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Visual information search in simulated junction negotiation: Gaze transitions of young novice, young experienced and older experienced drivers

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Abstract
Older drivers and young novice drivers have problems negotiating road junctions and this is reflected in the accident statistics for these driver populations. Explanations for problems with junction negotiation largely focus on limitations in visual information processing and observation errors associated with age and experience. Investigations of drivers viewing behaviour have used measures of fixation and gaze frequency and duration to highlight drivers information processing and search, capacity and requirements. The use of more specific measures of search strategy, such as gaze transitions, has been less common, particularly for the task of gap selection in junction negotiation. Gaze transitions provide information on the positional relationship of fixations, providing a useful tool for highlighting gaps in driver's visual information acquisition strategies. The gaze transitions of three driver groups (young novice, young experienced and older experienced) were compared during gap selection in right turn junction negotiation manoeuvres. When scanning the junction, young experienced drivers distributed their gaze more evenly across all areas, whereas older and novice drivers made more sweeping transitions, bypassing adjacent areas. The use of a preview strategy in the decision phase was less evident in the older experienced group compared to the younger groups. It is suggested that response preparation requirements of the decision phase impact on older drivers' ability to maintain a preview strategy. The application of results to driver training interventions and future research are discussed.

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Introduction

Problems at junctions

It is widely accepted that older drivers find the task of junction negotiation difficult (Breker, et al. 2003; Creaser, Rakauskas, Ward, Laberge, & Donath, 2006), are prone to driving errors at junctions (Anstey & Wood, 2011; Boufous et al, 2008), and are over represented in high injury severity collisions at junctions (Langford & Koppel, 2006; Clarke et al, 2010), particularly at junctions intersecting roads with high speed limits (Baldock & McLean, 2005; IAM, 2010). In particular, older drivers experience problems turning right at junctions (left in countries where driving is on the right) and are typically involved in right turn (cross flow), 'failure to yield' collisions (McGwin & Brown, 1999; IAM 2010). Such problems generally become more prevalent for drivers over the age of

65 (Daigneault, Joly & Frigon, 2002; IAM 2010). There is evidence to suggest that young novice drivers (with less than three years of driving experience) also have difficulty with the task of junction negotiation (Clarke, 2000; Crinson & Grayson, 2005; Forsyth, 1995; RoSPA 2002) and are typically involved in right turn (cross flow), passive right of way violation collisions at junctions (Forsyth, 1995; West & French, 1993; Clarke, Forsyth & Wright, 1998a). However, the young driver propensity to involvement in accidents at junctions declines rapidly as a function of increased experience (Clarke, Ward, Bartle & Truman, 2006). For young experienced drivers ('lower risk'), problems and accidents at junctions are less prevalent, than for older experienced and young novice drivers (IAM, 2008; Maycock, 2002).

Current explanations for drivers' problems at junctions

Explanations of older driver's problems in junction negotiation have largely focused on the effects of age-related functional decline and changes in processing style. The age-related functional deficits identified as having the greatest implications for older drivers 'at risk' of collision are: speeded visual selective attention, visual discrimination, dual task performance, task switching, response inhibition, reaction time, motor performance or sequencing (Anstey & Wood, 2011; Breker et al. 2003). Specific problems in gap selection have been attributed to the misjudgement of speed or distance (Scialfa et al, 1991) and the ability to judge whether or not a collision will occur (De Lucia, Beckley, Myer & Bush, 2003). Investigations into stimulus response processing have highlighted age-related slowing in response selection and movement initiation (Salthouse, 1985 & 1989; Stelmatch & Nahom, 1992). Furthermore, in complex road traffic situations, requiring the parallel processing of multiple channels of information, older drivers adopt a processing style that is more serial in nature than that of younger drivers (Hakamies-Blomqvist, Mynttinen & Backman, 1999).

Where older driver problems in junction negotiation may originate from processing limitations, due to typical age-related functional decline (Anstey & Wood 2011; Breker et al. 2003; Keskinen, Ota & Katila, 1998), young novice driver problems are largely a result of their low exposure to junction scenarios, and are manifest in processing limitations associated with limited resource capacity, and a low awareness of the potential risks of the road traffic environment, compared to that of more experienced drivers (Groeger & Clegg, 1994; Osborn & Owens, 2010; Hickford, Piao & Preston, 2011). Research shows that young novice ' at risk' drivers have difficulties in assessing risks and gathering relevant visual information, they also take longer than more experienced drivers to detect hazards, especially as road traffic situations become more complex (West & French,1993; RoSPA, 2002). Problems in junction negotiation and associated age and experience related processing limitations have been described extensively in the literature, yet little attention has been paid to how drivers search for the visual information they require to identify safe gaps in cross flow traffic during right turn junction negotiation scenarios.

Drivers' visual search at junctions

Driver's eye movements are significantly different when approaching junctions compared to driving on roads with no junctions, and change on close approach to junctions (Ko, Higgins, Chrysler & Lord, 2009). There is a tight link between gaze location and allocation of attention in natural tasks, and gaze patterns have been shown to indicate how drivers select the data to be encoded (Hamid, Stankiewicz and Hayhoe, 2010), making visual search strategies a useful line of enquiry in understanding driving problems in junction negotiation. Furthermore, scenario specific visual training has been shown to improve drivers' visual search skills (Chapman, Underwood & Roberts, 2002; Pollatsek, Narayanaan, Pradhan & Fisher, 2006; Konstantopoulos, 2009). Information on specific differences between the visual search strategies of 'at risk' and 'lower risk' driving populations might therefore be useful in informing training interventions aimed at improving junction scenario specific viewing strategies of 'at risk' driver populations.

Goldberg and Kotval (1999) distinguished between two main categories of measure in visual search; measures of processing and measures of search. Investigations of drivers viewing behaviour have used measures of fixation and gaze frequency and duration to highlight drivers information processing and search, capacity and requirements. A gaze transition is the movement of the eyes between one fixation and the following fixation, providing information on the positional relationship of fixations (Ko, Higgins, Chrysler & Lord, 2009). The use of more specific measures, such as gaze transitions, in highlighting drivers search strategies has been less common, particularly for the task of gap selection in right turn junction negotiation manoeuvres.

Lui, (1998) identified typical scan paths associated with turning right and overtaking in simulated driving. Two predominant patterns of scanning were identified; one involving a preview of the road ahead with the next fixation to the road directly in front of the vehicle, the other one involving lateral transitions consistent with positioning. Underwood et al (2003) extended this work to compare different driving populations, although the study was limited to straight-road driving rather than junctions. The scanning patterns of young novice and young experienced drivers during on-road driving were dominated by transitions towards the road far ahead. It is proposed that drivers direct their gaze, predominantly, to the focus of expansion because that is where information on approaching vehicles first becomes available (Helander & Soderberg, 1972; Mourant & Rockwell, 1970, Chapman & Underwood, 1998), and this was interpreted as a 'preview strategy'. This was less pronounced in the young experienced group, for whom transitions were distributed more evenly. Underwood, Phelps, Wright, Van Loon and Galpin (2005) also looked at sequence patterns for younger and older experienced drivers during a hazard detection task, however, few age-related differences were found.

The present study uses gaze sequences to consider the effects of age and experience and to highlight differences between the search strategies of 'at risk' and 'lower risk' driver populations, in a simulated right turn junction scenario. In line with Underwood et al. (2003) it is predicted that a preview strategy will dominate for all groups, although this will be less pronounced in the young experienced group who will show a more even distribution in their gaze transitions across areas of interest (AOI). In differentiating the effects of age, and experience, some similarities in the viewing behaviour of the two younger driver groups (novice, experienced) are expected and some in the viewing behaviour of the two experienced driver groups (young, older) are expected. The different reasons underlying the junction difficulties of young novice and older experienced drivers should be revealed in quite different viewing strategies.

Method

Participants

Forty-two drivers took part in the study. The sample comprised 14 novice drivers (mean age 20.57 years; SD = 2.47 years), 14 young experienced drivers (mean age 23.79 years; SD = 3.04 years) and 14 older experienced drivers (mean age 66.43 years; SD = 5.03 years). Driving experience indicated by period on full licence and estimated mileage during last 12 months was also noted for the three groups: Novice drivers (mean driving experience: 6.6months; 3680 miles); young experienced drivers (mean driving experience: 6.8 years 8425 miles) and older experienced drivers (38.9 years; 7250 miles). Drivers were recruited by advertising in a local newspaper, at driving centres and at the University of the Third Age. All participants reported that they were free from any medical condition or prescribed medication that might impair driving performance, and reported having normal or corrected-to-normal eyesight.

Apparatus

A SensorMotoric Instruments (SMI) head mounted eye tracking system was used to collect data relating to gaze and these data were stored in MPEG format. Analysis was conducted using Observer 3.0. The simulation environment comprised a fixed based driver assessment rig and a simulated junction scenario. The visual scene was divided into seven areas of interest (AOI) as shown in Figure 1. 'Far' AOIs represent distances of more than 60m from the driving position, 'middle' AOIs 20-60m, 'near' AOIs less than 20m and the 'centre' AOI within 10m. The scenario started with a convoy of eight cars passing the junction from both directions followed by a series of negotiable gaps that increased in 1.5s increments. A predefined finished point was identified in the straight section of the road following the right turn manoeuvre.

Figure 1: Categorisation of visual scene into 'areas of interest' defined by distance from driver position.

Procedure

Drivers were seated in the fixed based driver assessment rig and the head mounted eye tracking system was fitted and calibrated. After five minutes of practice in using the simulator, a simulated junction scenario was presented. Drivers were instructed to make a right turn manoeuvre in their own time and only when they felt comfortable doing so. Following the manoeuvre drivers were asked to stop at a predefined point in the straight section of the road.

Results

The duration of recordings for drivers differed according to which gap they selected. For this reason and to allow comparison, recordings were analysed in two phases. An initial scanning phase consisted of the first 10 seconds of each scenario in which there were no negotiable gaps. A decision phase consisted of the 5 seconds immediately prior to initiating the manoeuvre, so although each person's decision phase occurs at a different point in the scenario, they are functionally matched in representing the gaze patterns associated with each driver's accepted gap. Cursor position taken from the video recordings was coded frame-by-frame and categorised by AOI. Each code represents 40ms of observable scanning and subsequent analysis converted these codes into gazes if maintained for longer than three frames (120ms).

The following analysis considers the transitional probabilities associated with gazes across the AOIs in both scanning and decision phases. The analysis follows that used by Underwood et al. (2003). Gaze position by AOI was used to construct a first order Markov matrix for each of the three groups (novice, young experienced, older experienced) and the two phases. After refixations on the same area were excluded, transitions were tested using a binomial test to calculate the z-score associated with each transition. Equal *a priori* probabilities could not be assumed so expected transitional probabilities were based on observed gaze distribution. Results are shown in Table 1 with significant transitions ($p<.05$) highlighted in Figures 2 and 3.

Table 1. Mean gaze frequency at each of the 7 areas of interest in the scanning and decision phase for the three driver groups. [Standard deviations of means are in brackets.]

Driver:	Novice		Experienced		Older	
Phase:	Scanning	Decision	Scanning	Decision	Scanning	Decision
Far Right	4.64 [2.53]	2.00 [0.88]	3.79 [1.63]	1.64 [1.22]	3.29 [2.05]	1.93 [0.83]
Middle Right	3.93 [2.50]	1.86 [1.10]	4.57 [1.74]	2.14 [1.61]	4.21 [2.29]	1.93 [0.92]
Near Right	1.64 [1.22]	2.21 [1.12]	2.43 [2.47]	2.14 [0.95]	2.14 [2.11]	2.50 [1.16]
Centre	0.57 [0.65]	1.64 [1.34]	1.14 [1.41]	1.50 [0.85]	1.71 [2.02]	1.36 [0.93]
Near Left	0.36 [0.84]	1.14 [1.29]	2.14 [1.41]	1.29 [0.83]	0.93 [1.38]	1.21 [1.12]
Middle Left	0.86 [1.46]	0.93 [0.83]	2.57 [1.65]	0.93 [1.00]	1.36 [1.28]	0.93 [1.14]
Far Left	1.36 [1.45]	1.43 [0.85]	2.00 [1.04]	1.14 [0.95]	1.57 [1.40]	1.79 [0.80]

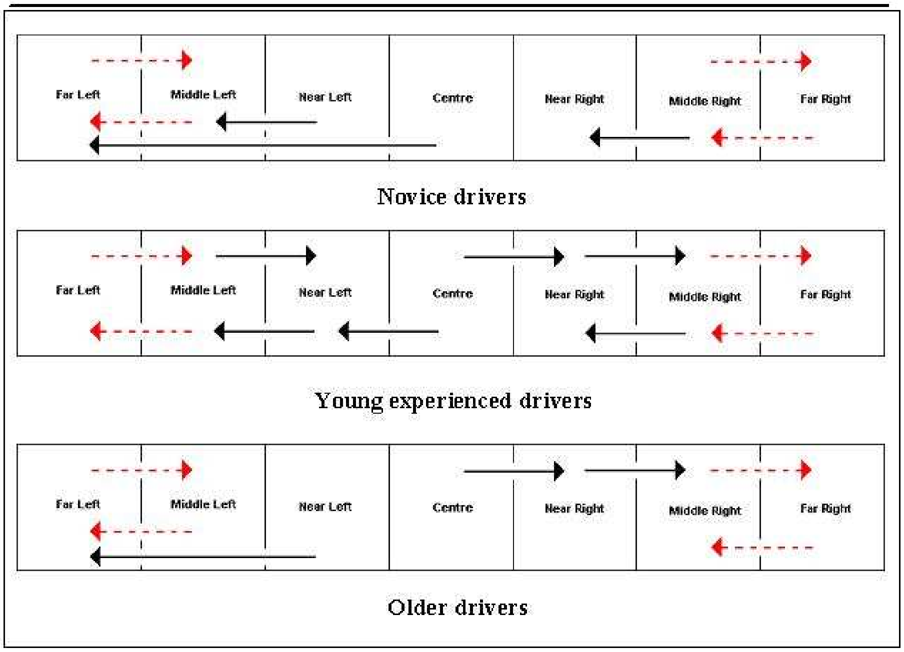

Figure 2. Significant transitions in the scanning phase Transitions shared by all drivers are shown as dotted arrows.

In the scanning phase four transitions were common to all drivers (see Figure 2). These were back and forth between far and middle areas on both sides. Significant transitions unique to each group were also found. For novice drivers, this was from centre to far left whereas for older drivers this was from near left to far left. Two unique transitions were found for young experienced drivers from centre to near left and from middle left to near left. Young experienced and novice drivers shared transitions from middle to near right and from near to middle left. Young and older experienced drivers shared transitions from centre to near right and from near to middle right. Aside from transitions shared by all drivers, novices did not share any transitions with older drivers. However, novice and older drivers both made ‘sweeping’ transitions, bypassing adjacent areas in favour of the next AOI. In contrast, the transitions of young experienced drivers were restricted to adjacent areas, creating a pattern of more evenly distributed gaze behaviour across AOIs.

In the decision phase (Figure 3) only two significant transitions, near right to centre and far to middle right, were shared by all drivers. Three unique transitions were found for novice drivers, these were from centre to near left, centre to middle left and middle to far left. A unique transition from far to middle left was also found for young experienced drivers. No unique transitions were found for older experienced drivers. Young experienced drivers shared a transition from middle to far right with novice drivers and a transition from near to far left with older drivers. Similar to the scanning phase, no transitions were shared by novice and older drivers other than those common to all drivers.

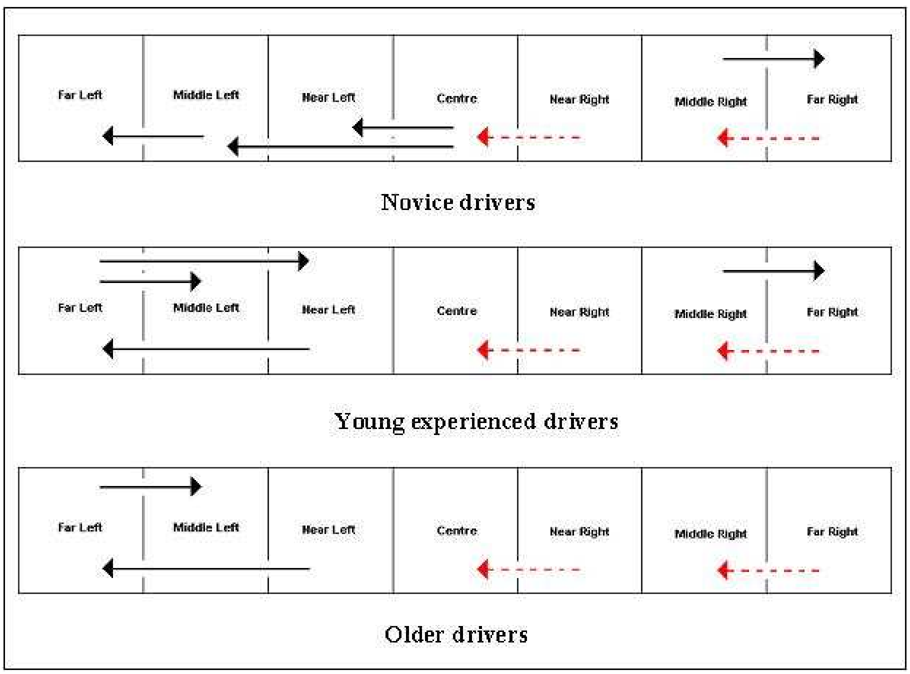

Figure 3. Significant transitions in the decision phase. Transitions shared by all drivers are shown as dotted arrows

Discussion

Explanations for problems with junction negotiation largely focus on limitations in visual information processing and observation errors associated with age and experience. The aim of the present study was to examine the transitions made by the different driver groups when selecting safe gaps at a junction. Reliable transitions were identified using an analysis of two gaze sequences. It was predicted that, in line with Underwood et al (2003), a preview strategy would dominate for all groups, although this would be less pronounced in the young experienced group who would show a more even distribution in their gaze transitions across areas of interest (AOI).

The scanning phase

In total twelve reliable transitions were found in the scanning phase, of which four were shared by all driver groups. The results confirm that all drivers adopted a preview strategy in which they predominately searched between the middle and far areas to the left and the right of the junction. As also predicted, the backward and forward gaze behaviour between the far and middle areas shown by all drivers was extended to the middle and near areas for young experienced drivers, equating to a more even distribution of gaze transitions across the areas of interest for young experienced group.

In differentiating the effects of age from those of experience, the gaze transitions of both younger driver groups (young novice, young experienced) showed gaze transitions from middle right to near right and near left to middle left. One interpretation might be that when searching for safe gaps through which to transverse the junction, younger drivers adopt a strategy in which vehicles approaching from the right are monitored from right to left as they pass through the junction. It is possible that information from the centre area is not required at this point because the decision to initiate the manoeuvre has not yet been made. Perhaps older drivers are less able to adopt such a strategy due to age related functional decline. Alternatively, older drivers may simply adopt a different strategy to compensate for such decline.

In differentiating the effects of experience from those of age, both experienced driver groups (young experienced, older experienced) shared transitions from centre to near right and from near to middle right, suggesting that experience teaches drivers that it is also important to monitor traffic from the left as it crosses the junction, and until it has passed. It was proposed that the different reasons underlying the difficulties of young novice and older experienced drivers in junction negotiation would be reflected in different viewing strategies. Apart from transitions shared by all drivers, novices and older drivers shared no further transitions. However, young novice and older drivers both showed a similar pattern, with sweeping transitions between non-adjacent areas to the left of the junction. Research suggests that visual input is suppressed during sweeping eye movements (Irwin, Carlson-Radvansky & Andrews, 1995), indicating a less efficient scanning strategy in which information from adjacent areas may be missed, for 'at risk' young novice and older drivers, compared to the more evenly distributed gaze of young experienced drivers.

The decision phase

Nine reliable transitions were found in total during the decision phase, of which only two were shared by all driver groups. These were from far right to middle right and near right to centre. Transitions from near right to centre may represent drivers tracking the last car of the formation before initiating the manoeuvre to ensure the earliest point of departure.

Whereas the transitions from far right to middle right may reflect a final check to ensure the gap is clear.

Young experienced drivers shared two transitions with older drivers; near left to far left and far left to middle left, suggesting an experience related requirement for preview information about traffic approaching from the left. As with the scanning phase, no transitions were shared by novice and older drivers, highlighting the different underlying reasons for young novice and older driver's problems at junctions. Sweeping transitions across the left areas were found for all drivers in the decision phase and the increase in the number of sweeping transitions for this phase may reflect the urgency to obtain relevant information from specific sources before committing to the manoeuvre.

Sweeping transitions towards the far areas may represent the sampling of information based solely on distance. Multiple transitions between adjacent areas could indicate the following of cars or gaps in order to extract information on both speed and distance. According to this assumption, young experienced drivers may have adopted a general strategy based on speed and distance in the scanning phase, whereas the sweeping transitions towards the far left area may represent a greater emphasis on distance based information for ' at risk' novice and older drivers. In the decision phase, all drivers show some sweeping transitions to the left of the junction highlighting a more even distribution between the use of information on speed and distance for all drivers compared to the scanning phase.

It was predicted that all drivers would show a preview strategy of transitions towards the road far ahead, where cars are most likely to first appear. The results suggested that this occurred in the scanning phase and the decision phase, but for older drivers, preview of the far right was less evident. A reduced emphasis on this area in the decision phase may allow for an increased preparation for the motor responses necessary to initiate the manoeuvre, and a processing style that is more serial than that of younger drivers. Previous research suggested that young experienced driver would distribute their gaze more evenly across the visual field than novice drivers. The transitions of young experienced drivers were more evenly distributed across adjacent areas in the scanning phase compared to novice drivers but this was less clear in the decision phase, again perhaps due to the impending requirement for a motor response.

Conclusion

One of the aims of the present study was to highlight differences between the visual information acquisition strategies of 'at risk' and 'lower risk' drivers, and to consider potential applications to driver training interventions.

Young experienced drivers are at 'low risk' of accident involvement at junctions compared to both young novice drivers and older experienced 'at risk' drivers, and show a more even distribution of gaze across areas when scanning for information. It is also suggested that their strategy includes a greater emphasis on the judgement of speed and distance compared to that of the 'at risk' groups, and this requires further research.

Results indicate that the requirement for response preparation in the decision phase may limit the distribution of visual search and monitoring strategies in 'at risk drivers'. Future interventions aimed at training driver's visual search strategies might include practice in applying an evenly distributed search strategy, should highlight the importance of remembering to monitor traffic as it passes through the junction from the left to right, and should include tasks designed to develop judgement of speed and distance. The opportunity to practice delivering motor responses in parallel to on-going effective visual search should be an essential part of such training interventions.

The time constrained nature of the task restricted the number of gaze sequences that could be analysed. Future studies using a larger sample would enable more sequences to be analysed and more advanced Markov procedures to be applied. Subsequently, a model of drivers eye movements at junctions could be developed that could predict future gaze sequences. Further work should also be conducted to integrate training of visual search strategies into driver training interventions.

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