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Visual search patterns in trained and untrained novice drivers

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Abstract

As drivers become more experienced many changes have been observed in their patterns of visual search. Differences between novice and experienced drivers are particularly marked in demanding or hazardous road situations and this has led researchers to speculate that limitations in search patterns may explain some of the accidents where newly qualified drivers are involved. This paper reports a training intervention that informs novice drivers about their typical patterns of visual search and stresses the need for scanning multiple locations in the visual scene for sources of potential danger. Two groups of drivers were evaluated on three occasions over the course of their first year after gaining a full driving licence. The evaluations involved recording drivers' eye movements while driving a route on real roads in traffic, and while watching videos of hazardous situations. One of the groups received the training intervention before the second occasion of testing. The intervention produced notable changes in the drivers' search patterns in both situations though not all changes were still detectable at a final phase of testing three to six months after the intervention had been delivered.

Keywords: Visual search; Driver training; Hazard detection; Eye movements

1. Introduction

A newly qualified driver has been estimated to be approximately three times more likely to be more involved in a road traffic accident than one with five additional years of age and driving experience (Maycock, Lockwood, & Lester, 1991). Studies in our laboratory (e.g. Chapman & Underwood, 1998a,b; Crundall & Underwood, 1998) have consistently found that visual search strategies, especially in hazardous situations differentiate between these groups of drivers. This paper describes a brief training intervention which has been designed to teach novice drivers' about

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the deficiencies in their visual search. This paper briefly overviews some of the theoretical justification for this intervention and describes a large evaluation study which compares visual search in novice drivers who have taken part in the intervention with a control group who have not. As well as providing a test of the intervention, the study also provides insight into the development of driving styles and visual search over the course of the first year of licensed driving.

1.1. Drivers' eye movements

Many studies have recorded and analysed drivers' eye movements. From a road safety perspective it is common sense that a driver must look at the appropriate locations in a traffic scene in order to gain information about risks and potential risks in the scene. At a more theoretical level it can be argued that an analysis of a driver's eye movements provides insights into the driver's processing of the visual scene which may not be consciously available to the driver for self-report. The basic patterns of drivers' eye movements are well known from a number of studies. For much of the time the driver fixates an area near to the focus of expansion (the point in the moving visual field ahead of the driver where fixed objects appear stationary) with regular excursions to items of road furniture, road edge markings, and other vehicles (e.g. Helander & Söderberg, 1972; Mourant & Rockwell, 1970). As the visual field becomes more complex, the number of eye movements made increases, and the mean fixation duration decreases (Erikson & Hörberg, 1980; Miura, 1990). There are also a number of interactions between the type of road environment and the events occurring. Thus mean fixation durations tend to be longer when viewing films of rural roads than urban ones (Chapman & Underwood, 1998a), reflecting the greater visual complexity of the urban scenes, but are longer when dangers are present than when they are absent (Chapman & Underwood, 1998a,b). While the first effect may be driven purely by the visual characteristics of the scene, the second presumably reflects the driver's knowledge about danger and the additional time spent processing such information.

Support for the conclusion that fixation durations represent the time spent processing hazard-related information is provided by the finding that newly qualified drivers appear to be more affected by this than more experienced drivers (Chapman & Underwood, 1998a), with novices tending to fixate for longer than experienced drivers in hazardous situations. Differences with experience have also been reported in the spread of visual search. Mourant and Rockwell (1972) reported that novice drivers concentrate their search in a smaller area, closer to the front of the car. More recently Crundall and Underwood (1998) have reported differences in horizontal search, with experienced drivers having greater spread of search when driving on dual-carriageways.

1.2. Training visual search

Changes in visual search as a function of traffic experience suggests that improvements in visual search are one of the factors that contribute to the lower accident rates of older, more experienced drivers. Research in our laboratory has provided some tentative support for this conclusion. We have found that drivers with longer fixation durations while watching films of hazardous situations tend to score more highly on a questionnaire measure of accident liability. This effect appeared both for a mixed group of novice and more experience drivers, $r(115) = 0.24, p < .01$, and for the group of novice drivers on their own, $r(74) = 0.28, p < .05$. This also accords with the beliefs of the many driving instructors who stress the importance of a wide and rapid pattern of visual search to their pupils (e.g. Miller & Stacey, 1995). It would clearly be of great interest to know whether measures of visual search in experienced drivers correlate with actual accident involvement for such samples, however, to our knowledge no study has yet explored this possibility. Nonetheless, there is good reason to hope that improvements in novice drivers' visual search strategies might bring about a reduction in the high number of accidents that such drivers are involved in.

There are dangers in assuming that visual search itself can be taught to drivers. It is possible that observable changes in visual search are themselves caused by deeper understanding of road situations. Consequently we have chosen to develop an intervention which not only teaches visual search strategies, but attempts to teach some of the underlying skills upon which we expect such strategies to rely. A good prior knowledge of the road environment and the potential sources of danger will allow drivers to rapidly process new information and assess its relevance to the current road situation. We assume that the shorter fixation durations of experienced drivers in hazardous situations reflect their greater knowledge of such situations from past experience. This allows current information to be rapidly processed within existing schemata, and irrelevant information to be quickly dismissed. Once information at the current point of regard has been processed, the driver needs to fixate new areas of the visual scene for alternative sources of information. Regular scanning of many areas of the visual field may be necessary to ensure that the driver rapidly becomes aware of changes in the behaviour of other traffic participants. A failure to scan sufficient locations has sometimes been described as 'perceptual capture'.

Many authors have stressed the importance of anticipation, particularly in the context of hazard perception ability (e.g. McKenna & Crick, 1994). Anticipation is clearly a key ingredient in successful scanning in that good anticipation of the road ahead and the behaviour of other traffic is necessary both in selecting appropriate areas of the visual field to fixate next and in knowing when the behaviour of the object currently fixated is sufficiently unpredictable that extended fixation of that object is required. Our aim in designing an intervention to improve newly qualified drivers' visual search strategies was to train all three of these components—knowledge, scanning, and anticipation, rather than simply focusing on changing observable patterns of eye movements.

1.3. A training intervention

An intervention was designed that could be delivered in the form of a short training video. The video and procedure were chosen to train the three types of skill identified above and to provide a research tool for understanding the way in which such skills might change during the course of the intervention. The training video was based around a selection of films of potentially dangerous driving situations. Films used for the training intervention were chosen such that they would not subsequently appear in any of the tests that we used for evaluating the effects of training. The whole training took less than one hour and was divided into five stages as follows:

1.3.1. Initial commentary

In this task drivers watch four films of potentially dangerous driving situations. They provide a running commentary describing what they are looking at. They also press a response button as soon as they detect dangers in the situation. This stage both provides a baseline level of performance for the individual and encourages them to think about where they are looking by having to verbalise. Having to describe these hazardous situations is expected to improve drivers' knowledge of such situations.

1.3.2. Visual search task

Here drivers watch five new clips of potentially dangerous situations. The clips are played at half speed so that the driver has plenty of time to anticipate what will happen next and to describe both what they are looking at and what they think is potentially hazardous. Here a widened visual search is encouraged by having critical areas of the visual scene circled. Areas of general interest are circled in blue while areas of the scene constituting a specific current hazard are circled in red. The slow speed of the clips gives the driver plenty of time to understand why objects in each area are potentially hazardous and encourages them to anticipate the future actions of traffic participants. After the driver has described each clip they watch the clip again and listen to an expert commentary on the same clip which describes why each area was circled.

1.3.3. Anticipation and hazard processing task

This time five clips are presented but each is stopped at critical moments and the driver is asked either to anticipate what will happen next, or to answer a question about what has just happened. This task is aimed to both encourage the driver to anticipate future events and to process previous events deeply. After the driver has had time to answer the question the clip is replayed and the correct answer is provided with an explanation.

1.3.4. Skill development

In this stage the 10 clips from the previous two stages are replayed at full speed, but with red and blue circles superimposed on them as in the visual search task. The driver's task is to comment on the clip and spot hazards as in the initial commentary task. The purpose of this stage is to give the driver a chance to use the visual search skills taught in the second stage of the intervention with films running at full speed and to use the knowledge from the previous stage to anticipate forthcoming hazards.

1.3.5. Unsupported commentary

In this final stage the drivers watch a further four films and perform commentary and button responses as in the initial task. This provides a final chance to use the skills from the previous stages without the support provided by circles on the video. It also provides a final performance measure that can be compared with their initial performance. Although the intervention itself is designed to provide a way of assessing the driver's progress, in this paper we will focus on a separate evaluation study which explores the effects of the intervention on visual search measures when performing separate tasks.

2. Method

2.1. Participants

143 newly qualified drivers were recruited with the aid of the Driving Standards Agency who arranged for questionnaires to be distributed to all successful practical driving test candidates in

Nottingham and surrounding areas. Drivers were divided at random into control and intervention conditions.

2.2. Procedure

Drivers were tested three times during the first year of driving after passing their practical test. The first occasion was as soon as possible after passing the test, the second occasion was three months later, and the final occasion was a further three to six months later in the year. On each occasion of testing they performed a number of tasks and filled in several questionnaires. Each time they were tested the participants took part in a drive on real roads in an instrumented vehicle. The vehicle was a standard saloon car with manual transmission. Vehicle speed and other controls were recorded continuously on and in-car computer, and when another vehicle was being followed, its distance was recorded using a laser rangefinder mounted behind the radiator air inlet on the front of the vehicle. After an initial drive of approximately 20 min, the driver stopped the vehicle and the experimenter fitted a NAC 7 eyemark recorder on the driver's head. For the remaining part of the drive (approximately 15 min) eye movements were recorded on NTSC video, superimposed on a field view of where the driver's head was facing. This part of the study and the analysis of eye movement data replicates the procedure described in Crundall and Underwood (1998). The full drive was designed to include a variety of road types (urban, rural, and dual-carriageway) and a variety of speed limits (30, 40, 60 and 70 mph).

At each phase of testing, drivers also watched a series of 13 short videos of potentially dangerous driving situations. Three matched sets of 13 videos were used and administration of different sets was counterbalanced across participants over the three phases of testing such that all participants had viewed all 39 videos by the end of testing. While watching the videos, participants were asked to press a response button whenever they detected a hazardous event. Participants' eye movements were recorded using a Dual Purkinje Image Generation 5.5 Eyetracker from Fourward Technologies. The order in which the drive and video task took place was randomized across participants.

At the second occasion of testing, immediately before the drive and the video tasks approximately half of the drivers took part in the brief training intervention described above. The remaining drivers took part in a control condition which involved answering questions about their own driving histories and experiences. Either the training intervention or the control condition took approximately 50 min to complete.

3. Results

Following up newly qualified drivers over the course of a year is a difficult challenge, especially since the post-qualification period is frequently marked by the move from school to college or university often in another part of the country. Of the 143 drivers who took part in the initial testing, we were able to test 116 at the second phase, at which the intervention was administered to 57 of those present. We were able to test 103 at the final phase, three to six months after the intervention. There was thus a considerable loss of participants over the three phases of testing. In addition it was not always possible to obtain good eye tracking data at all phases of testing, or to guarantee that each driver would have sufficient opportunities for a free choice of speed or headway at each phase. In the analyses that follow, whenever possible we compare over all three phases of testing, for both groups and split by roadway type, however, in most cases it is necessary to aggregate over roadways or phases in order to increase the sample size for particular comparisons. Where this has been done it is noted in the text, elsewhere, the sample size available for full analyses in made clear by the degrees of freedom in individual analyses, though this will differ from measure to measure. Where analyses compare control and intervention groups, data from the 27 drivers who only completed the first stage of testing are automatically excluded.

3.1. Speed and headway

For the purposes of analysis, 18 fixed locations were identified on the route. Based on the readings from the headway monitor and inspection of a video recorded from a forward facing camera, each driver was classified into one of three categories at each of these 18 locations. These categories were directly following another vehicle, having a free choice of speed, or having their speed influenced by other aspects of the road situation without directly following a particular vehicle. Occasions where they were directly following another vehicle were used to calculate that driver's average time headway when following, and occasions where they had a free choice of speed were used to calculate the driver's average free speed. Data from the third category were discarded. Table 1 summarises these speed and headway choices across the four different speed zones for the three phases of testing. The relatively low speed in the 60 and 70 mph zones are worth commenting on. The 60 mph zones were generally rural country roads with regular bends that would make it extremely difficult to continuously exceed the speed limit, while the 70 mph

Table 1
Mean free speeds (mph) in under four different speed limits when no vehicle was immediately ahead, and time headways (s) when following another vehicle

	Speed limit (mph)			
	30	40	60	70
Free speed				
Before training	27.57	41.53	45.40	47.49
(s.d.)	(4.63)	(5.33)	(4.32)	(4.67)
After training	25.87	42.89	47.87	49.37
(s.d.)	(4.95)	(5.22)	(5.14)	(5.02)
Follow-up	27.29	43.54	47.90	49.88
(s.d.)	(3.69)	(5.08)	(4.37)	(4.93)
Time headway				
Before training	2.18	1.61	1.26	1.41
(s.d.)	(1.19)	(0.66)	(0.39)	(0.81)
After training	2.05	1.56	1.33	1.10
(s.d.)	(0.55)	(0.51)	(0.25)	(0.22)
Follow-up	1.92	1.52	1.22	1.07
(s.d.)	(0.58)	(0.58)	(0.38)	(0.29)

Group standard deviations are provided below each mean.

speed limits apply to relatively short sections of urban multiple carriageway roads, where the need to change lane regularly is likely to constrain the drivers' speed choices.

For the purposes of analysis, speed and headway data were aggregated across the four speed limit zones. There was a main effect of phase of testing, with speeds having increased significantly by the final phase of testing, $F(2, 168) = 6.82$, $p < 0.01$, however, there were absolutely no differences between the control and intervention groups, $F(1, 84) = 0.01$, and no interaction between groups and phase of testing, $F(2, 168) = 1.72$. Time headways also appeared to reduce by the final phase of testing, although the overall analysis was not significant, $F(2, 96) = 1.36$, and neither were group differences, $F(1, 48) = 0.60$, or interactions, $F(2, 96) = 0.12$. To increase the data available for analysis, mean headways from the initial two phases of testing were averaged and this average was compared to the follow-up data. In this analysis the reduction in headway is found to be significant, $F(1, 71) = 6.64$, $p < 0.05$, although there is once again no group effect, $F(1, 71) = 0.98$, or interaction, $F(1, 71) = 0.34$.

3.2. On road visual search

Three sections of the route were selected for detailed eye movement analysis. Each section consisted of 45 s of driving where conditions were relatively constant for all subjects (e.g. areas likely to be relatively uncongested and free from traffic controls). The three sections differed in the type of road environment involved (rural, urban, and dual-carriageway). Because of missing data in numerous cells it was not possible to conduct a full analysis over groups road types and phases. Instead we have conducted group by road type analysis of variance at each phase separately. Means are presented in Table 2.

Table 2
Eye movements while driving for training and control groups over the three phases of testing

	Control group			Training group		
	Rural	Suburb	Dual	Rural	Suburb	Dual
Fixation duration						
Before training	407	345	387	360	339	414
After training	412	393	444	415	382	446
Follow-up	393	310	411	399	360	437
Horizontal variance						
Before training	34.5	40.5	46.1	37.2	35.0	42.6
After training	22.8	39.3	51.6	41.0	61.1	59.1
Follow-up	35.6	54.7	47.4	33.7	64.4	49.5
Vertical variance						
Before training	25.8	25.5	36.0	29.8	20.1	30.1
After training	25.4	21.3	29.1	25.7	26.8	33.7
Follow-up	20.6	21.3	20.2	29.0	21.2	33.3

Mean fixation durations are given in ms and mean variance in the spread of visual search (in degrees of visual angle squared) is provided for both the horizontal and vertical axes. Measures are calculated separately for urban stretches of road, rural stretches, and for dual-carriageway driving.

For fixation durations there was a main effect of road type at each of the phases of testing, $F(2,98) = 8.84$, $p < 0.01$, $F(2,144) = 2.64$, $p = 0.075$, and $F(2,86) = 14.57$, $p < 0.01$, with suburban roads generally producing lower fixation durations than the other road types. There were no main effects or interactions involving the between subjects factor, apart from an interaction between group and road type at the time of initial testing, $F(2,98) = 5.67$, $p < 0.01$. Since this interaction arose before the intervention had actually taken place, and there is no sign of group differences in fixation durations in the later phases, we shall not consider this effect further.

On initial testing there was a main effect of road type on spread of horizontal search, $F(2,86) = 5.55$, $p < 0.01$, with rural roads showing less spread of search than the other road types, but no effect of group or interaction involving the between subjects factor. Immediately after testing there was again a main effect of road type on horizontal spread of search, $F(2,134) = 16.73$, $p < 0.01$, but also a main effect of group, $F(1,67) = 6.30$, $p < 0.05$, with drivers who had performed the intervention showing greater spread of horizontal search. At the final phase of testing the main effect of road type on spread of horizontal search remained, $F(2,88) = 8.37$, $p < 0.01$, but there was no longer any effect of group or interaction involving the group factor. There were initially no significant effects on vertical spread of search either in between group comparisons or in comparisons of the three roadway types, although at the second phase of testing there was a marginal effect of roadway type, $F(2,84) = 2.85$, $p = 0.06$, and at the final phase of testing this effect was significant, $F(2,58) = 3.63$, $p < 0.05$, with drivers showing a greater spread of vertical search on dual-carriageways than on the other road types.

3.3. Search of dangerous situations

The 39 clips were divided into sections when the danger was clearly present and those where it was not (see Chapman & Underwood, 1998a). To increase the amount of data available for individual analyses, data were aggregated across different road types, and anlayses of variance were conducted individually for each of the three phases of testing. Summary data are presented in Table 3. Mean fixation durations were longer when dangers were present than when they were not at all three phases of testing, $F(1,82) = 80.5$, $F(1,86) = 83.3$, and $F(1,68) = 34.9$, respectively, all $p < 0.01$. Fixation durations were shorter for the intervention group immediately after receiving training, $F(1,86) = 5.71$, $p < 0.05$, but there were no group differences initially, $F(1,82) = 0.72$, or at the follow up stage, $F(1,68) = 0.87$. There were no significant interactions between the factors at any phase.

Horizontal variance in fixation locations was significantly lower when dangers were present at all three phases of testing, $F(1,85) = 82.7$, $F(1,88) = 71.3$, and $F(1,70) = 155.7$, respectively, all $p < 0.01$. While there were no group differences in spread of horizontal search initially, $F(1,85) = 0.87$, the intervention group had a wider spread of search both immediately, $F(1,88) = 7.20$, $p < 0.05$, and at the follow up, $F(1,70) = 9.50$, $p < 0.01$. There were no significant interactions between the two factors at any phase. Vertical variance in fixation locations was also significantly lower when dangers were present at all three phases of testing, $F(1,85) = 53.7$, $F(1,88) = 48.3$, and $F(1,70) = 67.2$, respectively, all $p < 0.01$. There were no significant group differences in vertical spread of search or interactions between the two factors at any phase.

Table 3
Eye movements while watching videos of hazardous driving situations for training and control groups over the three phases of testing

	Control group		Training group	
	Danger	Safe	Danger	Safe
Fixation duration				
Before training	545	444	561	438
After training	563	439	503	406
Follow-up	609	551	554	491
Horizontal variance				
Before training	4.32	5.95	3.74	6.38
After training	4.21	6.55	5.49	7.67
Follow-up	4.07	6.05	5.22	7.60
Vertical variance				
Before training	0.33	0.62	0.37	0.62
After training	0.34	0.61	0.43	0.70
Follow-up	0.24	0.50	0.27	0.55

Mean fixation durations are given in ms and mean variance in the spread of visual search (in degrees of visual angle) is provided for both the horizontal and vertical axes. Data are divided into measures taken when clear dangers were actually present in the scenes, and those taken from safer parts of each driving scenario.

4. Discussion

In addition to the effects of the intervention, it is of interest to consider the changes that occur independently over the course of the first year of driving. By the final phase of testing all drivers were driving faster and tending to keep shorter time headways than they had been at the initial phase of testing. While this may be partly related to the participants' increased familiarity with the testing situation, it is also consistent with our findings when comparing newly qualified drivers with older, more experienced ones (Underwood, Crundall, & Chapman, 1997); paradoxically, older, more experienced, and statistically safer drivers are often more likely to engage in risky behaviours like speeding and tailgating. The early months of unsupervised driving may actually be characterised by increasing risky behaviours, along with a rapid improvements in skill. Spontaneous changes in visual search patterns over the course of the first year of driving, however, were not detected. Fixation durations and spread of search in the control group remained roughly constant across all three phases of testing. This suggests that changes in visual search pattern between novice and experienced driver status are indicative of a skill that is spontaneously developed only slowly, and one which may fruitfully be the target of training interventions.

The brief intervention that we have implemented does have clear influences on visual search patterns. Changes in visual search strategy when watching hazardous video situations are immediately identifiable, and some of these changes remain detectable three to six months later. This is of course the area in which we such changes were most likely, the content of the training is itself videos of dangerous situations. Additionally, participants are not required to control a vehicle while watching the videos, and it is possible that this makes it easier for them to adjust their visual search strategies (see also Underwood, Chapman, Bowden, & Crundall, 2002). The reduction in fixation durations in the intervention groups does suggest that the trained drivers are successfully avoiding perceptual capture and it is possible that enhanced knowledge of the types of dangerous situations they will encounter in the videos is speeding their processing. The fact that this is coupled with an increase in horizontal variance also suggests that the intervention has been successful in improving scanning behaviour. It is encouraging to find that this increase in scanning, at least in the laboratory task, is still detectable at the time of follow up. One concern with the pattern of results is that the changes between our intervention and control group do not exactly mimic the differences between novice and experienced drivers that have been reported previously (Chapman & Underwood, 1998a). Although we once again found very clear differences in fixation durations and spread of search between dangerous and safer situations, changes in scanning brought about by the intervention did not seem to be limited to the dangerous situations. Our trained drivers extended search strategies and reduced fixation durations even when no hazards were present. Although this is not necessarily a problem, it does suggest that the trained novices may be using a more conscious scanning strategy than the one automatically adopted by experienced drivers when situations require it.

There was also good evidence that the intervention changed visual search strategies on the road, at least at the stage of initial testing. This suggests that drivers are able to transfer skills learned during a brief video-based intervention into their actual on-road behaviour, however, there remain some areas of concern with our findings. The particular area in which novices had been found to have deficient visual search strategies previously was when driving on dual-carriageway roads (Crundall & Underwood, 1998). Once again, the broadening of search strategies brought about by the intervention was not particularly pronounced for dual-carriageways. There are at least two possible reasons for this, the first is a hypothesis explored by Underwood et al. (2002)—that visual search strategies during highly demanding dual-carriageway driving are largely determined by control skill limitations. Until novice drivers have fully learned how to maintain lane position in demanding multiple carriageway roads, they may have no spare resources to broaden their range of visual search. A second explanation for this finding is the simple fact that our intervention did not concentrate on such roads. In merging lanes on a multiple carriageway road it is particularly important that the driver engages in checking of mirrors and looking over their shoulder at the blind spot (Underwood, Crundall, & Chapman, 2002). It is not possible to simulate such situations realistically using a simple video-based technique. It would clearly be of interest to develop and evaluate interventions which were specifically targeted at such situations. Such interventions could either be developed as a part of standard on-road driver training, or within advanced driving simulators, although the need for realistically positioned mirrors and simulation of the blind spot rules out the use of most existing low-cost simulators for this purpose.

The intervention we have implemented has been successful in changing novice drivers' visual search strategies, and at least some of these changes have been relatively long-lasting. This is an impressive achievement for an intervention that takes under one hour to complete and requires nothing more complex than a video recorder. Nonetheless, there are a number of practical and theoretical questions that remain to be answered. Theoretical questions are raised about the degree to which the changes in visual search brought about by the intervention are caused by the same mechanisms that bring about changes in visual search as a function of traffic experience. The practical side of this question is of course whether the large scale introduction of such an intervention would actually bring about reductions in accident rates.

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