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Selective searching while driving: the role of experience in hazard detection and general surveillance

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Novice drivers have been found in previous studies to display a limited search of the immediate environment, relative to experienced drivers, when manoeuvring on a dual-carriageway road. The present study investigated whether this reduction in the variance of search along the horizontal plane was a product of less frequent glancing in the car's mirrors. Novice and experienced drivers were observed as they made lane changes in relatively unobstructed conditions and when they needed to move into a lane already occupied by traffic. Novice drivers were found to rely more than experienced drivers upon their internal mirror, even when the lane-changing manoeuvre required information about traffic in the lane best reflected in the external, door-mounted mirror. Novices did increase their use of the external mirror in response to driving needs, suggesting that they did have an awareness of the situation that required inter-weaving with traffic in their destination lane. Their reliance upon the internal mirror may be a product of a habit acquired specifically for the driver licensing examination, in which exaggerated inspection of the internal mirror is regarded as being desirable.

1. Introduction

In a review of models of driving behaviour, Ranney (1994) highlighted visual search as an aspect of driving that must be central to a complete description of the cognitive abilities necessary for a skilled driver. The identification of salient information, both static and moving objects, is critically important at both the strategic level of activity involving navigation and route-choice, and at the tactical level that involves manoeuvring relative to other vehicles and avoiding unexpected hazards. Failure to search the roadway effectively is likely to result in a collision with another vehicle, or at best neglect of route information. This paper reports a study of the patterns of visual search by drivers of different abilities as they negotiate sections of multi-lane roadway that present different levels of difficulty.

Current evidence suggests that newly qualified drivers are particularly vulnerable to driving errors that are associated with inefficient visual search. An analysis of written police reports of road traffic accidents in California reported by Lestina and Miller (1994) found that the single most common contributor to a crash was failure to search the roadway. Drivers were cited as not searching far enough ahead, or of being culpable through inattention, or failing to avoid distraction. Most importantly, it was the very youngest drivers who experienced accidents that were

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associated with failure to search for conflicting traffic. In the 15–19-year-old group, 39% of accidents had some contribution from this factor, with the next most frequent contributor being failure to comply with the road rules (right-of-way accidents), some 18% of all accidents. If young drivers have difficulty in adequately searching the roadway before making a manoeuvre such as a lane-change or when entering a main road from a side road, then this would open the possibility for accident reduction through more extensive training in preparation for the driver licensing test. A difficulty in relying upon written police reports of accidents is that they are based more upon judgement than upon direct observation. The present authors have previously reported behavioural evidence of inadequate search by novice drivers that does support the Lestina and Miller (1994) conclusion, however (Crundall and Underwood 1998). The purpose of the present report is to extend the analysis of road-search behaviour and to determine the source of the information being used by novice and experienced drivers as they perform specific manoeuvres.

The previous study of the inspection of the road environment, as drivers encounter different road types, found that novice drivers did not differentiate between rural, suburban and dual-carriageway roads whereas on the dual-carriageway the experienced drivers increased their searches markedly (Crundall and Underwood 1998). The dependent measure of importance in that study was the variance of the search in the horizontal plane, using eye fixation data taken from a head-mounted eye-tracker. When drivers look straight ahead there is little variance of fixation position, but as they look around to check on the position and speed of traffic in adjacent lanes, then the variance increases. It was found that this measure of location variance increased on the dual-carriageway for the drivers with 9 years of driving experience, relative to other road types, but that there was no such increase for drivers who had recently completed their driving test. The task being performed by the drivers in this study was a lane change on a dual-carriageway in which there was fast-moving traffic in the lane that was to be entered. Before entering this lane the positions of the vehicles moving in the lane must be established in order to determine whether a gap is available, and the experienced drivers reflected this task by looking around them more than they had done on other roads. The novices showed no noticeable difference in their search behaviour in comparison with how they searched rural and suburban roads. An important question here is whether the novices were unaware of the danger involved in performing a lane-change in fast-moving traffic, or whether they had an inadequate level of vehicle-control skill to be able to collect more information than they were already processing.

The novices tested by Crundall and Underwood (1998) may have been unaware of the difficulty of making a lane-change on a dual-carriageway, or they may have been unable to do anything more than to maintain the vehicle's current speed, headway and lane-position. The first option here is that the mental model of the driving task is incomplete for novice drivers, perhaps because they have little experience of driving on dual-carriageways. At the time the study was conducted, it was not necessary for a trainee driver to experience dual-carriageway driving at all, and driving on these roads was not a necessary part of the driver licensing test. If the novices were unaware of the potential hazards that are associated with changing lanes then there would be little reason for them to increase their search for these hazards. The second option is that the novices were under-skilled and that the components of the driving task such as steering to maintain lane position, and maintaining the required engine speed through gear changes, were not fully

automatized (Underwood and Everatt 1996). If all of a driver's attention is occupied by the task of controlling the vehicle, then there would be little opportunity for collecting new information about neighbouring traffic.

There are two sources of evidence to suggest that novice drivers had developed a 'situation awareness' that enabled them to appreciate the increased difficulty associated with dual-carriageways, and that their difficulty is in the amount of attention required for controlling the vehicle. Crundall and Underwood (1998) reported that there was an indication of novices having longer fixation durations on the dual-carriageway, suggesting an increase in the cognitive load associated with the difficulty of the lane-change that was required. Longer fixations are associated with increasing difficulty in reading tasks (Underwood 1985, Underwood *et al*. 1990, Rayner 1998), and in a laboratory task in which we showed video clips recorded from a moving vehicle, novice drivers again had longer fixations than experienced drivers, especially when viewing dangerous situations (Chapman and Underwood 1998). The authors tentatively conclude that the novices implicitly recognized the difficulty of the lane-change manoeuvre, but did not increase their search in response to their recognition of this difficulty. This straightforward interpretation is confounded by drivers having long fixations on the rural road, but this is most likely a product of a non-demanding road requiring little search.

The second source of evidence suggestive of an adequate mental model in novice drivers comes from a laboratory study using video clips of the same roads used in the original comparison of road types (Underwood *et al*. 2001). Eye-tracking measures were again taken as novices and experienced drivers watched video clips taken from a car driven along the same route as was used in the Crundall and Underwood (1998) study, with a button-pressing hazard detection task. If the novices were unaware of the hazards on dual-carriageways, then their fixation patterns should be uniform across the three road types. Alternatively, if their fixations when driving were limited by their available attention, then they should show the same increase in search patterns as the experienced drivers. Novices may have not fully automatized their sub-routines for the operational control of the vehicle and, by eliminating this aspect of the task, resources would then be available for scene inspection (Crundall *et al*. 1999). The laboratory study found that both types of drivers increased their horizontal scanning when shown a video clip taken on a dual-carriageway. This is taken as suggesting that the novices had developed a similar mental model of the task of driving on a dual-carriageway, and that the differences in scanning when driving were a product of the relatively increased mental workload imposed on novice drivers.

One difficulty in interpreting the report by Crundall and Underwood (1998) is that each driver experienced different traffic conditions, and this problem was addressed in the video experiment using the same design but with the same stimuli shown to all drivers. A second difficulty is that the most sensitive measure of individual driver differences was a rather crude measure of variance in the location of fixations. As drivers encounter specific road traffic conditions, they should search for information specific to those conditions. When drivers overtake slower moving vehicles on a typical rural road, for example, it is crucial to know that the opposing carriageway is clear of oncoming traffic and that they themselves are not in the process of being overtaken by a faster vehicle. Similarly, when preparing to manoeuvre into an outer lane of a dual-carriageway, it is important to know when a gap in the traffic is available, and to do this it is necessary to monitor the images in the door mirror.

The present study compared the use of mirrors in novice and experienced drivers as they perform lane-changing manoeuvres on a dual-carriageway similar to the road used by Crundall and Underwood (1998). Robinson *et al.* (1972) have demonstrated that, for experienced drivers, mirror checks are sensitive to the presence or absence of traffic, and Recarte and Nunes (2000) found that mirror checks are sensitive to road complexity. The present study looks at mirror use both as a function of driver experience and road complexity. As part of a longer observation of their driving behaviour, volunteers made a safe change into an inside filter lane, a safe change into an offside lane on a slip road, and a more hazardous change to an offside lane where inter-weaving with current traffic was necessary. The extent of mirror checking is used to determine whether the increased horizontal variance previously seen in experienced drivers is, in part, a result of the increased inspection of their driving mirrors.

2. Method

2.1. *Participants*

A total of 42 participants, 21 experienced drivers and 21 novice drivers, aged from 17 to 30 years, took part in this study. Experienced drivers were recruited by using an advertisement in the local evening newspaper, and novice drivers were recruited with the help of the Driving Standards Agency. The novice drivers were recruited immediately after they had passed their driving test. The experienced drivers had a mean driving experience of 9 years, and the novices were recruited and tested shortly after their driving test (mean interval of 7.8 weeks). During this time the novices reported that they had driven an average of 835 miles. The experienced drivers reported that they drove an average of 9200 miles per annum. The mean age of the experienced drivers was 27 years and the mean for the novices was 18 years. The local Ethics Committee gave approval for the project, and comprehensive motor and personal accident insurance was provided for the drivers. The participants were therefore not liable for any vehicle damage or for third party liability, but they were obliged to drive within legal constraints, and the task did not require them to violate any traffic regulations. All drivers were paid for their participation.

2.2. *Materials*

The participants were required to drive on a fixed test route in a test car (Ford Escort) equipped with two video cameras positioned inside the car and near to the internal driving mirror and near to the driver's door mirror. These cameras were directed towards the driver's eyes. A third video camera was directed forwards, and was used to identify the field of view of the driver and the section of road being travelled. The video images of the drivers' direction of gaze and field of view were recorded via a multiplexer to a single VHS videotape. A Panasonic VHS video player and a Panasonic Editing Controller (Panasonic Ltd, Japan) were used to collect and analyse the data from the original car tapes. The visual angle subtended by the line of sight when looking directly ahead and the line of sight when looking at the internal driving mirror was 40°, and the angle to the external door mirror was 41°.

2.3. *Design and procedure*

The study used a mixed design, comparing experienced and novice drivers, three sections of roadway, and the use of two mirrors.

The three sections of roadway required different manoeuvres. In the first section the drivers were required to make one change of lane to the left. The section started at a signal-controlled junction, and with no competing traffic in the destination-lane. The manoeuvre was required in order to obtain access to a filter lane at a roundabout at the end of the section. The second section consisted of a two-lane slip-road leading from this roundabout to a multi-lane trunk road. Drivers prepared to enter the multi-lane carriageway by moving to the right lane of the slip-road. In the third section drivers had to move a further lane to the right. This section of roadway consisted of the two lanes of slip-road merging with two further lanes of trunk road. At the end of this section the four lanes diverged into two, two-lane trunk roads, and traffic from the two right-hand lanes frequently made lane change manoeuvres to join the exiting trunk road to the left. Opposite changes are made by the traffic emerging from the slip-road, in order to join the exiting trunk road to the right. These cross-over manoeuvres required vehicle integration and driver awareness of proximal traffic.

The chosen roadway was a part of the A453 dual carriageway from Nottingham towards Clifton. Each section took a minimum of 15 s to drive and had clearly defined environmental markers (road signs, road markings and road light gantries) that were used as start points for the purpose of analysis. The drive was undertaken as part of a longer drive, and participants were not alerted to the significance of the three sections of interest to this study, or to the environment markers that were to be used in the analysis.

Participants were first given a summary of the driving task that they were to perform. They were told that they were to drive normally and safely on public roads, after leaving the University campus, following instructions given to them by the experimenter, who occupied a rear seat. They were informed that various aspects of the drive would be recorded. After introducing the participants to the vehicle and demonstrating the controls, drivers were familiarized with the car's handling characteristics with a 10-min drive that did not form part of the road test. No driver expressed any difficulty during this familiarization period, and nor did they perform any manoeuvre to indicate that the study should be terminated.

3. Results

The recordings taken were duration of fixations in the direction of two mirrors, as a function of driving experience and as a function of road layout. Fixations were identified with a frame-by-frame analysis of the recording taken from each mirror camera. The sampling rate was 25 frames per second. A fixation was defined by the driver's eyes being fully directed at a given mirror camera. For each of three resultant measures—number of fixations made, total inspection time allocated to each mirror, and the mean duration of fixations—separate analyses were performed. A fixation was defined as the period between the end of an eye movement that resulted in inspection of a mirror, and the start of a movement to take the eye away from inspection of the mirror. Fixations were therefore uninterrupted periods of inspection. The total inspection time was the total duration of all fixations on each mirror during each 15-s sampling period. This is a measure of the total amount of visual attention given to each mirror, independent of the number of separate glances made by the driver.

For number of fixations and total inspection time, each analysis of variance (ANOVA) used one between-subjects factor (driving experience) and two within-

subjects factors (road layout and mirror inspected). Sometimes a driver did not look at a mirror during the sampling period, and for the analyses of number of fixations and total inspection time this was scored as zero fixations and as zero ms, respectively. For the analysis of fixation duration, where the interest was in variations of actual fixations, this neglect of a mirror resulted in missing cells, and so a separate procedure was adopted, whereby two analyses were performed upon data averaged over different conditions. This produced one ANOVA comparing drivers (between-subjects) and mirrors (within-subjects), and one ANOVA comparing drivers (between-subjects) and road layout (within-subjects).

3.1. *Number of fixations*

The number of fixations made in the direction of the internal driving mirror and the external door mirror are presented in table 1, as a function of road layout and driving experience. An analysis of variance indicated a main effect of road type (F (2, 80) = 9.5, $p < 0.001$). Scheffé comparisons indicated reduced use of mirrors in zone B (1.14 fixations), the two-lane slip-road, relative to zone A (1.68 fixations) when entering a near-side filter lane, and relative to zone C (1.87 fixations), when entering the main carriageway. (Paired comparisons, here and throughout, are reported only if reliable at $p < 0.05$ or better.) There was also a main effect of mirror used (F (1, 40) = 17.7, $p < 0.001$), with a greater number of glances towards the external door mirror (1.96 fixations) relative to the internal driving mirror (1.17 fixations), and there was no effect of driving experience ($F < 1$).

Mirror used interacted with both driving experience (F (1, 40) = 7.7, $p < 0.01$), and with road type (F (2, 80) = 21.1, $p < 0.001$), and these two interactions were analysed by inspecting the simple main effects. There was no reliable interaction between experience and road zone ($F < 1$), and no reliable three-way interaction ($F < 1$).

Whereas experienced drivers used the two mirrors to different extents, relying more on the external door mirror (F (1, 40) = 24.4, $p < 0.001$), novice drivers did not use the mirrors selectively (F (1, 40) = 1.0). There was no reliable effect of experience in the use of the internal mirror (F (1, 80) = 3.1), but experienced drivers looked more often in the external mirror (F (1, 80) = 5.1, $p < 0.01$).

The second interaction involved mirrors and road zone, with greater use of the external door mirror only in zone C, when entering the main carriageway (F (1,

Table 1. Numbers of glances in each mirror as a function of driving experience and road type (standard deviations are in brackets).

	Zone A (entering the filter lane)		Zone B (slip road)		Zone C (entering the main dual-carriageway)	
	Internal mirror	External mirror	Internal mirror	External mirror	Internal mirror	External mirror
Experienced drivers	1.33 (1.2)	2.00 (1.3)	0.81 (0.9)	1.62 (1.1)	0.67 (0.9)	3.14 (1.5)
Novice drivers	2.00 (2.0)	1.38 (1.1)	1.24 (1.3)	0.90 (1.1)	0.95 (1.0)	2.71 (1.9)

120) = 57.9, $p<0.001$). In the other zones there was no difference in the use of the two mirrors (both $F<1$).

3.2. *Total inspection time*

For each mirror in each road zone the durations of all fixations were aggregated to produce a measure of the total amount of visual attention given to that mirror. If no fixations were made, then a value of 0 ms was entered into this analysis, to reflect the neglect of the mirror. The means are presented in table 2, as a function of mirror, roadway, and driving experience. The means for each driver were entered in an analysis of variance that indicated a main effect of road type (F (2, 80) = 28.88, $p<0.001$). Scheffé comparisons indicated that in zone C, entering the main carriageway (1620 ms) mirrors received more attention than in either zone A, entering the near-side filter lane (762 ms) or in zone B, on the two-lane slip-road (681 ms). The ANOVA also revealed a main effect of mirror used (F (1, 40) = 24.46, $p<0.001$), with more attention given to the external mirror (1397 ms) than to the interior mirror (645 ms). There was no main effect of driving experience ($F<1$).

Two interactions emerged from the ANOVA. Driving experience interacted with mirror selected (F (1, 40) = 5.8, $p<0.05$), and road type also interacted with mirror selected (F (2, 80) = 22.9, $p<0.001$). These two interactions were further inspected with analyses of simple main effects. There was no reliable interaction between experience and road zone ($F<1$), and no reliable three-way interaction ($F<1$).

Drivers gave the two mirrors different amounts of attention, with no effect of driving experience in the use of the interior mirror (F (1, 80) = 2.9), but with experienced drivers looking longer than the novices in the exterior mirror (F (1, 80) = 4.2, $p<0.05$). The experienced drivers spent more time looking in the exterior mirror than in their interior mirror (F (1, 40) = 27.1, $p<0.001$), but this difference was not reliable for the novice drivers (F (1, 40) = 2.9).

The interior mirror was used to similar extents on the three sections of road ($F<1$), whereas the exterior mirror was used more selectively (F (2, 160) = 51.3, $p<0.001$). There were no differences in the use of the interior and exterior mirrors in zone A ($F<1$) or in zone B ($F<1$), but a marked increase in the use of the exterior

Table 2. Total inspection time (ms) for each mirror as a function of driving experience and road type. The durations of all fixations made by each driver during the sampling interval were aggregated in order to derive this measure of accumulated visual attention. When no fixation was made a value of 0 ms was entered for this measure (standard deviations are in brackets).

	Zone A (entering the filter lane)		Zone B (slip road)		Zone C (entering the main dual-carriageway)	
	Internal mirror	External mirror	Internal mirror	External mirror	Internal mirror	External mirror
Experienced drivers	575 (488)	991 (758)	406 (459)	1004 (640)	453 (467)	2796 (1626)
Novice drivers	796 (904)	686 (513)	690 (818)	627 (816)	952 (1068)	2280 (1931)

mirror in zone C, when the drivers were changing lane on the main carriageway (F (1, 120) = 68.9, $p < 0.001$).

3.3. *Durations of fixations*

The mean duration of each fixation in each mirror is shown in table 3, as a function of driver experience and road type. Not all drivers inspected each mirror on each section of road, and a few drivers neglected both mirrors during the 15-s sampling period. These occasions were scored as 0 fixations and as 0 s inspection in the previous analyses, but when estimating the durations of actual fixations it is appropriate to average only fixations that have been made. Introducing scores of 0 ms would result in an under-estimate of the real average. Excluding non-fixations from this analysis produces missing cells for the ANOVA, and this was handled by conducting two analyses, one in which each driver's fixations were averaged across the three road types, and one in which fixations were averaged across the two mirrors. For the first ANOVA there were then no missing cells, as every driver looked into each mirror at sometime during testing. For the ANOVA averaged across mirrors there were some drivers producing no data because they had not looked into either mirror during one section of road. This ANOVA was conducted with no data from two experienced drivers and no data from five novice drivers.

A two-factor ANOVA with fixation durations averaged across road types was used to inspect the effects of driver experience and mirror use. All drivers contributed data to this analysis. A main effect of mirrors was found (F (1, 40) = 14.1, $p < 0.001$). There was no effect of experience (F (1, 40) = 2.5) and no interaction ($F < 1$). The main effect of mirrors resulted from fixations in the interior mirror being briefer (469 ms) than those in the exterior mirror (581 ms).

A second two-factor ANOVA was conducted on fixation data averaged over the two mirrors, to inspect the effects of experience and road type. The drivers who looked into neither mirror during any road section were excluded from this analysis. The ANOVA revealed a main effect of road type (F (2, 64) = 5.9, $p < 0.01$), but no reliable effect of driving experience ($F < 1$) and no reliable interaction ($F < 1$). The main effect of road type was inspected using Scheffé comparisons. These indicated shorter fixations in mirrors in zone A (456 ms) relative to both zone B (562 ms) and zone C (590 ms). The fixations in zones B and C did not differ in duration.

Table 3. Mean duration of each fixation (ms) in each mirror as a function of driving experience and road type. When no fixation was made no value was entered for this measure, and therefore the means are derived from varying cell sizes (standard deviations are in brackets).

	Zone A (entering the filter lane)		Zone B (slip road)		Zone C (entering the main dual-carriageway)	
	Internal mirror	External mirror	Internal mirror	External mirror	Internal mirror	External mirror
Experienced drivers	438 (201)	490 (208)	480 (176)	566 (187)	461 (141)	669 (212)
Novice drivers	413 (161)	469 (142)	538 (150)	669 (165)	549 (151)	654 (303)

3.4. *Looking over the shoulder*

The video recordings were also used to count the number of drivers who looked over their shoulders during each 15-s sampling period. Neglect of a mirror may be associated with reliance upon direct inspection of the scene, and this would be indicated by frequent glances over the driver's shoulder. For the first section of road, 15 experienced drivers and 14 novices looked over their shoulder. For the second section of road, the figures for experienced and novice drivers were 8 and 3, respectively, and for the third section the figures were 14 and 15, respectively. There is no evidence here that the novices were looking over their shoulders rather than looking in their mirrors.

4. Discussion

The experiment was designed to observe the use of driving mirrors as novice and experienced drivers manoeuvred three sections of roadway, completing a lane change in each section. The concern was to determine whether the increase in variance in the location of fixations along the horizontal plane, reported by Crundall and Underwood (1998), could be attributed to experienced drivers making greater use of their mirrors under demanding driving conditions. There were no overall differences between novice and experienced drivers in the analyses of the number of mirror glances, in the total amount of attention given to the mirrors, or in the durations of the fixations on the objects in the mirrors, but driving experience was evident in a number of specific effects that emerged in interactions.

Experienced drivers used their exterior mirrors more than novices. This result was evident in the analyses of the number of fixations made and the related measure of total inspection time. Novices did not use their mirrors selectively, whereas experienced drivers directed their attention more to the exterior mirror, where information about vehicles in the next traffic lane was available. As the required manoeuvre was to move into this lane, it is clearly important to collect information about existing traffic, and to identify a gap prior to execution of the manoeuvre. Both novice and experienced drivers did increase their use of the exterior mirror in the section of road where the lane change involved negotiations with fast-moving traffic on the main highway, but this increase in selectivity was most prominent for the experienced drivers. This pattern appeared both for the number of glances in each mirror and for the total amount of attention given to each mirror. As an indication of this selectivity, consider the ratio of the amount of time given to the external mirror against that given to the internal mirror (data in table 2). For experienced drivers this ratio is 6.2 to 1, whereas for novices it is 2.4 to 1, when entering the main dual-carriageway.

The pattern of results with number of fixations was similar to that using total inspection time, suggesting that there is a very simple relationship between inspections and inspection time. This is not the case, because if inspection time were a multiplier of number of fixations and fixation duration, then all fixations would be of similar duration. The data in table 3 suggests that fixation durations show sensitivity to the task in hand, and in particular fixations in the exterior mirror were more than 100 ms longer in duration than fixations in the interior mirror. The duration of a fixation is generally taken as an indication of the difficulty or quantity of material being inspected, and this is supported here by the observation that the easiest section of roadway (entering an unobstructed filter lane with no competing traffic) attracted the shortest fixation durations. It is concluded that when drivers

looked in their internal mirrors it was to confirm the presence of a following vehicle, but when they looked in their external mirror the workload was increasing and that this was indicated by the increased fixation duration of each glance. At this point they were assessing the nature of the hazardous manoeuvre required of them by calculating the speed of the adjacent traffic, and searching for a gap between vehicles in preparation for a lane change into a stream of traffic.

The most hazardous section of two-lane highway driven here was a section that required a cross-over or inter-weaving manoeuvre, and this section prompted both groups of drivers to increase their use of the external mirror to assess the traffic in their own destination lane. This section of driving was associated with a doubling or tripling of the use of the external mirror, but even on the relatively non-hazardous sections most of the drivers checked their mirrors. On these occasions the drivers were maintaining general surveillance, possibly as a matter of habit in preparation for a manoeuvre. Even though they may not have been expecting any difficulties, they were attentive.

The previous study of driving on a dual-carriageway demonstrated an increase in the variance of horizontal fixation locations for experienced drivers, relative to other roads (Crundall and Underwood 1998), and the present results suggest that at least part of this increase can be attributed to increased use of the external mirror by these drivers. Novice drivers look around themselves less than experienced drivers to search for potential hazards and to maintain a general awareness of the locations of the neighbouring vehicles. One residual question concerns the awareness of novice drivers of the need to maintain their surveillance in general, and the search for hazardous events in particular. Our novices may have searched the surrounding roadway less than the experienced drivers because they had an under-developed 'situation awareness' of the needs of the task of lane-changing that was set them here (the incomplete mental model hypothesis). Alternatively, their mental resources may have been so completely consumed by the task of controlling the vehicle that they had no opportunity to collect information about the neighbouring traffic (the mental resources hypothesis). As already mentioned, there are two sources of evidence that suggest that novices are aware of the needs of the task, in that their fixation durations increased as the workload on the dual-carriageway increased (Crundall and Underwood 1998), and in a laboratory task that placed no demands upon their driving skills they inspected a video-recording of a dynamic roadway scene in which their search patterns resembled those of experienced drivers (Underwood *et al.* 2001). In the study presented here, there is also evidence of novices varying their behaviour as the task demands are increased. When they entered the most demanding section of the test route, they made increased use of the exterior mirror. This was not as marked an increase as that shown by the experienced drivers, but it is an indication of the sensitivity of their behaviour as the driving task changed in difficulty.

The two hypotheses are not necessarily independent, of course, and Brown and Groeger (1988) have described hazard detection as a joint function of experience and vehicle-handling skill. Experience provides an opportunity to encounter hazardous situations that are remembered and that subsequently modify the driver's behaviour when similar circumstances prevail. At the same time, an increase in driving experience helps in the development of vehicle control skill and the gradual automatization of some of these skills serves to release mental resources for tasks such as surveillance.

One difficulty with experimental studies of novice drivers is deciding whether changes is behaviour over time are the result of changes in age or traffic experience. This is a confound in the association between selective use of mirrors and the experience of the drivers, in that the experienced drivers are older than the novices. It is theoretically possible that the effects are age-related rather than experience and mileage-related. The association between accident liability and inexperience argues against this explanation. In Britain a driver in their first year of driving since passing the test has been estimated to be 69% more likely to be involved in an accident than one in their second year of driving (Forsyth *et al.* 1995). Modelling of this effect suggests that it can be largely attributed to changes in traffic experience (Maycock *et al.* 1991), with a 38% reduction in accident risk over the first year for a 17-year-old being solely attributable to the increased experience (Forsyth *et al.* 1995). Modelling such changes to account separately for age and experience is only possible when very large cohort samples are followed over time. It is strongly suspected that the differences observed between the young novices and the older more experienced drivers are largely attributable to changes in experience. However, it is not practically possible to test this directly with the experimental studies. A more fruitful approach appears to be the development of training interventions that might produce changes in the relevant behaviours (Chapman *et al.* 1998). Where such interventions are successful in moving the behaviour of novice drivers closer to that of their more experienced counterparts we not only provide evidence that experience was the important factor, we may also be achieving the more significant goal of saving lives on the roads.

There is a further explanation of the reliance of the novice drivers upon the internal mirror at times when crucial information is available only in the external mirror. When making a lane change into a lane of fast-moving traffic, in which vehicle integration required awareness of the locations of vehicles in the offside lane, more reliable information is available in the external mirror than in the internal mirror. The internal mirror provides excellent information about vehicles directly behind, and about vehicles following at some distance in all lanes. The external mirror provides information about adjacent vehicles in the destination lane prior to the lane-change manoeuvre. Both groups of drivers increased their use of the external mirror at the point in the test route when inter-weaving became necessary, but the novices did not use this mirror to the same extent as the experienced drivers. One possible explanation of this difference is that the novices had recently succeeded in a driver licensing test in which consultation of the interior mirror is stressed. Trainee drivers are encouraged to emphasize the way in which they look into the interior mirror, to ensure that their examiner has noted this behaviour, but consultation of the exterior mirror, which at times is more pertinent, is more difficult for examiners to monitor. It is this neglect in training and in the driver licensing examination that may spill-over into the driving behaviour of novices after they have successfully completed their training. Only with experience and with encounters of potentially hazardous situations do drivers learn to overcome this dependence upon their internal mirror.

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