks, although the number of cones touched or knocked over during the manoeuvring task was not 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 differences in the 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 spaces. It is likely that monocular cues such as hue, alignment and size are more important in manoeuvring through obstacles within this range. Interestingly, Wood and Troutbeck (1992) reported that manoeuvring errors were made only when the binocular visual fields are restricted to a horizontal extent of less than 80°.

### *Reversing*

Visual impairment significantly affected the accuracy of parking and subjects took significantly longer to reverse into the parking bay under conditions of visual impairment (Figure 9). The finding of a significant effect of visual impairment on reversing accuracy was contrary to that found for the young normal subjects where visual impairment only increased the time to complete the reversing task but had no effect on accuracy (Wood and Troutbeck FORS 1992). When the reversing time and accuracy were combined to give a reversing score, it was shown that visual field restriction, followed by cataract had the greatest affect on reversing.



**FIGURE 9.** Histogram representing the group mean results for reversing scores for the three visual impairments relative to baseline (solid vertical line).

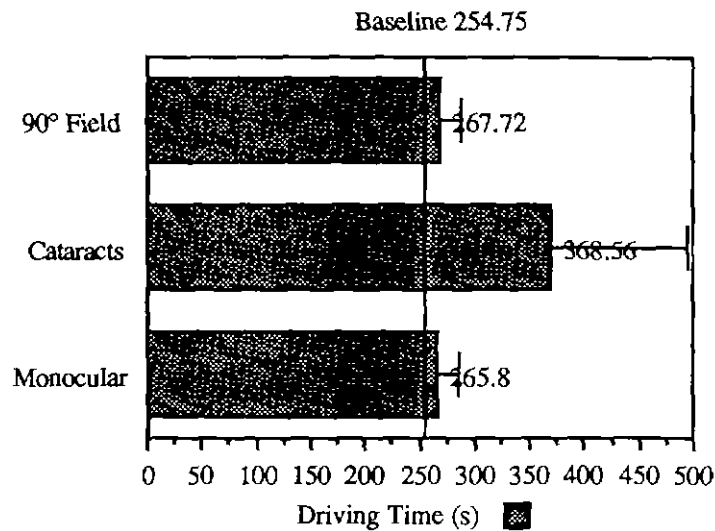
No record of compensatory head movements were made in this study, although qualitative assessment indicated that head movements were more extreme when the fields were restricted as compared to the other visual conditions.

### ***Road position***

Subjects adopted a different road position when driving under conditions of visual impairment compared to baseline. There was, however, a great deal of variation in road position between drivers whilst driving along the closed circuit. A value larger than baseline indicated that subjects drove nearer the kerb, whilst a value smaller than baseline indicated that subjects drove nearer to the centre line of the road. Thus subjects with monocular vision tended to drive to the left (the kerb of the road) compared to the baseline condition, whilst for the visual field restriction and the cataract condition, subjects drove nearer to the centre line (this effect being greatest for the cataract condition). The fact that imposition of cataracts resulted in subjects driving nearer to the centre line of the road may indicate a greater possibility of collisions, as subjects will be driving closer to oncoming traffic.

### ***Driving time***

The time to complete the circuit (not including the manoeuvring and reversing tasks) was significantly longer for the cataract condition, followed by visual restriction and monocular vision compared to baseline (Figure 10). 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).

### *Driving score*

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 had the greatest effect on driving performance.

### **True visual impairment**

The results for the subjects with visual impairment arising from cataracts supports the findings for the simulations, where driving performance was reduced compared to the age-matched normal control subjects. These differences were significant for driving time and driving score as well as for manoeuvring time and manoeuvring errors. The fact that all of the differences in driving performance between the cataract subjects and the age-matched normal subjects were not significant is likely to have arisen because the subjects had a range of degree of cataracts, ranging from very early lenticular haze to well defined lenticular changes, although none of the subjects had cataracts which reduced their visual acuity to a level below 6/12 and therefore were eligible for a driving license.

### **Questionnaire-based assessment**

The results from the self assessment of driving performance supported those derived from the field tests, where the cataract simulation was rated worse, followed by visual field restriction, then monocular vision, with baseline conditions being the preferred conditions for driving. Interestingly, the way in which subjects perceived their own driving performance didn't always correspond with the field based assessment of driving performance. For example, subjects felt that cataracts caused the greatest detriment to their reaction time responses, despite the fact that

visual field restriction actually had the greatest effect on reaction time. These results reinforce the notion that although it is possible to derive some useful information on driving performance by questionnaires, they also presents a subjective and often biased perception of driver performance, and should be used in conjunction with more objective measures of driving.

### **Visual Performance Measures**

#### ***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 license test.

#### ***Useful Field of View***

The number of errors on the UFOV task increased with eccentricity, particularly for the visual field restriction, when the level of difficulty was low. However, when the level of difficulty was increased, eccentricity had little effect on error rate as almost the maximum number of errors were made at 8° for all visual conditions, so that a ceiling effect was reached. This is in contrast to the results of the young drivers where eccentricity was an important factor at all levels of difficulty (Wood and Troutbeck FORS 1992).

The cataract condition resulted in the highest error scores for targets presented centrally, indicating that contrast is an important factor in performing this task. Field restriction resulted in the greatest number of peripheral errors regardless of whether distractors were present or not. This is likely to have arisen because of a ceiling effect, where subjects made almost the maximum number of peripheral errors in the absence of distractors for the field restriction condition and thus the addition of distractors had no effect, even though subjects indicated that the presence of the distractors seemed to increase the difficulty of the task.

The finding that visual impairment results in a decrease in driving performance and an increase in the number of errors on the UFOV 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 central and peripheral errors on the UFOV task for the prediction of driving performance was illustrated for the restricted fields condition, which

resulted in reduced driving performance and a significant increase in peripheral errors, but had little impact on central error scores. Peripheral sensitivity or awareness should thus be accounted for in the assessment of vision for driving eligibility.

#### *Functional Visual Fields: Divided Attention & Threshold Peripheral Targets*

Binocular perimetric sensitivity was significantly reduced by visual impairment. Simulated cataracts reduced sensitivity uniformly across the field and this is in accord with previous reports on the effect of true cataract on visual fields measured with static automated 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 below 90°. There was some inter-individual variation regarding the degree of visual field restriction that resulted from wearing the simulating goggles which is reflected by the larger error bars at the limits of the visual fields (at eccentricities of 30° and 45°). For the monocular condition, a scotoma was present at 15° in the left field representing the blindspot of the left eye and the horizontal extent of the visual field on the right side was reduced by approximately 30°. For the baseline condition, binocular sensitivity decreased with increasing eccentricity from the fovea along both meridians and was significantly higher in the inferior field compared to the superior field in accord with previous studies (Wood et al 1992). Binocular perimetric sensitivity (baseline conditions) was higher than monocular sensitivity (recorded for the left eye in this study) by a factor of approximately  $\sqrt{2}$ . This arises from binocular summation and is in accord with previous studies (Wood et al 1992).

Central reaction times measured during assessment of peripheral sensitivity were worse (increased reaction times) for the monocular condition but these differences were not significant. The finding that central reaction times for the restricted field and baseline conditions were not significantly different is not unexpected, since 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.

#### **True visual impairment**

The results for the subjects with cataracts support those for the simulations demonstrating reduced scores compared to those of the age-matched normal subjects for all of the visual performance measures. Disability glare scores were higher for the cataract group which is in accord with the findings of Elliott and Bullimore (1993), who also found significantly higher disability glare scores for their cataract subjects compared to a group of elderly normal subjects. Similarly, the Pelli-Robson scores were poorer for the cataract group compared to the age-matched normal group, this supports the findings for the simulations, and also other studies

which have demonstrated that the Pelli-Robson chart without glare has good discriminative ability for differentiating between subjects with cataracts and age-matched control subjects (Elliott and Bullimore 1993). Reaction times were also longer for both the simple and the forced choice task for the cataract subjects compared to the controls; the cataract subjects also made more errors for the forced choice condition. This indicates that drivers with cataracts would be much slower in reacting and responding to changes in their visual environment, such as the appearance of other road users or pedestrians, and therefore would be less able to initiate appropriate avoidance action.

These findings are of considerable importance in light of the fact that the conventional high contrast letter chart (as used in the driver licensing centres) demonstrated very little difference between the mean scores for the cataract and the control groups. Thus drivers can have significant reduction in visual and visual-related functions, which may have a detrimental effect on their driving performance, but still be able to pass the vision test in the driver licensing centres.

#### **Correlation between driving performance and visual function**

The results demonstrate highly significant correlations between driving performance and measures of functional vision. Not surprisingly, these correlations were highest for overall driving score which took into account driving time and number of errors made during the course, rather than for the more specific tasks of manoeuvring and reversing.

The finding of a correlation between driving performance and functional visual fields is supported by the work of Sloane et al (1991), who reported a significant correlation between UFOV scores and accident rates in elderly drivers. Interestingly, the relationship between the UFOV and driving scores only holds when the UFOV task involves a high level of demand with a complex central task and peripheral targets embedded within a distractor array. Similarly, the divided attention visual fields measured on the HFA did not reflect changes in driving performance as well as the high demand UFOV task, which is likely to have arisen because the peripheral targets were presented against an empty field in the HFA test, whereas in the driving situation, relevant targets appear against a background of clutter or irrelevant objects.

Significant correlations were demonstrated between overall driving score and Pelli-Robson letter CS for all visual impairments. Such a relationship has not been previously reported. However, Elliott et al (1990) reported that binocular Pelli-Robson Letter CS were highly correlated with cataract patient's perceived visual disability, particularly their subjective assessment of the effect of vision on their mobility orientation. Similarly, a relationship between letter contrast sensitivity and tasks such as reading has been demonstrated (Rubin and Legge 1989).



This finding of a significant relationship between Pelli-Robson Letter CS and driving performance together with the fact that the test is rapid and easy to administer indicates its potential as a predictor of driving performance.

### **Visual impairment and driving: General comments**

The results demonstrate that imposing visual impairment on elderly normal subjects reduced driving performance, despite the fact that all subjects satisfied the visual requirements for driving when wearing the simulating goggles and these effects were greatest for the cataract condition.

### ***Cataracts***

The reduction in contrast and increase in glare 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. These findings were supported by the results for the subjects with true cataracts, who had poorer driving performance 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. This arises because vision is measured using high contrast letters in the driving test centres, which do not reflect the decrement in visual function experienced by patients with cataracts (Bernth-Petersen 1981). These results are supported by the fact that some 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. It is interesting to note, however, that elderly persons cite glare and dim illumination as conditions under which they experience problems in everyday life (Kosnik et al 1988) and cataracts are given as one of the reasons that elderly persons self-regulate their driving and surrender their driving license (Kosnik et al 1990).

### ***Binocular visual field restriction***

When the binocular visual field was restricted to a maximum horizontal and vertical extent of 90° subjects drove slower and reaction times increased. Indeed, it has been shown that binocular field restriction has to be relatively severe (a maximum horizontal and vertical extent of 40°) before it has a significant effect on the other aspects of driving measured (Wood and Troutbeck 1992). The fact that driving performance appears to be related to the extent of the binocular field restriction concurs with studies of patients with retinitis pigmentosa, where patients with mild visual field loss did not have significantly different accident rates to those of age-matched normal

subjects (Fishman et al 1981), whilst those patients with more severe field loss had higher accident rates and poorer driving performance (assessed in a driving simulator) compared to patients with less severe loss and those with normal fields (Szlyk et al 1992). Similarly, Johnson and Keltner (1983) reported that drivers with severe binocular field loss had twice the accident and conviction rate of those drivers surveyed with normal fields. The degree of binocular visual field loss in these drivers is likely to be high, as visual fields were measured using a one-level screening technique which will detect only relatively severe visual field loss (Gramar et al 1982). Conversely, Burg (1967) 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°. The techniques for assessment of the visual field studies was however, relatively crude.

### *Monocular vision*

Monocular vision had no significant effect on any of the driving measures except road position, despite the fact that monocular vision was imposed without adaptation and would have been more traumatic than being monocular from birth or when adapted to over a period of time. This finding of a minimal effect of monocular vision on driving performance is in accord with previous studies (Edwards and Schachat, 1991; Johnson and Keltner, 1983; McKnight et al, 1991). Johnson and Keltner (1983) found no significant difference in the accident and conviction rates for drivers with monocular visual field loss as compared to a normal control group. Similarly, McKnight et al, (1991) reported that monocular drivers were not significantly worse than binocular drivers in the safety of most day-to-day driving functions. Edwards and Schachat (1991) demonstrated through an interview-based investigation, that 87% of patients retained their ability to drive following loss of one eye (through enucleation), where the period between enucleation and the interview varied between 2 and 25 years. A number of less recent reports have suggested that monocular drivers are more dangerous and have more accidents than binocular drivers (Keeney, 1968; Kesby, 1978; Kite and King, 1961; Liesmaa 1973), however, the experimental design of these studies and the analysis and interpretation of results has been questioned (North, 1985).

### **Visual impairment and driving: overall comments**

The results of this study provide evidence that both simulated and true visual impairment can have a direct impact on driving performance. Interestingly, for many of the driving measures subjects compensated for artificial visual impairment by driving slower rather than increasing their error score. 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 first part of the study was conducted with simulated visual impairment imposed 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 cataracts 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. As predicted, for the subjects with true cataracts in whom visual impairment had developed slowly, some adaptation had occurred and the decrement to driving performance was not as marked as for those subjects in whom visual impairment had been suddenly imposed. However, the decrement in driving performance for subjects with cataracts compared to the age-matched controls was significant and is of great importance for the increasingly elderly driver population, as most persons aged 65 years and over have some degree of cataract.

It is also important to note that the results of this study may only be applied to driving on a closed road circuit free of other vehicles. These conditions were selected in the interests of safety as the effect of visual impairment on driving performance were not known. It is acknowledged that driving in the presence of other road users is a far more complex task than that involved in the study. However, the number of signs and their information content was relatively high and the reaction time task was included to increase the degree of information processing for the driving task in an attempt to compensate for the lack of other vehicles on the road.

#### *Differences between old and young subjects*

The impact of visual impairment was significantly worse for the elderly compared to the young drivers reported previously (Wood and Troutbeck FORS 1992). These differences were significant for reaction time and reversing score, with significant interaction effects for many of the other driving tasks. The finding of increased reaction times for the elderly subjects is in agreement with previous studies which have reported that a general slowing of information processing speed (Salthouse 1985) and increased reaction times (Korteling 1990) are part of the aging process. We hypothesise that these changes may contribute to the reduction in driving performance reported with age. This hypothesis is supported by the study of Wolfelaar et al (1991) who looked at the merging behaviour of elderly drivers and demonstrated that speed of judgement in a traffic merging task was significantly related to four choice reaction times measured in the laboratory. This also concurs with Cooper (1990) who found that elderly drivers most commonly reported not stopping at red lights or stop signs as their major driving fault.

The visual performance of the elderly subjects was also significantly reduced for a number of tasks. For the UFOV test, elderly subjects had more problems as the level of demand was increased and when they were required to locate a target within a cluttered array. This is in agreement with a previous study, in which the differences in UFOV scores between young and elderly observers was also greater when the task was set at a high level of central and peripheral demand (Sekuler and Ball 1986). These results are also in accord the findings 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 sign surrounded by other street signs (Kosnik et al 1988).

These effects are important, as they highlight areas that elderly drivers have difficulty with and emphasize the significance of the impact of visual impairment (particularly cataracts) on driving performance. The importance of these differences will become more evident over the next few decades as the driving population ages.

#### **Implications for the performance of the road system.**

The driving performance of older drivers is becoming a more important issue. Goebel (1993) indicated that the elderly have a greater chance of a collision when compared with younger drivers and that their performance should influence road design standards and road safety programs. Other studies and papers (eg Dunne 1993) have concentrated on the elderly drivers' ability to read signs given that contrast is an important factor. The general gist is that larger signs are needed. This may well be true but, since many signs are not read, the question of more strategically placed signs would seem to be more important.

The conclusions from this study are that the elderly have more difficulty finding information from a cluttered view than do young drivers. Furthermore, drivers with cataracts find it more difficult again.

The location of traffic control signs like stop signs and give way signs is specified in the Australian Standards. Generally, they are in a conspicuous position and are re-enforced by the road geometry. These signs are not considered to provide a problem for the elderly. Information signs, however, are not controlled as well and often have to compete with advertising signs. Figure 11 is taken on Wickham Terrace and shows a direction sign between advertising signs and awnings.



FIGURE 11.

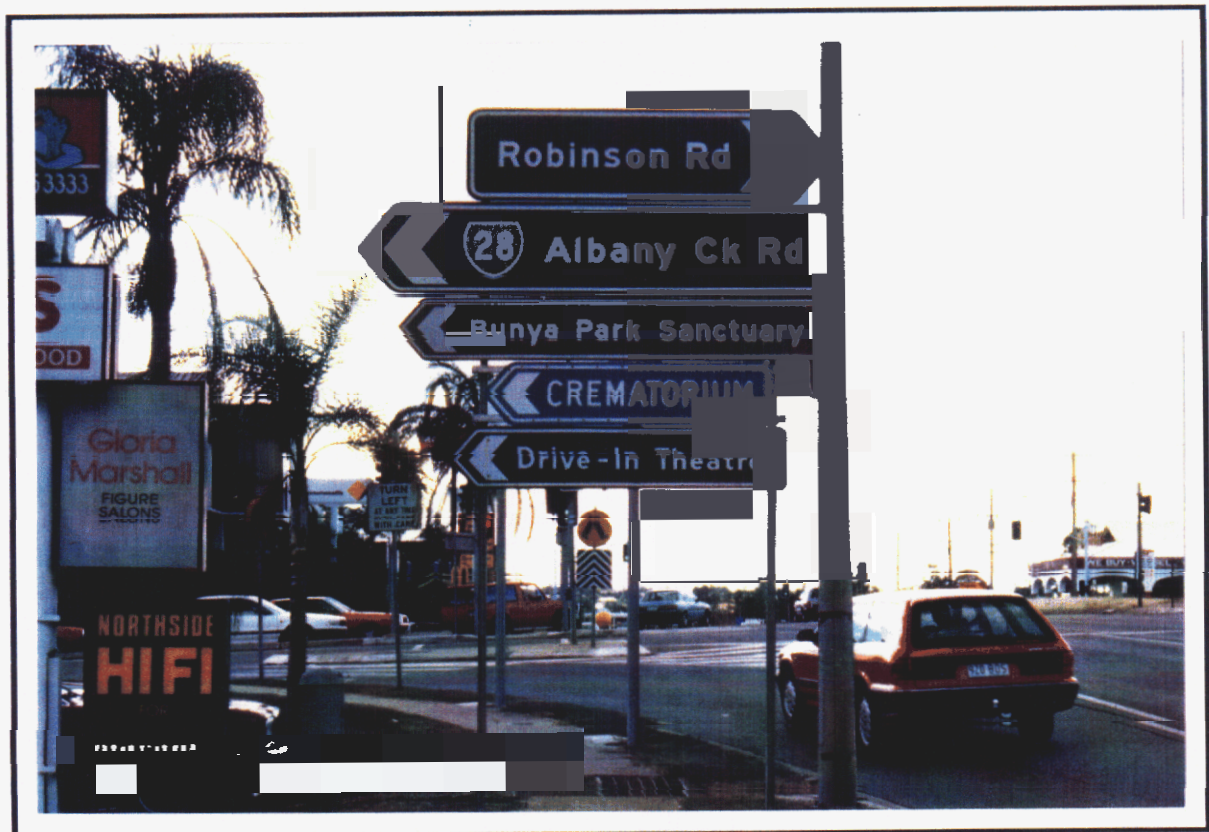


FIGURE 12.

Drivers are expected to locate the sign, read the message and act on the information within a few car lengths. This is a difficult task for any driver, let alone the elderly or those with cataracts. Figure 12 is a view of signs on Gympie road near Albany Creek Road. This sign arrangement is cluttered. It is expected that drivers would find it more difficult to find the correct road and in this case to confirm that the road continues to the Sunshine Coast. Not all signs have poor characteristics. The sign in Figure 13 is a good example. It is clear, effective and easily recognised.



**FIGURE 13.**

Reaction times for the elderly when the stimulus was in the central view were 4.1s as compared with 1.2s for the young subjects (Wood and Troutbeck FORS 1992). The stopping distances and therefore the sight distances would be increased by 2.9s of travel.



Using the assumption in NAASRA (1988), the "Approach Sight Distance" on the Stopping Sight "Distance" values would be as shown in Table 11.

Speed (km/h)	Stopping Sight Distance		
	Young drivers	Elderly drivers	% increase
40	28	60	115
50	40	80	101
60	55	103	89
70	72	128	78
80	92	156	70

**TABLE 11.** Comparison of stopping sight distances for the young and elderly drivers under baseline normal conditions.

The time required to see a stimulus in the periphery is 7.8s for the elderly against 2.6s for the young drivers; this is an increase of 5.2s of travel time. The distance travelled during this increased reaction time is shown in Table 12.

Speed (km/h)	Extra distance travelled by the elderly	
	metres	equivalent car lengths
40	58	8
50	72	10
60	87	12
70	101	14
80	110	17

**TABLE 12.** Calculated extra distance that would be travelled by elderly drivers compared to young drivers when stopping.

These distances might mean the difference between seeing or not seeing a child, or another car at an intersection. In both of these examples, it can be seen that the elderly driver is at risk or puts other road users at risk. In practice, the elderly generally drive much slower and the effective risk is lessened.

One of the main problems for the elderly driver is that their driving abilities and performance gradually changes, thus they may not be able to detect that their performance has been significantly degraded until an incident occurs or until they are advised. It is highly unlikely that any, other than gross changes, in the visual performance of elderly drivers will be detected using the current system, because vision is measured using high contrast letter charts at the driver testing centre and at the doctor's surgery (when they attend for their medical). The indication is that testing using low contrast letter charts such as the Pelli-Robson Letter CS chart and functional field measures would be more appropriate as these would highlight changes in vision

due to age and the formation of cataracts and on the basis of these results patients could be advised of their increased risk and situations to avoid, such as the late afternoon with the sun low on the horizon, peak traffic and night driving.

Other measures to combat the problems of elderly drivers have been considered by Tarawneh et al (1993) who reported on a study of the 105 drivers between the ages 65 to 88. The drivers were tested for vision, their visual perception, their cognitive ability, reaction time, physical fitness and driving knowledge in the laboratory. The driving test comprised a 19 km circuit in Omaha, Nebraska involving both left and right hand turns. Their ability to perform turns was assessed and used in the analysis. Tarawneh et al (1993) concluded that vision, visual perception, cognition and driving knowledge were correlated with the driving performance of older drivers. Finally they felt the effective countermeasures would be physical therapy, perceptual therapy, driver education and traffic engineering.

In a follow-up paper, McCoy et al (1993) reported on the evaluation of the countermeasures defined by Tarawneh et al (1993). They looked at the effectiveness of inexpensive traffic engineering measures such as painted extensions to channelisation islands, larger street names, wider lanes, improved intersection signalisation, advanced warning signs and so on. The conclusion reached was that the traffic engineering measures were cost effective for moderate traffic volumes. They give calculations to predict if these engineering measures would be cost effective based on the driving style and the treatments used in this study. However, these results may not be transferable to Australia. McCoy et al (1993) also found that physical therapy was more effective than driver education and more effective than perceptual therapy in increasing driving performance. The combined effect of driver education and physical or perceptual therapy did not produce a statistically better result over any one action. The research indicated that simple traffic engineering measures may be successful in improving the driving performance of the elderly.

## CONCLUSIONS

Simulated visual impairment had a significant effect on the driving and vision performance of old normal subjects. The effects being greater for the cataract condition. The subjects with true visual impairment confirmed the results of the simulations and demonstrated that subjects with true cataracts had significantly poorer driving and vision performance compared to an age-matched normal group. When the results of the elderly drivers were compared to that of a previous study of young, it was found that the elderly drivers had significantly longer reaction times, when targets were presented both centrally and peripherally and poorer ability to detect targets within a cluttered array. The implications of these findings were considered.



## ACKNOWLEDGEMENTS

We gratefully acknowledge the cooperation of the Queensland Department of Transport and the Queensland Police for providing the Mt Cotton Complex for the driving studies in the field.

---

**REFERENCES**

- Australian Bureau of Statistics. Projections of the populations of Australia, States and Territories 1987 to 2031. Catalogue No. 3222.0, 1988.
- Australian Bureau of Statistics. Road traffic accidents Queensland. Catalogue No. 4906.3, Brisbane, 1992.
- Avolio BJ, Kroeck KB, Panek PE. Individual differences in information-processing ability as a predictor of motor vehicle accidents. *Hum Fact* 27: 577-588, 1986.
- Bailey IL, Bullimore MA. A new test for the evaluation of disability glare. *Optom Vis Sci* 68: 911-917, 1991.
- Ball KK, Beard BL, Miller RL, Roenker DL. Mapping the useful field of view as a function of age. *Gerontologist* 27: 166A, 1987.
- Bernth-Petersen P. Visual functioning in cataract patients. *Acta Ophthalmol* 59: 198-205, 1981.
- 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, 131-142, 1988.
- Carman PD, Brown H. Brightness of fine detail in ground photography. *J Opt Soc Am* 49: 629-636, 1959.
- Ceralla J, Poon LW, Williams DM. Age and the complexity hypothesis. In: Poon LW (Ed) *Aging in the 1980s: Psychological Issues*. Washington DC. Am Psychol Ass, 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.
- Dunne FJ. 2020 Vision, an eye on the future. Proceedings of the 6th National Conference of the Australian Institute of Traffic Planning and Management, Gold Coast, Queensland, 1993.
- Edwards MG, Schachat AP. Impact of innucleation for choroidal melanoma on the performance of vision-dependent activities. *Arch Ophthalmol* 109: 519-521, 1991.

- 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.
- Elliott DB, Bullimore MA. Assessing the reliability, discriminative ability, and validity of disability glare tests. *Invest Ophthalmol Vis Sci* 34: 108-119, 1993.
- Federal Office of Road Safety. *Driver Licensing Practices in Australia*. Dept of Transport and Communications. Canberra, 1990.
- Fishman GA, Anderson RJ, Stinson L, Haque A. Driving performance of retinitis pigmentosa patients. *Br J Ophthalmol* 65: 122-126, 1981.
- Goebel G. Safety on our Roads; Who's responsible, Who cares? Keynote Address to the 6th National Conference of the Australian Institute of Traffic Planning and Management, Gold Coast, Queensland, 1993.
- Gramer E, Gerlach R, Kriegelstein GK, Leydhecker W. Topography of early visual field defects in computerized perimetry. *Klin Mbl Augenheilk* 180: 3515-3523, 1982.
- Henderson RL and Burg A. Vision and audition in driving. Report No DOT-IIS-801-265, US Department of Transportation, National Highway Safety Administration, Washington DC, November 1974.
- Hirsch RP, Nadler MP, Miller D. Glare measurement as a predictor of outdoor vision among cataract patients. *Ann Ophthalmol* 16: 965-968, 1984.
- Hofstetter HW. Visual acuity and highway accidents. *J Am Optom Ass* 47: 887-893, 1976.
- Jette AM, Branch LG. A ten-year follow-up of driving patterns among community-dwelling elderly. *Hum Fact* 34: 25-31, 1992.
- 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.
- Keeney AH. Relationship of ocular pathology and driving impairment. *Trans Am Acad Ophthalmol Otolaryngol* 72: 737-740, 1968.
- Keltner JL and Johnson CA. Visual function, driving safety, and the elderly. *Ophthalmology* 94: 1180-1188, 1987.
- 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.
- Kline DW, Kline TJB, Fozard JL, Kosnik W, Schieber F, and Sekuler R. Vision, aging, and driving: The problems of older drivers. *J Geront: Psychol Sci* 47: 27-34, 1992.
- Korteling JE. Perception-response speed and driving capabilities of brain-damaged and older drivers. *Hum Fact* 32: 95-108, 1990.
- Kosnik W, Winslow L, Kline D, Rasinski K, Sekuler R. Visual changes in daily life throughout adulthood. *J Gerontol* 43: 63-70, 1988.
- Kosnik W, Sekuler R, and Kline D. Self-reported visual problems of older drivers. *Hum Fact* 32: 597-608, 1990.

- Liesmaa M. The influence of a drivers vision in relation to his driving. *Optician* 166: 10-13, 1973.
- McCoy PT, Tarawneh MS, Bishu RR, Ashman RD, Foster BG. Evaluation of countermeasures for improving the driving performance of older drivers. Paper presented at the 72nd Annual Meeting of the Transportation Research Board. January 1993.
- McKnight AJ, Shinar D, Hilburn B. The visual and driving performance of monocular and binocular heavy-duty truck drivers. *Accid Anal Prev* 23: 225-237, 1991.
- Moskowitz H. Effects of alcohol on peripheral vision as a function of attention. *Hum Fact* 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.
- NAASRA (1988) *Guide to Traffic Engineering Practice Part 5 Intersection at Grade*. National Association of Australian State Road Authorities (now AustRoads), Sydney.
- North RV. The relationship between the extent of visual field and driving performance - a review. *Ophthal Physiol Optics* 5: 205-210, 1985.
- Owsley C, Ball K, Sloane ME, Roenker DL, Bruni JR. Visual/cognitive correlates of vehicle accidents in older drivers. *Psychol Aging* 6: 403-415, 1991.
- 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.
- Rubin GS, Legge GE. Psychophysics of reading. IV - The role of contrast in low vision. *Vision Res* 79-91, 1989.
- Salthouse TA. Speed of behaviour and its implications for cognition. In: Birren JE and Shaie KW (eds). *Handbook of the psychology of aging* (2nd Ed. pp 400-426) New York: Van Nostrand. 1985.
- Sekuler R, Ball K. Visual localization: age and practice. *J Opt Soc Am A3*, 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.
- Shinar D. *Driver visual limitations: Diagnosis and treatment*. (Contract DOT -HS-5-1275) Wash. D.C.: U.S. DOT, 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.
- Szlyk JP, Alexander KR, Severing K, Fishman GA. Assessment of driving performance in patients with retinitis pigmentosa. *Arch Ophthalmol* 110: 1709-1713, 1992.

- Tarawneh MS, McCoy PT, Bishu RR, Ballard JL. Factors Associated with the Driving Performance of Older Drivers. Paper presented at the 72nd Annual Meeting of the Transportation Research Board. January 1993.
- Troutbeck R and Wood JM. The effect of restricting vision on driving. *J Am Soc Civ Eng (Transportation Section)*, In press.
- Walker J, Sedney CA, Mast TM. Older drivers and useful field of view in a part-task simulator. Transport Research Board, 71st Annual Meeting, Washington DC. 1992.
- Waller PE. Renewal licensing of older drivers. In: *Transportation in an aging society*. Vol 2, 1988.
- Wolffelaar PC van, Rothengatter JA and Brouwer WH. Elderly drivers traffic merging decisions. In: *Vision in Vehicles III*. Cunningham GR (ed.) pp 247-255, 1991.
- Wood JM, Troutbeck R. The effect of restriction of the binocular visual field on driving performance. *Ophthal Physiol Opt*, 12: 291-298, 1992.
- Wood JM, Troutbeck R. The effect of visual impairment on driving performance. Federal Office of Road Safety Report. Dept of Transport and Communications. Canberra, 1992.
- 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. *Graefe's Arch Clin Exp Ophthalmol* 227: 157-161, 1989.

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

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

11. Please comment on any other components of your driving performance that was impaired by the experimental ocular conditions.

---

---

---

## APPENDIX 1

## 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, write the letter/ 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 LEDs 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 roadway. (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