VISUAL SEARCH PATTERNS IN OLDER AND YOUNGER DRIVERS

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ABSTRACT

Despite substantial research on visual function among older drivers, there is a paucity of research on how age-related changes in visual search patterns and other functional abilities impact on driver behaviour. This study investigated visual search, cognitive performance and driving performance of younger (25-35 years) and older drivers (65-75 years) in a high-level driving simulator. Participants completed two simulated test drives, incorporating complex and hazardous events. Driving measures included speed and braking and steering responses. Data from a FaceLAB eye tracking system was linked with the driving scenario to provide information on time to fixation and fixation duration for critical stimuli and events in the driving environment. Overall, the findings indicated that older drivers travelled at slower speeds and were more variable in their travel speed than younger drivers. Older drivers detected hazards later than younger drivers and differed in the proportion of time looking at hazards, the road ahead, peripheral areas and the speedometer. The relationship between visual search strategies, driving performance and a range of cognitive measures was also explored. The study provided a useful model for evaluating visual strategies and potential interventions for drivers with vision impairment.

INTRODUCTION

In most western societies, advances in health and changes in demographics mean that a substantial rise in the proportion of older persons will be experienced in the foreseeable future. In Australia, the proportion of the population aged 65 years and older is predicted to more than double current levels by the middle of this century, with the percentage of those aged 85 or over expected to increase four-fold in that time frame (ABS, 1999). This older cohort is likely to place higher demands on the provision of safe mobility options including the use of motor vehicles (OECD, 2001). The expected shift in the population age distribution and associated mobility changes has lead to predictions of a trebling of fatal crashes over current levels in the next 30 to 40 years without effective countermeasures being implemented (Fildes, Fitzharris, Charlton, & Pronk, 2001; Hu, Jones, Reuscher, Schmoyer, & Truett, 2000).

Research on older driver crashes indicates that this group is over-represented in serious and fatal crashes per kilometre driven (Diamantopoulou, Skalova, Dyte, & Cameron, 1996). However, some caution is needed in interpreting conventional measures of older driver exposure-adjusted crash rates. Comparisons based on annual distances travelled may be too simplistic and may inflate older driver risk, as they are typically compared with other age groups having larger yearly driving exposure (Janke, 1991). Recent evidence suggests that independent of age, drivers travelling more kilometres will typically demonstrate reduced crash rates per kilometre travelled, compared with those driving fewer kilometres (Hakamies-Blomqvist, Raitanen & O'Neill, 2002). As the next cohort of older drivers become more mobile, the crash risk of older drivers may be moderated by larger annual distances travelled. This will be important to monitor in the future.

Typically, older drivers crashes have a distinct pattern that differs from younger drivers (Pruesser, Williams, Ferguson, Ulmer, Weinstein, 1998; Zhang, Lindsay, Clarke, Robbins, & Mao, 2000). Numerous studies indicate that the predominant casualty crash type for older drivers is skewed towards crashes involving complex road environments or high cognitive workload. The typical crash of an older driver occurs at an intersection and is commonly associated with the following behavioural characteristics: turning; a high speed limit; waiting for a gap in traffic; a failure of observation or attention; and a failure to yield the right of way (Clarke, Forsyth, & Wright, 1998; McGwin & Brown, 1999; Pruesser, et al., 1998).

Safe driving requires effective visual functions as well as cognitive skills. These include the ability to understand and remember traffic rules and signs, follow directions, utilise executive functions, allocate attention, process information quickly and accurately, and minimise the effects of distraction. Owsley et al. described the driving task as a "visually cluttered array, both primary and secondary visual tasks, and simultaneous use of central and peripheral vision. In addition, the driver is usually uncertain as to when and where an important visual event may occur" (Owsley, Ball, Sloane, Roenker & Bruni, 1991, p404).

Given the central importance of vision as a source of sensory information for driving, it seems logical that deficits in visual performance associated with ageing would be related to crash risk and may explain, in part, the characteristic crash patterns for older drivers (Burg, 1967; Hills and Burg, 1977). Burg argued that more explanatory power might be attributable to age-related declines in higher level processing. Others have also noted that common clinical measures of visual function have not been found to be strong predictors of crash risk (e.g., Decina & Staplin, 1993; Gresset & Meyer, 1994) and seem to share only minimal relationships with the perceptual requirements of driving in complex and dynamic traffic conditions (Schiff & Arnone, 1995).

Intuitively, it is also expected that safe driving would be dependent on unrestricted fields of vision and effective visual search strategies to identify critical cues and hazards in the road environment. These abilities, too, are likely to change with age, although there is some limited evidence that individuals may be able to adapt their visual scanning patterns to compensate to some degree for some visual deficits (e.g., Lövsund, Hedin, & Törnros, 1991; Pambakian, et al., 2000).

Despite the purported importance of visual scanning, little research has been undertaken to examine the visual search characteristics of older drivers and how these abilities might be used to negotiate hazards in the driving environment. This paper is part of an ongoing investigation into the visual scanning behaviour of older and younger drivers. The study presents some results describing the relationship between visual search strategies, driving performance and a range of cognitive measures.

METHOD

Participants

Two groups of drivers participated in the study, a group of older drivers (n=25) aged 65-75 years, and a group of younger drivers (n=20) aged 25-35 years. Participants had self-reported normal or corrected-to-normal vision. Participants were also screened (by self-report) for epilepsy and other medical conditions which have a known association with crash risk. Older participants had been involved in previous research by Monash University Accident Research Centre (MUARC) and had agreed to be contacted about future research. Younger participants were acquaintances of MUARC employees recruited through word of mouth.

Apparatus

Simulator:

The high-level driving simulator located at MUARC was used to assess driving performance. The simulator consists of a stationary full-sized sedan on a motion platform with full vehicle controls. Four projectors provided graphic images of the simulated road scenes with 180° of forward vision and 60° of rear vision from the driving position, and a sound system provided noises of the engine and road environment.

Three separate drives were used, all set in daylight conditions and on bitumen roads. The first drive was a familiarisation drive completed with the assistance of a researcher, and allowed the participant to become comfortable with the simulated environment and vehicle controls. The test drives consisted of one rural drive and one residential drive.

The results in this paper focussed on only one of these drives – the residential scenario. The speed limit throughout the residential drive was 60 km/h with one lane in each direction. The residential drive incorporated five hazardous events:

1. A truck in the opposing lane encroaching on the participant’s lane when turning left;
2. **(a)** A 4WD stopped at the roadside and **(b)** a vehicle pulling out from a driveway just after the parked 4WD;
3. **(a)** A car turning into the road ahead from the left and **(b)** the car suddenly brakes and then accelerates;
4. **(a)** A pedestrian appears from the right at an unsignalised intersection and **(b)** crosses the road.

Eye tracking:

The FaceLAB system comprises two unobtrusive cameras set on the dashboard and calibrated for angles and depth of the seated driver in order to establish movement parameters of the eyes and head in three dimensions. Camera images and recordings are linked to a user-operated computer interface for various custom and default set-up procedures. The system is designed to recognise and track facial features and markers (small stickers) placed on the drivers face. The system also recognises the iris, pupil and eyelids with the user manually adjusting size and shape parameters to achieve optimal recordings of the gaze.

Cognitive Tasks:
In addition to the simulator driving tasks, participants completed 3 brief tasks to evaluate various aspects of cognitive performance. The tasks were taken from a battery of test items previously used as a pre-screening tool for identifying at-risk older drivers (see Charlton, Fildes, Koppel, Andrea, Newstead, Oxley & Pronk, 2002 for rationale), and are as follows:

(i) Motor-Free Vision Perception Test (MVPT) (Colarusso & Hammill, 1972)
Participants are shown a figure (model) and four incomplete figures (response alternatives) and are required to select the figure which, if completed, would look just like the model. The task comprises 11 tasks in total. Number of errors is scored (max. = 11).

(ii) Months Backwards Test (Katzman, Brown, Fuld, Peck, Schechter & Schimmel, 1983)
This test was taken from the 6-item Short Blessed Test which has been shown to reliably indicate both the presence and severity of dementia. In this task, participants are asked to recite the months of the year backwards starting from December. The number of errors and the time taken to complete the task is recorded. The timing of this task begins when the participant started the sequence and continues regardless of omissions, juxtapositions, or corrections until the sequence is completed or 75 seconds has elapsed.

(iii) Trail-Making Test (Trails A and B)
These tasks are paper and pencil tests requiring complex visual scanning, attention and motor speed. The first part (Trails A) requires the participant to draw lines connecting consecutively numbered circles on a page), and the second part (Trails B) requires lines to be drawn connecting consecutively numbered and lettered circles in alternating sequence. The test is sensitive to progressive cognitive decline in dementia (Greenlief, Margolis & Erker, 1985).

Questionnaires
Participants completed pre-drive and post-drive questionnaires. The pre-drive questionnaire was designed to collect demographic information and details about driving experience including average weekly driving distance. Immediately following the simulated driving task, participants completed a short questionnaire about their experience in the simulator, and covered aspects such as simulator discomfort.

Procedures
The experimental procedures were approved by the Monash University Standing Committee on Ethics in Research Involving Humans and all participants provided informed consent prior to participating in the study. Participants first completed the set of cognitive tasks and pre-drive questionnaire. Next, participants were introduced to the simulator vehicle and the driving procedures were explained. At the beginning of the familiarisation drive, markers were placed on participants' faces and the

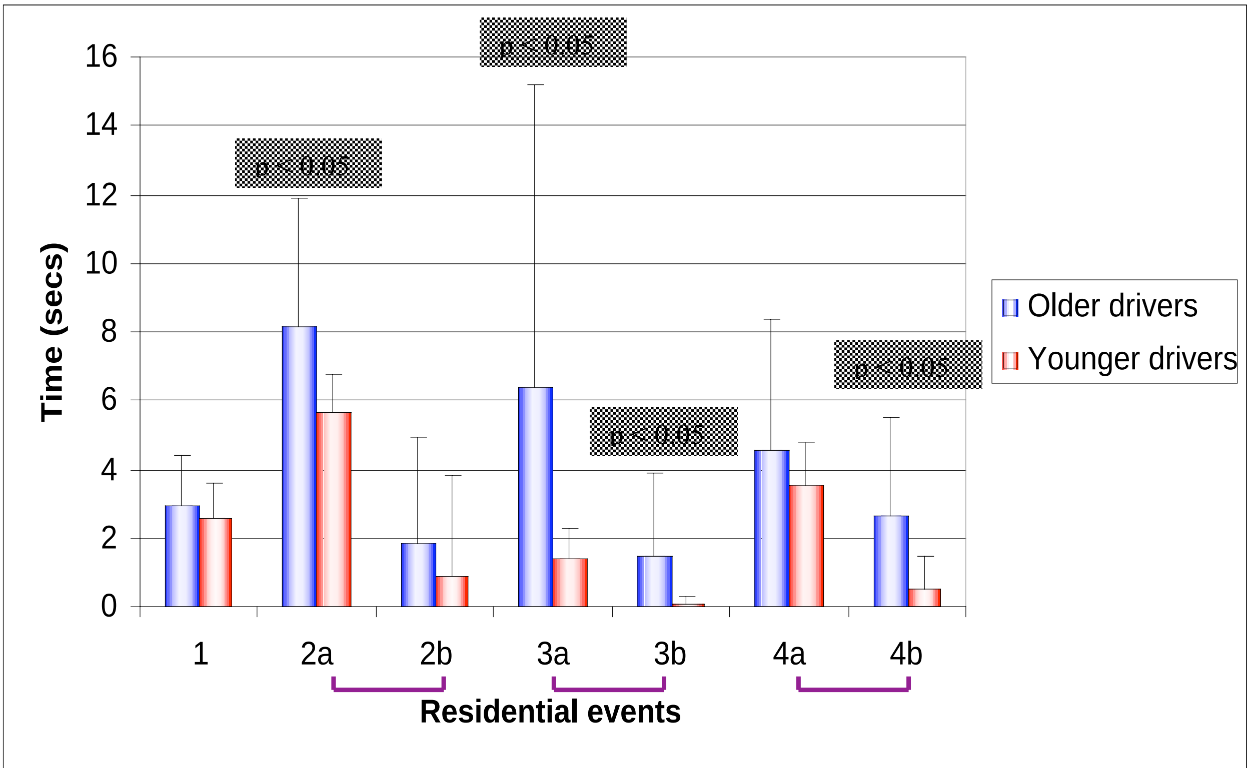
infrared lighting was adjusted to achieve adequate brightness on the face and eyes with minimal reflection for the purpose of gaining optimal gaze tracking. During the drives, participants were instructed to obey all road rules, avoid collisions and maintain the speed limit wherever possible, but should react to road events as they would if they were actually driving on the road. Following the final drive the post-drive questionnaire was administered. All the tasks were completed in one session of approximately 90 minutes duration.

RESULTS

Data reported here is based on 19 older drivers and 18 younger drivers (attrition rates are due to simulator discomfort or missing FaceLAB data). The groups differed in their average driving experience (50 years versus 10 years) but not weekly driving exposure (approx 250kms per week).

Visual Scanning Data
In the majority of scenarios, data demonstrates that the older drivers saw the target/hazard later than younger drivers (see figure 1). For example, in Event 2, the mean time for older drivers to fixate on the parked car was just over 8 seconds, as compared to just under 6 seconds for younger drivers.

Figure 1. Time Taken to Fixate on the Target



More detailed analyses were conducted for visual scanning data for scenario 2 (a) and (b) (a car is parked on the left hand side and a second vehicle approaches road from a driveway just beyond this car (see Figure 2).

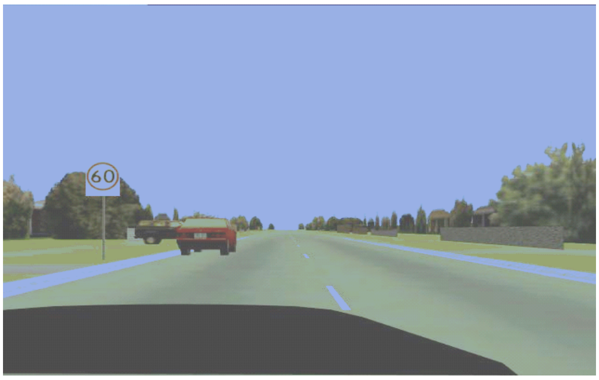


Figure 2. Scenario Events 2 (a) and (b)

The results demonstrated that older drivers had a broader visual search strategy than younger drivers, both laterally and vertically. Older drivers spent more time looking at the road ahead, significantly more time looking at the speedometer (13% of time compared to 3% of time) and significantly less time than younger drivers looking at the specific hazard (26% versus 45%).

Driving Performance

Numerous variables are available from the simulator based on the speed and position of the vehicle and use of vehicle controls. This data demonstrated that the older drivers had a lower mean speed than younger drivers in the majority of events, but their speed was more variable than the younger drivers. Results from Event 2 indicated that the older drivers' mean speed during the first phase (2 (a) car appears parked on road side) was 38kph ($SD = 6.4$) in comparison to a mean speed of 46kph ($SD = 5.3$) for the younger drivers ($p<0.001$). Similar findings were observed for the second phase (2(b) when a second vehicle reverses out of a driveway), mean speeds were 34.9 kph and 43.9 kph for older and younger drivers, respectively, $p<.001$).

In event 2(b), despite differences in time to first see the hazard, no differences were observed in braking time for the two groups [M=1.687s (SD 1.517s) and 1.081s (1.144) for older and younger drivers respectively].

Cognitive Tests

Results indicated that there were no significant differences between the groups in number of errors on the MVPT. However, older drivers took a significantly longer time to complete the Trails B task, $M = 99.71$ seconds ($SD = 30.67$ s), compared with the younger drivers $M = 58.33$ seconds ($SD = 20.92$s), $t(37) = -4.837$, $p<0.001$.

Relationships Between Cognitive Measures, Visual Search and Driving

Several significant relationships were found between visual search patterns and driving performance (see table 1). Again, for Event 2, participants who took longer to fixate on the target tended to travel at a significantly lower mean speed through this event (r = -.351).

Participants who spent significantly less time looking at the road ahead also tended to travel at a significantly lower mean speed through this event (r = -.354), and not surprisingly participants who saw the target later applied the brakes significantly later (r = .456).

Table 1. Relationships between visual search patterns and driving performance for Event 2 (a)

	Mean Speed	Speed SD	Time to Brake	Time to Accelerate
Capture Time	r = -.351*	r = .025	r = .456**	r = -.299
% Time on Target	r = .175	r = -.253	r = -.180	r = .036
% Time on Road	r = -.354*	r = .127	r = .196	r = -.114
% Time on Peripheral	r = -.243	r =.305	r = .150	r = .041
% Time on Speedometer	r = -.194	r =.139	r = .157	r = .0.85

For the second part of the 2nd residential event (see Table 2), there was also a significant relationship between several visual search variables and driving performance. Consistent with Event 2a, participants who saw the target later applied the brakes significantly later. In addition, participants who spent less time looking at the target (hazard) and more time looking at the road ahead tended to apply the brakes significantly later

Table 2. Relationships between visual search patterns and driving performance for Event 2(b)

	Mean Speed	Speed SD	Brake Time	Acc. Time
Capture Time	r = -.117	r = .187	r = .612**	r = -.170
% Time on Target	r = .271	r = -.292	r = -.418*	r = -.169
% Time on road	r = -.339	r = .130	r = .434*	r = .239
% Time on peripheral	r = -.347	r = .135	r = .407	r = .205
% Time on speedo	r = .104	r = .183	r = -.041	r = -.083

There were also significant relationships demonstrated between cognitive performance, visual search patterns and driving performance. Participants who scored more errors on the MVPT tended to spend significantly less time looking at the target (r = -.365) and at the road ahead (r = -.376). Also, participants who took longer to complete the Trails B task were more likely to travel at a lower speed than participants who took a shorter time to complete the task (r = -.458). When group data were analysed separately, different patterns of correlations among these variables emerged. Notably, for older drivers, the MVPT was significantly associated with both Capture Time and Mean Speed in Event 2 ($r = -.607$ and $r= -.716$, respectively), while no significant relationships were observed between these variables for young drivers. Similarly, for older drivers, Months Backwards was highly related to variability in speed and Trails B was highly correlated with percent time spent looking at the road ahead ($r = .635$ and $r=.545$, respectively) while for younger drivers, these measures were not significantly related (p's$>.05$). In general, these patterns of correlations showed that for older drivers, poorer cognitive performance was related to longer times to see the hazards, slower and more variable average speeds and a greater proportion of time spent looking at the road ahead.

DISCUSSION

In summary, this study provided evidence of differences in visual scanning patterns in older and younger drivers, and the relationship to cognitive and driving performance. Older drivers tended to have a broader (less focussed) visual scanning pattern than younger drivers, both laterally and vertically. A key finding was that older drivers first fixated on hazards later than younger drivers. They spent a smaller proportion of time during the driving event looking at the hazard. They also spent more time looking at the speedometer, possibly reflecting slowness in reading the vehicle speed display panel. This suggests a potentially dangerous and distracting behaviour while negotiating a hazardous event. The results also indicate that older drivers respond to hazardous events by choosing a slower travel speed than younger drivers. Those older drivers who displayed poorest cognitive abilities also tended to be slower in directing their gaze towards critical hazards. These drivers also had the slowest travel speeds. This may indicate sellf-regulatory capacities appropriate to their declining functional abilities. However, speed reduction in itself, may not be sufficient compensation to avoid all hazards.

It is possible that the broader pattern of visual scanning evident in older drivers is a positive strategy adopted by drivers to compensate for a restricted field of vision. Also, although the older driver fixated on hazards much later than the younger driver, it is possible that they had already detected it in their peripheral field of view. This needs to be explored in future research. An important element was that the older drivers appeared able to take appropriate action to avoid the hazard (based on braking time responses). These variations in scanning patterns also have important implications for drivers' ability to interact with vehicle information systems.

There are some limitations of this study which need to be considered. Firstly, there is the issue of adaptation to the simulated environment and its effect on driving performance. More research needs to be conducted to validate the driving simulator performance with on-road driving, specifically with older drivers. Older drivers appeared to be more sensitive to simulator discomfort and future research should bear in mind the need to over-recruit to compensate for higher attrition rates for older participants. Furthermore, while FaceLAB provides new and important information that has been challenging to record in the past, a number of difficulties were experienced in tracking eye movements of participants wearing glasses with highly reflective surfaces and frames that cast shadows across the eyes during certain head movements.

Also, eye tracking data provides only a limited indication about the driver's focus of attention on specific events or hazards while driving. The driver may fixate on elements in the driving environment without attending to that information. This is evidenced in the road environment by a class of crashes labelled "looked-but-failed-to-see" (Hills, 1980). However, the FaceLAB provides an opportunity to examine exactly this phenomenon by employing auxiliary tasks requiring attention.

Future research is planned which will focus on the effect of driver age and vision conditions on visual scanning and driving and the effectiveness of in-vehicle technologies and other interventions to compensate for vision impairment.

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