PERGAMON

Transportation Research Part F 5 (2002) 87–97

TRANSPORTATION RESEARCH PART F

www.elsevier.com/locate/trf

Visual search while driving: skill and awareness during inspection of the scene

Geoffrey Underwood *, Peter Chapman, Karen Bowden, David Crundall

School of Psychology, University of Nottingham, Nottingham NG7 2RD, UK

Received 7 February 2002; received in revised form 19 March 2002; accepted 20 March 2002

Abstract

Novice drivers tend to restrict their search of the road on dual-carriageways, relative to the scanning observed in experienced drivers. The present study determined whether the difference was the result of novices having limited mental capacity remaining after vehicle control had been maintained, or whether it resulted from an impoverished mental model of the events likely to occur on a dual-carriageway. Novice and experienced drivers watched video-recordings taken from a car travelling along a variety of roads, including dual-carriageways, and their eye movements were recorded to determine the scanning patterns as they followed instructions to indicate hazardous events. The experienced drivers showed more extensive scanning on the demanding sections of dual-carriageway in this task. This supports the hypothesis that the inspection of the roadway by novices is limited not because they have limited mental resources residual from the task of vehicle control, but that they have an impoverished mental model of what is likely to happen on dual-carriageways.

Keywords: Visual search; Eye movements; Attention; Driver training; Skill development; Mental models

1. Introduction

When newly qualified drivers encounter difficult driving conditions, their search of the road becomes stereotypical and inflexible. Their inspection of the environment for potential hazards becomes inadequate at exactly the time when hazards are more likely to occur. When their cognitive load is increased by the appearance of multiple hazards, novice drivers tend to look inflexibly at the road directly ahead of them. This result was reported by Crundall and Underwood (1998) for the case of novices driving on a dual-carriageway that varied between two and

* Corresponding author. Tel.: +44-115-951-5313; fax: +44-115-951-5324.
E-mail address: geoff.underwood@nottingham.ac.uk (G. Underwood).

1369-8478/02/$ - see front matter
PII: S1369-8478(02)00008-6

three lanes, with sliproads and merging traffic, with novices searching along the horizontal meridian no differently on this road than on a relatively quiet rural road. Falkmer and Gregersen (2001) have recently reported a similar result, finding that learner drivers scanned the roadway less on a high-demand city route than on a less-demanding rural road. Our purpose here is to attempt to understand this paradoxical result whereby relatively unskilled drivers restrict their scanning for hazards on the roadways where hazards are most likely to appear.

Why should novice drivers fail to scan for hazards such as other vehicles merging with intersecting trajectories on the roads most likely to present them with dangers? The explanations to be considered here suggest that (i) novices need to look at road markers in order to steer the vehicle, and so are unable to look around them for hazards; (ii) novices are unable to allocate sufficient cognitive resources to visual search on these roads; and (iii) novices have an inadequate mental model of the dangers present on these roads, and choose not to look around them. These hypotheses are not independent of course, and Brown and Groeger (1988) have pointed out the relationship between experience and skill in hazard detection. As we become more skilled in handling the vehicle, with the automatisation of subtasks (Underwood & Everatt, 1996), cognitive resources are released and can be allocated to other tasks such as general surveillance. When we no longer have to concentrate on the position of the gear lever and co-ordinated sequence of clutch pedal depression and release when changing gear, then we can think about the traffic around us while performing this operation apparently without thinking about it (see Groeger & Clegg (1997) for an alternative view of the automatisation of gear changes). Increased skill is associated with an increase in the capacity for acquiring information about the events around us. At the same time as we are developing our vehicle handling skills through practice, we gain experience of traffic events that include accidents, near accidents, and hazardous conjunctions of traffic that develop our situation awareness. When we next encounter similar situations we have an increased awareness of the potential danger, and will scan the scene more extensively than previously.

The three hypotheses emphasise (i) steering control limitations; (ii) vehicle control limitations; and (iii) the driver's situation awareness or mental model. The first two hypotheses are closely related, with steering control being a special case of the demands of vehicle control. Mourant and Rockwell (1972) and Summala, Nieminen, and Punto (1996) have demonstrated that novices tend to look at the road closer to the vehicle than do experienced drivers, suggesting that they have not yet learned the use of peripheral vision for steering. If they must look at road markers close to the vehicle, then they will have limited scope for looking at other objects in the roadway. This is not quitxe the same as our second hypothesis, which sees central cognitive resources being tied up in all aspects of vehicle control, including gear changing and steering, and so the novice driver does not have resources available for scanning the road scene and acquiring new information about potential hazards. For experienced drivers, we know that varying the demand of the driving task will cause variations in their acquisition of information. Recarte and Nunes (2000) and Robinson, Erickson, Thurston, and Clark (1972) found that mirror-checking is reduced as the mental load of driving increases. Mirror-checking is a useful measure in determining the cognitive load of driving, because it is not an essential part of vehicle control except when lane-changing, unlike speed and vehicle positioning control. Underwood, Crundall, and Chapman (2002) have reported that mirror-checking also varies with driving experience, with greater selectivity of the mirror used in experienced drivers, and Schweigert and Bubb (2001) have also reported fewer fixations on mirrors and other non-essential objects as driving demands increase. As the demands of a secondary task increased, drivers compensated by reducing the frequency of glances to their mirror and also by increasing the distance to the car ahead (see also Recarte & Nunes, 2000). This evidence is consistent with the view that when driving demands increase, experienced drivers can re-allocate their cognitive resources and modify their inspection of the available scene. Crundall, Underwood, and Chapman (1999) have presented evidence that supports this hypothesis of the effective perceptual field of the driver expanding with experience.

The third hypothesis explains the increased search patterns of experienced drivers as a product of their previous traffic encounters. As they interact with other vehicles and observe the behaviour of road users, they accumulate a mental catalogue of events that happen on different kinds of roads, and of their probability of happening. Van Elslande and Faucher-Alberton (1997) have likened these situation-specific expectancies in driving to Schank and Abelson's (1977) "scripts" that can help guide us through environments that are new in themselves, but that are sufficiently similar to previously encountered circumstances for us to generalise our behaviour. A novice necessarily has an impoverished catalogue by comparison, built mainly as a non-driving road user. It is possible, therefore, that when Crundall and Underwood (1998) novices scanned the dual-carriageway to a lesser extent than the experienced drivers, they were behaving like this because they were unaware of the special dangers associated with that particular type of road. They perhaps had insufficient exposure to this kind of road with which to build a mental model of the probable behaviour of other vehicles, and did not recognise the demands of inter-weaving lanes of traffic.

The present study sought new evidence to help discriminate between these hypotheses. Novice and experienced drivers have previously inspected different types of roads in different ways, but this may be due to the resources required for vehicle control, or due to differences in their mental models of driving encounters. We tested between the hypotheses by eliminating the need to control a vehicle. Drivers sat in the laboratory and watched video-recordings taken from a car as it travelled along five different roads, including the roads used by Crundall and Underwood (1998) to demonstrate scanning differences between experienced and inexperienced drivers. If novices have restricted search because their resources are allocated to vehicle control, then eliminated this task should result in visual search patterns in the laboratory that are equivalent to those of experienced drivers. If, however, their search patterns result from a mental model that does not inform them of the particular hazards associated with dual-carriageways, then they should continue to restrict the extent of their searches while watching video-recordings of these situations. To further investigate the mental models of novices we compared the most frequently fixated objects of the novice and experienced drivers, and we also asked the drivers to estimate their frequency of glancing at the objects that were available for view. If the mental model hypothesis is correct, then novices should have difficulty in predicting the objects that are the subject of the experienced driver's attention because they have not yet developed expectancies of the roadway events that can occur.

2. Method

2.1. Participants

Sixteen novice drivers and 16 experienced drivers were paid for their participation in this study. The novices were recruited as they passed their driving test, with the help of the UK Driving

Standards Agency, and had a mean age of 21.4 years and at the time of participating in the study they had a mean driving experience of 0.08 years. The experienced drivers were recruited through advertisements placed locally, and they had a mean age of 22.6 years and mean driving experience of 4.59 years. All drivers had normal or corrected-to-normal vision.

2.2. Materials and apparatus

Five video-recordings were taken from a moving car, with a camera mounted near the internal driving mirror, thereby providing a moving image of the view from a perspective close to the driver's position. The recordings were taken from the same route driven by the participants reported by Crundall and Underwood (1998), on rural, suburban and dual-carriageway roads. Each recording lasted 45 s and was selected on the basis of being characteristic of traffic conditions on each road.

The rural clip illustrated a drive along a two-lane road on which there was light traffic in each direction, and trees and open fields on each side of the road. The suburban clip showed a drive through a built-up area of houses and shops, with parked cars, other vehicles, and pedestrians clearly visible. Three of the recordings were taken on dual-carriageways, to capture driving under conditions of varying demand. In the first section of dual-carriageway there were four other vehicles visible travelling in the same direction as the camera, and no vehicles changing lane. This recording depicts an undemanding section of dual-carriageway. In the second recording, on a different section of road, vehicles were seen to be entering the main carriageway from a slip road, other vehicles were seen to exit from the main carriageway via a nearside slip road, and other vehicles changed between the two main lanes of the carriageway. This recording depicts a demanding section of dual-carriageway. The third recording showed a demanding section of different dual-carriageway, again with extensive interweaving, merging and exiting traffic.

The video-recordings were shown on a television monitor at a distance of 65 cm from the participants, projecting an image that subtended 42° horizontally and 31° vertically. Eye movements were recorded with a NAC EyeMark VII head-mounted eye-tracker. Participants sat directly facing the television monitor holding a sham response button box appearing to be attached to the back of a computer.

Two questionnaires were prepared with the purpose of determining what the experienced drivers thought they had been looking at, and what the novices thought that the experienced drivers would have been looking at. The questionnaires were divided into four sections, relating to different road types: rural, suburban, dual undemanding and dual demanding. For each of these road types the questionnaire listed the categories of objects visible in the video-recordings. The instructions on the questionnaires asked participants to enter a percentage next to each category of object, to indicate the amount of time that they thought that experienced drivers would have looked at these objects. The objects identified for each of the roads listed all objects that could be inspected and was as follows:

Rural road: Lane marking and edge of road; scenery; road ahead as far as can be seen; car in front; road directly in front of and adjacent to the vehicle; oncoming traffic.

Suburban road: Road ahead as far as can be seen; road directly in front of and adjacent to the vehicle; oncoming traffic; pavement; parked cars; shops and houses; pedestrians; side roads; kerbs, lane markings and traffic islands.

Undemanding dual-carriageway: Road directly in front of and adjacent to the vehicle; oncoming traffic; road signs; road barriers and lane markings; slip roads; vehicles in adjacent lanes; oncoming traffic vehicles travelling directly ahead; verges and scenery; road ahead as far as can be seen.

Demanding dual-carriageways: Road directly in front of and adjacent to the vehicle; oncoming traffic; road signs; road barriers and lane markings; slip roads; vehicles in adjacent lanes; oncoming traffic vehicles travelling directly ahead; verges and scenery; road ahead as far as can be seen; vehicles changing lanes.

2.3. Procedure

All participants were fitted with the eye-tracker, and the equipment calibrated using markers on the TV monitor. Recalibration was then done as necessary, during the interval between presentation of each of the five video-recordings.

Participants were instructed that they should watch the recordings as if they were the driver of the car, identifying as quickly as possible anything that happened that required the driver's attention. They were instructed to press the response button whenever such an event occurred. They were shown the video recordings in the order described above, i.e., rural, suburban, dual-undemanding, dual-demanding (1), and dual-demanding (2). This was the order in which the roads were encountered in the Crundall and Underwood (1998) study.

After watching the five video-recordings each participant was presented with the questionnaire that listed the possible items that could have been inspected in each recording. Although there were two recordings of demanding dual-carriageways, similar objects were visible, and so these two recordings were classified together. Participants were asked to offer an opinion as to the percentage of time that experienced drivers would have looked at these objects while watching the recordings.

3. Result

Eye fixation measures were taken from each participant while they watched each of the five recordings. The three measures taken were the mean fixation duration, variance of search along the horizontal plane, and variance of search along the vertical plane. These measures are presented in Table 1.

3.1. Fixation durations

Fixations were classified as occurring whenever three successive data samples from the NAC Data Processing Unit fell within two degrees of each other (for consistency with Crundall & Underwood, 1998). This gave a minimum fixation duration of 100 ms, and enabled pursuit tracking to be regarded as fixations.

The fixation durations summarised in Table 1 were submitted to a two-factor (road type and driver experience) mixed-model analysis of variance that revealed a main effect of road type ($F_{(4,120)} = 69.65, p < 0.001$), no effect of driving experience ($F_{(1,30)} < 1$), and no interaction between

Table 1
Mean fixation durations (ms) and variance of fixation locations along the horizontal and vertical axes, for novice and experienced drivers as they watched video-recordings of five road types (standard deviations are in brackets)

	Rural	Suburban	Dual-carriageway		
			Undemanding	Demanding (1)	Demanding (2)
Mean fixation duration (ms)					
Novice drivers	836 (376)	512 (78.4)	656 (269)	466 (98.5)	516 (147)
Experienced drivers	822 (200)	509 (81.1)	727 (338)	502 (162)	478 (95.3)
Horizontal variance (°)					
Novice drivers	25.9 (12.0)	40.5 (15.2)	25.9 (11.9)	42.3 (15.4)	44.0 (17.9)
Experienced drivers	28.4 (7.1)	50.2 (13.5)	32.5 (13.9)	56.5 (19.8)	61.9 (20.9)
Vertical variance (°)					
Novice drivers	2.89 (1.83)	4.43 (2.59)	5.04 (2.48)	5.78 (3.49)	9.56 (3.63)
Experienced drivers	2.40 (1.25)	4.14 (2.64)	4.45 (2.18)	6.58 (4.08)	11.60 (4.68)

these two factors ($F_{(4,120)} = 1.38$). The effect of road type was further inspected with Scheffé pairwise comparisons, with a significance level of $p = 0.01$. Participants made longer fixations while watching the rural road in comparison with all other roads, and longer fixations on the undemanding dual-carriageway in comparison with two demanding dual-carriageways and the suburban road.

3.2. Variance of horizontal search

The horizontal variances summarised in Table 1 were submitted to a two-factor mixed-model analysis of variance that indicated a main effect of road type ($F_{(4,120)} = 40.58$, $p < 0.001$), a main effect of driving experience ($F_{(1,30)} = 5.75$, $p < 0.05$), and an interaction between these two factors ($F_{(4,120)} = 2.66$, $p < 0.05$). Scheffé comparisons indicated reduced variance on both the rural road and on the undemanding dual-carriageway, in comparison with the suburban road and the two demanding dual-carriageways. The effect of driving experience, as indicated in Table 1, is that novices had reduced variance in their fixations compared to the experienced drivers. The interaction was further inspected with an analysis of simple main effects that indicated a difference between drivers on both of the demanding dual-carriageways ($F_{(1,150)} = 6.92$, $p < 0.01$, and $F_{(1,150)} = 10.98$, $p < 0.001$, for these two roads), and no difference between drivers on the rural road, suburban road, or undemanding dual-carriageway.

3.3. Variance of vertical search

A two-factor mixed-model analysis of variance was applied to the vertical variances that are summarised in Table 1. There was a main effect of road type ($F_{(4,120)} = 44.58$, $p < 0.001$), but no effect of driving experience ($F_{(1,30)} < 1$), and no interaction ($F_{(4,120)} < 1$). Scheffé comparisons indicated that the main effect of road type was due to reduced vertical variance on the rural road, compared to all four other road types. Secondly, the demanding dual-carriageway (2) had increased variance relative to the other four road types.

3.4. Content analysis of fixations

Each fixation made by the participants was categorised according to the objects mentioned in the questionnaires, and listed above. The fixations made on objects within each of the categories were aggregated, and used to calculate the percentage of time each participant spent looking at each category of object. Table 2 presents the most frequently fixated class of object by the experienced drivers, the percentage of time that the experienced drivers fixated this class of object, and the percentage of time the novices looked at these same objects.

These percentages were compared with a series of t-tests. On the undemanding dual-carriageway, the experienced drivers looked at vehicles travelling directly ahead more often than novices ($t_{(30)} = 2.39$, $p < 0.05$), and on the demanding dual-carriageway (2) they looked at vehicles in adjacent lanes more than the novices ($t_{(30)} = 4.04$, $p < 0.001$). Percentages on the other roads did not differ.

Two further analyses were performed, using the questionnaire estimates of where each group of drivers thought that the experienced drivers would look. The questionnaire estimates are presented in Table 3. Again, the baseline for comparison was the class of objects that the experienced drivers had actually inspected. So, for rural roads, where experienced drivers looked at the car ahead for 45% of the time, these analyses compared this value with the estimates made by the novices and experienced drivers of the amount of time that they thought an experienced driver would look at the car ahead. Fixation data from the two demanding dual-carriageways was averaged for comparison with the questionnaire estimates.

For the experienced drivers, the comparisons were between what they looked at and what they thought they had looked at. These comparisons were made with dependent-means t-tests, and all four comparisons were reliable. In each case they experienced drivers under-estimated the amount of time that they thought they had looked at the objects on rural roads ($t_{(15)} = 2.64$, $p < 0.01$), on suburban roads ($t_{(15)} = 4.47$, $p < 0.001$), on undemanding dual-carriageways ($t_{(15)} = 3.37$, $p < 0.01$), and on demanding dual carriageways ($t_{(15)} = 3.37$, $p < 0.01$).

For the novice drivers, the comparisons were between what they thought experienced drivers did and what they thought they themselves would do after they had gained more experience. To perform this task the novice drivers needed to believe that they knew what they should have been

Table 2
Mean percentages of inspection times on the most frequently inspected classes of objects on the five road types, and by the two groups of drivers

	Rural	Suburban	Dual-carriageway		
			Undemanding	Demanding (1)	Demanding (2)
	Car ahead	Parked cars	Car in front	Car in adjacent lane	Car in adjacent lane
Fixations by novice drivers	34.8 (17.0)	18.7 (8.2)	32.9 (16.5)	22.3 (11.6)	17.2 (6.7)
Fixations by experienced drivers	45.0 (15.6)	22.6 (9.7)	45.4 (12.8)	28.4 (8.3)	26.8 (6.8)

The most frequently fixated objects inspected by the experienced drivers are used as the baseline here, with the novices' percentages of fixations on those objects presented for comparison. Standard deviations are in brackets.

Table 3
Mean percentages of estimates of inspection times, made by an experienced driver, on the most frequently inspected classes of objects on the five road types, and by the two groups of drivers

	Rural	Suburban	Dual-carriageway	
			Undemanding	Demanding
	Car ahead	Parked cars	Car in front	Car in adjacent lane
Estimates by novice drivers of fixations by experienced drivers	26.9 (15.4)	9.38 (5.5)	23.4 (8.5)	12.9 (6.8)
Estimates of experienced drivers of fixations by experienced drivers	34.1 (17.4)	11.8 (5.5)	31.3 (10.4)	18.4 (9.1)

The most frequently fixated objects inspected by the experienced drivers are used as the baseline here, with the experienced drivers and novices' percentages of fixations on those objects presented for comparison. Standard deviations are in brackets.

looking at, and how they would behave when they had gained more experience. None of the novice drivers expressed any difficulty in performing this task. The comparisons for each road type were made with independent-means t-tests, and all four comparisons were reliable. In each case, the novices underestimated the amount of time that the experienced drivers looked at the most fixated objects on rural roads ($t_{(30)} = 3.30$, $p < 0.01$), on suburban roads ($t_{(30)} = 4.72$, $p < 0.001$), on undemanding dual-carriageways ($t_{(30)} = 5.72$, $p < 0.001$), and on demanding dual-carriageways ($t_{(30)} = 6.30$, $p < 0.001$).

4. Discussion

Novice and experienced drivers watched video-recordings taken from a car travelling along a range a road types, and their eye movements were recorded in order to determine whether they showed the same pattern of fixations as drivers who were in control of the vehicle. In previous studies it has been shown that on demanding roads novice drivers restrict the extent of their search of the environment (Crundall & Underwood, 1998; Falkmer & Gregersen, 2001). Specifically, when experienced drivers encounter a dual-carriageway with merging traffic, they look around them to a greater extent that do novices. The question asked by the present laboratory study was whether the novices fail to inspect the scene thoroughly because they have limited mental resources available after the demands of controlling the vehicle, or because they have a mental model of driving on a dual-carriageway that is incomplete in that it does not include expectations of inter-weaving vehicles that present potentially hazardous events. By placing the novices in a passive laboratory, in which the task is to watch a video-recording, the demands of vehicle control are eliminated. In this situation an adequate mental model of the dual-carriageway should lead to extensive scanning along the horizontal plane by both experienced and novice drivers. The analysis of the spatial variability of fixations in the horizontal plane found a difference between the two groups of drivers, with this variability of scanning being more extensive for the experienced drivers when they watched scenes recorded on both of the demanding sections of dual-carriageway (see Table 1). This suggests that even when they do not have control of the vehicle they still do not look around them as much as the experienced drivers, and that the cause of the scanning difference is not associated with the need to fixate lane markings for steering control, or with more general demands of vehicle speed and direction. It is more likely, therefore that novices fail to scan the roadway because they have not yet developed an understanding of the kinds of events that occur on these roads, or of the need to monitor adjacent vehicles that may be intending to change lane and thereby possibly require a change in the driver's own position on the road. An alternative explanation of the fixations of the novices is that they were, more simply, pursuing their habitual fixation patterns, being unable to adapt to the less rigorous conditions of the laboratory. This hypothesis would suggest that the novices could have looked around them more than they did in our laboratory task, but that their habitual scanpaths search patterns that persisted in looking close to the centre of the screen.

We have previously reported a laboratory study in which novice and experienced drivers watched video-recordings similar to those used here, but with somewhat different results (Underwood, Dobson, Chapman, & Crundall, in press). That study showed drivers just three video-recordings—a rural road, a suburban road, and a dual-carriageway that would be classified as undemanding. The pattern of results on these three roads was similar to the pattern in the present study. The difference between the studies is that we have now introduced video-recordings of demanding dual-carriageway driving in which adjacent vehicles change lane and inter-weaving manoeuvres are seen. It is the introduction of these recordings, and the differences between novices and experienced drivers as they watch the recordings, that leads us to the conclusion that the two groups of drivers are expecting different events, and that the experienced drivers have a richer mental model of driving on these kinds of roads.

In terms of cognitive descriptions of the development of expertise, we can say that the experienced drivers have developed a procedural understanding of the task (Anderson, 1983), and that their knowledge is implicit (Underwood & Bright, 1996). The subtasks are described in such a conceptualisation as having become automatised or compiled, and are unavailable to conscious scrutiny and verbal report. This model of skill acquisition distinguishes between procedural knowledge and declarative knowledge, and the questionnaire presented to our drivers after they had watched the video-recordings was designed to investigate their access to their knowledge of what they had looked at. In the case of the novice drivers, the questionnaire determined whether they know they might have looked at had they had more driving experience. The analysis of what the drivers did look at confirmed the difference between novice and experienced drivers. On an undemanding dual-carriageway the experienced drivers looked more than the novices at the car immediately ahead, possibly in anticipation of that car braking. On a demanding section the experienced drivers made more glances towards the adjacent traffic lane than did the novices, possibly checking for the appearance of a car intending to perform an inter-weaving manoeuvre. In each of these cases the novices inspected the objects selected by the experienced drivers less often. Differences were also found in the estimates of the fixation of objects made by the two groups of drivers.

Differences were found in the extent to which experienced drivers actually looked at objects, in comparison with the estimates of these fixation frequencies made by the two groups of drivers. In the case of the experienced drivers, the comparison was between what they had actually looked at, and what they thought they had looked at. On each road type they under-estimated the extent of fixation of the most frequently fixated object, consistent with the view that skill acquisition is associated with reduced declarative knowledge. The experienced drivers were inaccurate in their estimates what they looked at just a few minutes previously. In the case of the novice drivers, the comparisons were between what the experienced drivers did, and what they believed the experienced drivers did. Again, the pattern was one of under-estimation. On each type of road the estimates made by the novices were lower than the actual fixation frequencies made by experienced drivers. Both groups of drivers under-estimated the actual fixation frequencies of experienced drivers, but the data in Table 3 show that on all types of roads the novices were particularly inaccurate. The inaccuracies shown by all drivers in estimating what an experienced driver would look at, is an indication that the mental models used by drivers are implicit and not readily accessible to introspection.

The use of the present technique, whereby drivers watch video-recordings, is clearly some distance from an actual driving task, and its validity can be questioned as a measure of driving ability. The purpose, however, was not to assess driving performance but to observe how novice drivers scan a road scene when they do not have to control the vehicle. The task indicated differences between novice and experienced drivers that support the hypothesis that their inspection of the roadway is limited not because they have limited mental resources residual from the task of vehicle control, but that they have an impoverished mental model of what is likely to happen on dual-carriageways. Their mental model will develop as they encounter these kinds of roads and collect experiences of vehicles changing lanes in their proximity, but it also possible that they can could be made more aware of the problems associated with these roads through training targeted on the need to search for potential hazards.

Acknowledgements

We are very grateful to Mr. Peter Burton and his colleagues at the Driving Standards Agency, for help with the recruitment of the newly qualified drivers who participated in this study. Luis Nunes, Miguel Angel Recarte and Boris Velichkovsky provided invaluable comments on an earlier draft of this paper.

References

Anderson, J. R. (1983). *The architecture of cognition*. Cambridge: Harvard University Press.

Brown, I. D., & Groeger, J. A. (1988). Risk perception and decision taking during the transition between novice and experienced driver status. *Ergonomics, 31*, 585–597.

Crundall, D., & Underwood, G. (1998). Effects of experience and processing demands on visual information acquisition in drivers. *Ergonomics, 41*, 448–458.

Crundall, D., Underwood, G., & Chapman, P. (1999). Driving experience and the functional field of view. *Perception, 28*, 1075–1087.

Falkmer, T., & Gregersen, N. P. (2001). Fixation patterns of learner drivers with and without cerebral palsy (CP) when driving in real traffic environments. *Transportation Research F, 4*, 171–185.

Groeger, J. A., & Clegg, B. A. (1997). Automaticity and driving: time to change gear? In T. Rothengatter, & E. Carbonell Vaya (Eds.), *Traffic and transport psychology: theory and application* (pp. 137–146). Oxford: Pergamon.

Mourant, R. R., & Rockwell, T. H. (1972). Strategies of visual search by novice and experienced drivers. *Human Factors, 14*, 325–335.

Recarte, M. A., & Nunes, L. M. (2000). Effects of verbal and spatial-imagery tasks on eye fixations while driving. *Journal of Experimental Psychology: Applied, 6*, 31–43.

Robinson, G. H., Erickson, D. J., Thurston, G. L., & Clark, R. L. (1972). Visual search by automobile drivers. *Human Factors, 14*, 315–323.

Schweigert, M., & Bubb, H. (2001). Eye movements, performance and interference when driving a car and performing secondary tasks. Paper presented at the *Vision in Vehicles 9* conference, Brisbane, August.

Summala, H., Nieminen, T., & Punto, M. (1996). Maintaining lane position with peripheral vision during in-vehicle tasks. *Human Factors, 38*, 442–451.

Underwood, G., & Bright, J. E. H. (1996). Cognition with and without awareness. In G. Underwood (Ed.), *Implicit cognition* (pp. 1–40). Oxford: Oxford University Press.

Underwood, G., Crundall, D., & Chapman, P. (2002). Selective searching while driving: the role of experience in hazard detection and general surveillance. *Ergonomics*, *45*, 1–12.

Underwood, G., Dobson, H., Chapman, P., & Crundall, D. (in press). Eye movements during the inspection of dynamic traffic scenes. In Gale, A. G., Brown, I. D., Haslegrove, C. M., & Taylor, S. P. (Eds.) *Vision in vehicles VIII*. Amsterdam: Elsevier.

Underwood, G., & Everatt, J. (1996). Automatic and controlled information processing: the role of attention in the processing of novelty. In O. Neumann, & A. F. Sanders (Eds.), *Handbook of perception and action III: attention* (pp. 185–227). London: Academic Press.

Van Elslande, P., & Faucher-Alberton, L. (1997). When expectancies become certainties: A potential adverse effect of experience. In T. Rothengatter, & E. Carbonell Vaya (Eds.), *Traffic and transport psychology: theory and application* (pp. 147–159). Oxford: Pergamon.