Effect of Age and Visual Impairment on Driving and Vision Performance

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The effects of age and visual impairment on driving and visual performance were investigated for a sample of 46 subjects including 10 young visually normal subjects, 18 elderly visually normal subjects, and 18 elderly subjects with early cataracts. Driving performance was assessed on a closed-road circuit for a series of driving tasks including peripheral awareness, maneuvering, reversing, reaction times, speed estimation, road position, and time to complete the course. Visual performance was assessed using disability glare tests, Pelli-Robson letter contrast sensitivity (CS), a measure of the useful field of view (UFOV), and simple and forced-choice reaction times. The results showed that group (young normals, elderly subjects with normal vision or with cataracts) had a significant effect ($p < 0.05$) on driving and vision. The cataract subjects had poorer driving performance ($p < 0.05$) than either the elderly or young normal subjects, and the elderly subjects had poorer driving performance ($p < 0.05$) than the young. Similarly, the visual performance of the elderly subjects (with or without cataracts) was significantly worse ($p < 0.05$) than that of the young subjects. The elderly subjects had higher disability glare, poorer letter CS, and reduced ability on the UFOV task. These findings indicate that elderly subjects have poorer driving performance than young subjects and those with cataracts have still more difficulties, even though the cataract subjects had visual acuity ≥ 6/12 and were therefore eligible to drive. These changes were reflected by reduced visual performance.

The community is aging. This new generation of elderly persons considers driving to be a right rather than a privilege and are likely to continue to drive well into old age, resulting in a significant increase in the number of elderly road users. This is important because elderly drivers have more traffic convictions and accidents per kilometer driven than any other age group (*1*) and are more often involved in accidents at intersections and when making right turns, failing to yield at Stop signs, and being inattentive, and are more frequently cited as being at fault (*2*).

A number of studies have investigated specific aspects of driving performance in older individuals, and these have suggested that elderly drivers have slower reaction times (*3*), less accurate platoon-car following (*3*) and poorer merging behavior at junctions (*4*) than do 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 that 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 report problems with a number of driving tasks including lane changing, intersections, nighttime driving, unexpected appearance of other vehicles, and reading signs (*5,6*).

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. With age the lens becomes yellow and less transparent, the pupil becomes smaller and loses its ability to dilate in dim light, and the integrity of the macular pigment and neural pathways is altered. These changes lead to decreased light sensitivity, increased glare sensitivity, reduced visual acuity, and prolonged dark adaptation. 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 (*7*).

Central visual acuity is the visual attribute most commonly screened for driving eligibility; however, the level of acuity and the frequency of testing varies from country to country and state to state. 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. Indeed, only weak correlations have been shown between accident rates and either visual acuity (*8*) or visual fields (*9*), although other studies have reported a strong relationship between driving and visual field extent (*10,11*). The inconsistencies in these findings are likely to arise in part from differences in the methods employed, both in assessing driving performance and in measuring visual function. Council and Allen (*9*), for example, used a relatively crude technique to assess the visual fields, whereas Johnson and Keltner (*10*) used a perimeter that has been shown to be more accurate and reliable. Similarly, the measures employed to assess driving performance vary widely between studies. With the exception of studies such as that of Wood and Troutbeck (*11*), driving performance has been assessed by laboratory simulations or by self-reported or state-registered accident rates. Laboratory simulations may bear little relationship to on-road driving conditions and do not simulate the risks incurred in driving on road systems. Although accident rates are only a partial index of driving ability because many accidents remain unreported, the correlation between self-reported accident rates and state-registered accidents is poor (*12*).

Alternatively, it may be that the increase in elderly drivers will not compromise road safety, since aging drivers are believed to reduce their driving frequency. However, Jette and Branch (*13*) 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 which of their abilities were impaired relevant to driving. Owsley et al. (*12*) found that drivers who had been informed by their eye care specialist of significant eye health problems (such as cataracts or severe visual field loss) tended to avoid difficult driving situations. Thus being informed of visual impairment can be a persuasive means to achieve self-

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regulation, highlighting the need for studies to determine the effect of visual impairment on driving performance.

The overall aim of these ongoing studies is to test the hypothesis that age-related changes in visual function contribute to the alleged decrement in driving performance in elderly drivers. A unique methodological design was used to investigate this hypothesis, which incorporated assessment of driving performance under closed-road conditions rather than being derived indirectly from accident statistics. Vision was measured using functional tests that better reflect the normal visual environment than the simple letter tests currently employed by license testing centers.

SUBJECTS

Subjects were volunteers recruited through advertisement in a motoring magazine. All subjects were required to have distance visual acuity of 6/12 or better, to be in good health, and to be holders of a current driver's license.

In the study so far, 46 subjects have been tested, including 10 young subjects (mean age, 22.6 years; SD, 4.3 years) and 36 elderly subjects 18 of whom had normal vision (mean age, 67.7 years; SD, 3.3 years) and 18 of whom had a range of early cataracts (mean age, 68.6 years; SD, 4.2 years). Classification of the elderly subjects into either the visually normal or the cataract category was undertaken by a visual examination before the first session, in which a full case history was taken and ocular health assessed by biomicroscopy and ophthalmoscopy. Normal subjects had clear lenses by biomicroscopy and ophthalmoscopy and visual acuity ≥ 6/7.5. Cataract subjects had lens opacities as assessed by biomicroscopy and ophthalmoscopy and visual acuity ≥ 6/12.

Each subject was required to participate in two sessions on separate occasions, which included a driving assessment in the field and a visual function assessment in the laboratory. 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.

METHODS

Assessment of Driving Performance

Driving was assessed on a closed-circuit driving course that has been employed in previous studies of vision and driving (*11*). This circuit comprises a standard bitumen road surface including hills, bends, and straight stretches. The circuit was designed to permit the assessment of specific aspects of driving performance including those discussed in the following paragraphs.

Peripheral Awareness

As they drove around the circuit, subjects were required to report and identify any road signs or individuals seen. These included 19 standard road signs, 6 of which contained two extra pieces of information, which were changed between runs to minimize familiarity effects. Two individuals were also positioned at the roadside, and their location along the track was changed between runs. Peripheral awareness was given as an error score for the number of items of information not reported or identified.

Reaction Times

Two light-emitting diodes (LEDs) were located within the car, one positioned directly in front of the driver on the dashboard and the other at 30 degrees temporal to the left eye. The LEDs were linked to a timing mechanism connected to the brake pedal and a control box that the examiner operated. On illumination of the LED, the driver was required to lightly press the brake pedal as quickly as possible and the response time was recorded. Each LED was illuminated five times on average during each run, with the order and timing of LED presentation randomized and reaction time given as a mean value averaged throughout the course.

Speed Estimation

Subjects were instructed to drive at 60 km/hr (37 mph) along a straight flat stretch of the circuit while the view of the speedometer was obscured from the driver. The mean speed driven during that period was recorded. During the practice runs, the speedometer was visible to the drivers to familiarize them with the task and how the car performed when traveling at that speed.

Road Position

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

Driving Time

The time to complete the course, excluding the maneuvering and reversing tasks, was recorded for each run.

Maneuvering

Subjects were required to drive through a series of cones positioned on a wide flat section of the course. A number of different arrangements of cones were tested 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 maneuvering course without touching any of the cones. Each cone touched or knocked over was recorded by an examiner outside the car and given as an error score. The time taken to complete the maneuvering task was also recorded.

Reversing

Subjects were required to reverse into a standard parking bay as quickly and as accurately as possible. The distance from the outer edge of each of the tires to the inside border of the white lines delineating the parking bay was measured to calculate the straightness (expressed as an angle) and centrality of parking within the bay. The time taken to complete the reversing task was also recorded.

Research Vehicle

The car employed for these studies was instrumented to record its location and to assess various aspects of driving performance. Two LEDs were mounted within the car to provide the stimuli for the reaction time task and were linked to the brake pedal so an accurate measure of the time between illumination of the LED stimulus and braking could be made. A video camera was mounted in the back of the vehicle to record the road position of the vehicle along the driving course. The vehicle had automatic transmission and was selected in preference to a vehicle with manual control to increase the number of subjects eligible to participate in the study.

Procedures

Each subject was given several practice runs around the circuit (each circuit takes approximately 5 min to complete) until they were familiar with the car, the road circuit, and the driving tasks. This was followed by the recorded run, in which subjects were required to drive once around the circuit.

Assessment of Visual Performance

A battery of tests of visual function was employed, including a measure of functional fields, low contrast acuity, disability glare, and simple and forced-choice reaction times. All tests were undertaken binocularly, using the appropriate refractive correction for the working distance of the test.

Visual Acuity

Binocular visual acuity was measured using a high-contrast (90 percent) chart at the standard working distance of 6 m to give a measure of visual performance comparable with that used in driving test centers and to ensure that all subjects had binocular visual acuity ≥6/12.

Useful Field of View

A functional visual field test was included because studies have demonstrated significant correlations between functional visual field scores involving peripheral search within cluttered arrays and accident rates (*14,15*). A measure of the functional field known as the useful field of view (UFOV), as described by Sekuler and Ball (*16*), was employed that involved a computer-generated task to measure central and peripheral information processing. Targets consisted of cartoon faces that subtended 4 degrees by 3.5 degrees and were presented centrally and at one of 24 peripheral locations along 8 radial directions at eccentricities of 8, 17, or 26 degrees for a duration of 90 msec. The central task provided a stimulus for fixation as well as creating various levels of central demand. The peripheral component measured localization of targets when they were presented against an empty field (for the low level of difficulty) or within a distractor array (for the high level of difficulty). The distractor stimuli consisted of outline boxes of the same size and luminance as the targets. Subjects were required to detect the central targets and at the same time determine the location of the peripherally presented targets, making the task a divided attention search, which also tested the ability of the subject to recognize relevant targets within a cluttered array.

Pelli-Robson Letter Contrast Sensitivity

A test of letter contrast sensitivity (CS) was included because it has been suggested that such tests better reflect the visual environment, which includes low- as well as high-contrast detail (*17*). Letter sensitivity was measured using the Pelli-Robson letter CS chart as described by Pelli et al. (*18*), in which letter size remains constant but contrast decreases from the top left to bottom right of the chart in 0.15 log unit steps. Sensitivity was measured at the recommended luminance of 85 cd/m^2 and at a working distance of 1 m (*18*). Subjects were instructed to identify the letters starting with the high-contrast letters in the top left-hand corner and working down the chart until all the letters in a given triplet had been incorrectly identified. Subjects were encouraged to look at each line of letters for 20 to 30 sec and were forced to guess when they were unsure because scoring depended on a forced-choice paradigm.

Disability Glare

A test of disability glare was included because it is well established that tests of glare sensitivity more accurately reflect the functional decrement suffered by patients with cataracts than do visual acuity measures (*19*). An index of disability glare was derived by taking the difference in visual acuity measured for the low-contrast chart under no-glare and glare conditions using the Berkeley glare test (*20*). This test consisted of a reduced low-contrast Bailey-Lovie letter chart (Weber's contrast = 18 percent) mounted on a triangular opaque panel in the center of an opal Plexiglas panel at the medium glare setting (750 cd/m^2). 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 occurred from one condition to another. Responses were scored as a Visual Acuity Rating (VAR) in which 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

A laboratory test of reaction times was included since a general slowing of information processing has been reported as part of the normal aging process (*21*). Simple and forced-choice reaction times were measured using a computer-generated technique. A series of eight boxes (the stimuli) were generated on the computer screen with a response panel on the keyboard composed of eight buttons, each corresponding to one of the stimulus boxes. On initiation of the program, one of the boxes was illuminated at a randomly timed interval. For the simple reaction time task, the subject was required to press any response button when the stimulus boxes were illuminated. For the forced-choice task, subjects were required to press the response button corresponding to the illuminated stimulus box. For both the simple and the forced-choice tasks, the reaction time was recorded in milliseconds by a simple timer device; for the forced-choice task, an error rate was also recorded. Subjects were given a number of practice trials before the experimental run to familiarize them with the task. The results were given as the mean of 50 trials.

RESULTS

Driving Performance

A multivariate analysis of variance (MANOVA) performed with Genstat demonstrated a significant difference between groups even when the 10 driving measures were taken into account (F20,56 = 2.47; $p < 0.001$). A multiple correlation of the driving measures showed that the driving variables included in the MANOVA were not highly correlated (the highest correlation was $r = 0.41$ between central and peripheral reaction times). The results of individual ANOVAs for each of the driving measures are given in Table 1 and show significant differences ($p < 0.05$) between groups for driving time, maneuvering time, maneuvering errors, peripheral reaction times, and speed estimation.

Post hoc analysis using *t*-tests demonstrated that the driving performance of the cataract subjects was significantly worse ($p < 0.05$) than that of the young and elderly visually normal subjects for driving time, maneuvering time, and peripheral reaction times. The elderly visually normal subjects were significantly worse ($p < 0.05$) than the young subjects for peripheral reaction times, maneuvering errors, and speed estimation; the results for peripheral reaction times are shown in Figure 1.

Visual Performance

A MANOVA performed with Genstat demonstrated that there was a significant difference in visual performance between groups even when the nine measures were taken into account (F18,58 = 7.85; $p < 0.001$). A multiple correlation analysis of the visual performance measures demonstrated that none were significantly correlated (the highest correlation was between the central and peripheral UFOV errors for the low demand condition, where $r = 0.51$). The results of individual ANOVAs for each of the visual measures are given in Table 2 and demonstrate significant differences ($p < 0.05$) between groups for disability glare, Pelli-Robson letter CS, simple reaction times, and peripheral UFOV scores for the low and high levels of demand.

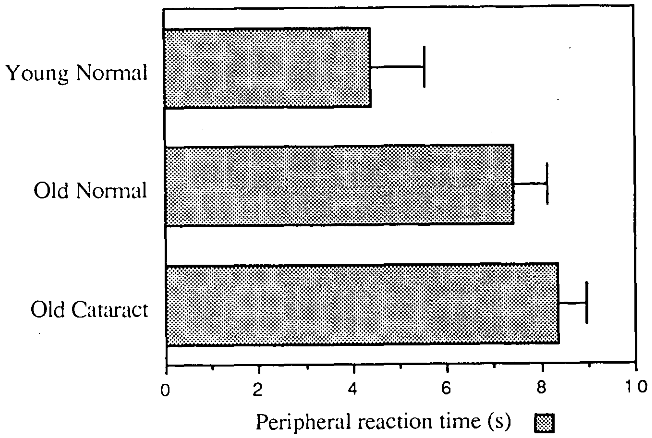

FIGURE 1 Histogram representing group mean results for peripheral driving reaction time for young normal subjects, elderly normal subjects, and elderly cataract subjects.

Post hoc analysis using *t*-tests demonstrated that the visual performance of the cataract subjects was significantly worse ($p < 0.05$) than that of both the young and the elderly visually normal subjects for simple reaction times, Pelli-Robson letter CS, and disability glare. Performance of the elderly visually normal subjects was also significantly worse than that of the young subjects for the high demand UFOV test, disability glare test, and Pelli-Robson letter CS.

DISCUSSION OF RESULTS

The study demonstrated that the elderly subjects had poorer driving performance as assessed on a closed-circuit driving course compared with the young subjects, and the elderly subjects with early cataracts had poorer driving performance than those who

TABLE 1 Results of ANOVA for Driving Performance (DF = 2,37 in all cases)

Driving Task	F statistic
Driving Time	4.68
Maneuvering Time	4.09
Maneuvering errors	3.66
Reversing Time	3.07
Reversing Errors	1.00
Peripheral Reaction Time	4.73
Central Reaction Time	0.01
Speed Estimation	4.24
Peripheral Awareness Errors	1.50
Road Position	1.23

TABLE 2 Results of ANOVA for Vision Performance (DF = 2,37 in all cases)

Visual Task	F statistic
Disability Glare	5.70
Pelli-Robson Letter CS	45.49
Simple reaction time	4.48
Forced choice reaction time	1.80
(Percent correct)	1.79
UFOV foveal low demand	0.93
UFOV peripheral low demand	4.56
UFOV foveal high demand	2.30
UFOV peripheral high demand	19.95

were visually normal, even though the cataract subjects had visual acuity ≥ 6/12 and were therefore eligible to drive.

Peripheral reaction times, driving times, and maneuvering times were significantly worse for the cataract subjects compared with the visually normal young and elderly subjects. The cataract subjects also had higher disability glare scores, reduced Pelli-Robson letter CS, and poorer peripheral performance on the UFOV for the high demand condition. When the young and elderly visually normal subjects were compared, it was found that peripheral reaction times, maneuvering errors, and speed estimation were worse for the older drivers, who also had higher disability glare scores, reduced Pelli-Robson letter CS, and poorer peripheral performance on the UFOV for the high demand condition.

Driving Performance

The finding of increased peripheral reaction times for the elderly subjects compared with the young subjects is in accord with studies that have reported a general slowing of information processing speed (*21*) and increased reaction times (*3*) as part of the aging process. These changes may contribute to the reduction in driving performance reported with age. This hypothesis is supported by the study by Wolffelaar et al. (*4*), who looked at the merging behavior of older drivers and demonstrated that speed of judgment in a traffic merging task was significantly related to reaction times measured in the laboratory, and also concurs with Cooper (*22*), who found that older drivers most commonly reported that their major driving fault was not stopping at red lights or Stop signs.

The elderly subjects with cataracts also had longer driving times compared with the young and elderly visually normal subjects. This has significant implications for traffic flow and may indicate that drivers with cataracts should avoid peak-hour traffic in which maintenance of a given traffic speed is necessary for constant traffic flow. The elderly subjects with cataracts also took longer to complete the maneuvering task, although they did not make significantly more errors than the other groups.

These results have important implications for road safety, since all elderly people have some degree of lens opacity as part of the aging process. Nevertheless, lens opacities must be relatively advanced to reduce visual acuity below the level required for driving because in driving test centers, vision is measured using high-contrast letters that do not reflect the decrement in visual function experienced by cataract patients. These results are supported by the fact that having cataracts is given as one of the reasons that the elderly self-regulate their driving and surrender their driving license (*5*). It is also possible that the changes in performance of older drivers demonstrated in this study may represent an underestimate of that seen in the driving population as a whole, because the subjects who participated were volunteers recruited via advertisement in a motoring magazine and thus were likely to have a greater interest in and awareness of driving.

It should be noted 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 because the effects 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 were 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.

Visual Performance

The finding that disability glare scores and Pelli-Robson letter CS were significantly worse for the old compared with the young subjects and that the scores for the elderly subjects with cataracts were worse than those of the visually normal elderly subjects is in agreement with previous studies (*23*). The disability glare results indicate that older individuals, regardless of whether they have lens opacities that are categorized as cataracts or not, have a greater sensitivity to light scatter than do younger individuals. The results for the Pelli-Robson letter CS chart suggest that the older subjects have more problems in detecting low-contrast images. These results are supported by the fact that some of the most common complaints of the elderly in general, particularly those with cataracts, are having poor vision for nighttime driving and being almost blinded by sunlight (*22,24*).

The findings of the laboratory reaction time tests were in general agreement with those recorded for subjects when driving, although the differences were not as pronounced when measured in the laboratory and were only significant for the simple and not the forced-choice task. This lack of difference likely reflects the fact that elderly persons have greater difficulties with divided-attention tasks such as the driving task in this study, where they were required to undertake a number of tasks as well as to respond to the reaction time stimulus, whereas in the laboratory the reaction time test was a relatively simple task and therefore not representative of a real-world situation.

For the UFOV test, the older subjects had more problems when they were required to locate a target within a cluttered array, which is in agreement with the findings of Sekuler and Ball (*16*). These results are also in accord the finding that the age-related decline in the extent of the UFOV, demonstrated both in the presence of distractors (*25,26*) and with secondary central tasks (*27*), reflects 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 (*28*).

These effects are important, because they highlight areas in which elderly drivers have difficulty 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 Performance of Road System

The driving performance of older drivers is becoming a more important issue. Goebel (*29*) indicated that the elderly have a greater chance of a collision compared with younger drivers and that their performance should influence road design standards and road safety programs. Other studies and papers have concentrated on the ability of elderly drivers to read signs, given that contrast is an important factor (*30*). The general gist is that larger signs are needed; however, since many signs are not read, the question of more strategically placed signs would seem to be more important.

TABLE 3 Calculated Extra Stopping Distance Traveled by Elderly Drivers with Cataracts Compared with Young Drivers

	Extra distance travelled by the elderly	
Speed (km/h)	metres	equivalent car lengths
40	43	6
50	54	8
60	65	9
70	76	11
80	87	12

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 still more difficult. In Australia, the location of traffic control signs, such as Stop and Yield signs, is specified in the standards, and they are generally in a conspicuous position and reinforced by road geometry. These signs are not considered a problem for the elderly. Information signs, however, are not as well controlled and often have to compete with advertising signs. 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. Sign arrangements are often cluttered. It is thus expected that elderly drivers would find it more difficult to find the correct road.

The time required to see a stimulus in the periphery was 8.3 sec for the elderly subjects with cataracts, 7.4 sec for the elderly subjects who were visually normal, and 4.4 sec for the young drivers; this is an increase of 3.9 sec of travel time for the elderly subjects with cataracts. The distance traveled as a result of this increase in reaction time is shown in Table 3. These distances might mean the difference between seeing or not seeing a child or another car at an intersection. From this example, 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 driving performance changes gradually; thus, drivers may not be able to detect a significant degradation in their performance until an incident occurs or until they are advised. It is highly unlikely that any change in the visual performance of elderly drivers other than a gross one would be detected with the current system because vision is measured using high-contrast letter charts at the driver testing center and the doctor's office (during medical checkups). The indication is that testing using low-contrast letter charts such as the Pelli-Robson chart and functional field measures would be more appropriate, because these would highlight any changes in vision due to age and the formation of cataracts. On the basis of these results, patients could be advised of their increased risk and situations to avoid, such as late afternoon with the sun on the horizon, peak traffic, and night driving.

Future Work

The results from this study provide a basis for further investigations, which will include larger numbers of subjects, both those with visual impairment and those who are visually normal. It is proposed that these studies will be undertaken both on closed roads and on public roads under daylight and nighttime conditions.

CONCLUSIONS

Elderly subjects (either with normal vision or with cataracts) had significantly worse performance for many of the aspects of driving assessed on a closed-circuit driving course than the young visually normal subjects. This was despite the fact that all of the elderly subjects had visual acuity $\geq 6/12$ and were therefore eligible to drive. The elderly subjects also had higher disability glare scores, reduced Pelli-Robson letter CS, and poorer peripheral performance on the UFOV for the high level of demand compared with the young subjects.

ACKNOWLEDGMENT

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

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Publication of this paper sponsored by Committee on Safety and Mobility of Older Drivers.