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Transportation Research Part F xxx (2003) xxx–xxx

TRANSPORTATION
RESEARCH
PART F

www.elsevier.com/locate/trf

Driving experience, attentional focusing, and the recall of recently inspected events

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Received 6 June 2003; received in revised form 4 September 2003; accepted 8 September 2003

Abstract

8 How does a driver's perception of roadway events change with experience? A laboratory study addressed
9 this question by comparing novice and experienced drivers as they watched video recordings taken from a
10 moving vehicle. While watching the recordings, the drivers had their eye movements monitored. When the
11 recording was paused, memory for immediately prior events was tested, and recall performance related to
12 what the viewer had been inspecting. The recordings were taken from a vehicle as it travelled along a series
13 of roads, and questions were asked about other road users and about roadway features. The experiment
14 asked about the relationship between driving experience and attentional capture, and about the recall of
15 events recently seen. What attracted attention were objects of central interest such as other road users
16 appearing close to the camera, and moving objects. When the memory test was administered immediately
17 after a hazardous event had occurred, such as a pedestrian stepping into the path of the camera vehicle,
18 then there was evidence of attentional focussing and reduced availability of details about incidental objects.
19 Recall performance generally reflected the pattern of eye fixations, but viewers did not always recall details
20 about fixated objects, and were sometimes able to recall information about objects that were not fixated.
21 Experienced drivers recalled more of the incidental events than the novices, but they were similar in their
22 recall of central events. This supports the association between driving experience and the extent of the
23 effective perceptual field.

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26 1. Introduction

27 Some events are more likely to capture attention than others when drivers scan the road ahead,
28 by virtue of the demand that they place upon task performance. If another road user appears the
29 driver may have to take rapid evasive action if they are travelling on a trajectory that would
30 collide with their own. Drivers are sensitive to such hazardous situations, and react to them by
31 rapidly refixating in the direction of the other road user (Chapman & Underwood, 1998; Un-
32 derwood, Crundall, & Chapman, 1997). During the early part of the fixation upon the other road
33 user the driver presumably makes a calculation about the expected time to contact without
34 braking (Cutting, Vishton, & Braren, 1995; Lee, 1976), in preparation for any required evasive
35 action. Chapman and Underwood (1998) reported that fixation durations increase as hazardous
36 objects appear in the field of view, even when drivers are watching video clips recorded from a
37 driver's perspective, rather than driving themselves. In that study, drivers watched the recordings
38 with the task being to press a response key if anything happened that should cause the driver of
39 the vehicle to brake or otherwise take evasive action. The increase in fixation durations may reflect
40 the increased workload as the viewer decides upon a course of action, or they may indicate in-
41 creased sampling of the trajectory of the other road user while calculating any changes to the time
42 to contact.

43 When drivers watch recordings of hazardous situations we have also found that there is reduced
44 saccadic activity, with saccade length less than during non-hazardous situations, and with con-
45 sequently reduced horizontal and vertical variance. In addition, the effective perceptual field
46 narrows (Crundall, Underwood, & Chapman, 1999, 2002). In the task used by Crundall et al. the
47 drivers watched the video recordings and were also required to detect the onset of small peripheral
48 targets at the edge of the display. Target detections decreased during hazardous situations, and
49 detection was impaired for up to 1.5 s after onset of the hazard. This perceptual narrowing may be
50 a similar phenomenon to that of “weapon focusing” in which viewers fixate longer and more often
51 on threatening objects (e.g., a hand gun) than on a replacement neutral object such a bank check
52 (Loftus, Loftus, & Messo, 1987). Using photographs of emotionally arousing events, Christian-
53 son, Loftus, Hoffman, and Loftus (1991) have reported a similar effect of focusing upon a central
54 subject (the victim of a road traffic accident), with fewer fixations and also impaired recall for
55 information incidental to the central subject. Together these studies suggest that during hazardous
56 situation we should expect increased focusing upon central objects, and reduced recall of infor-
57 mation about incidental objects.

58 When they watch video recordings of hazardous driving situations, experienced and novice
59 drivers differ in their behaviour (Chapman & Underwood, 1998; Crundall et al., 1999, 2002;
60 Underwood, Chapman, Bowden, & Crundall, 2002). Novice drivers, tested within a few weeks of
61 passing the practical examination that qualifies them as an unaccompanied driver, had longer eye
62 fixations on hazardous objects. They also tended to detect fewer peripheral events and the de-
63 crement was longer lasting than that of the experienced drivers. Using a dynamic simulated
64 driving environment, Shinoda, Hayhoe, and Shrivastava (2001) have found that the detection of
65 objects is influenced by acquired knowledge of the probabilistic structure of the environment, also
66 suggesting that experience of the environment will determine the allocation of attention. The
67 increased workload on novices during hazardous situations, indicated by their increased fixation
68 durations, and their impaired detection of peripheral events, gives rise to the prediction that the

69 focussing effects upon attention and upon recall should be greater for novices than those shown by
70 experienced drivers.

71 In an investigation of the accumulation of information about a scene through a succession of
72 eye fixations, Melcher and Kowler (2001) found an interesting discontinuity between fixation and
73 recall. Computer-generated displays of room scenes, containing objects including furniture and
74 furnishings, were shown for varying intervals, in preparation for a test of object recall. Recall
75 increased with increasing display durations, and at the longer intervals recall was predicted by
76 fixation patterns, with approximately 80% of the recalled items having been fixated. At the shorter
77 display intervals however, only about 50% of the successfully recalled items had been fixated. We
78 can recall items from a picture without looking directly at them. Although fixation upon an object
79 did determine recall with longer displays, failure to fixate did not preclude successful recall.
80 Repeated presentation of objects in the same locations resulted in a cumulative scene memory,
81 with recall gains for these repetitions, but fixation patterns did not appear to be used to build this
82 representation of the display. Fixation locations to be inspected were selected randomly, rather
83 than being dependent upon the presence of old or new objects, suggesting that inspection is not
84 determined by a record of which objects had been fixated earlier. Melcher and Kowler (2001)
85 concluded that we should be cautious when trying to infer mental states from fixation patterns,
86 and suggest that the selection of objects for fixation is random rather than determined by memory
87 for the layout of the search space. The advantage of such a strategy of not remembering the
88 locations of previous fixations, is that the resources available for encoding can be dedicated to
89 remembering object identities and locations rather than a history of fixation patterns. It is possible
90 that these conclusions are specific to the display conditions used by Melcher and Kowler. When
91 participants were recalling without fixating, the pictures were available for 1 s only, thereby
92 precluding fixation on more than three objects of the twelve shown in the display. At the longer
93 fixation interval of 4 s, it was possible to fixate all of the objects in the display, although it is
94 interesting that fixation durations increased with increasing display duration, suggesting that
95 when participants were given more time they spent longer encoding each object rather than
96 scanning the whole scene. This dissociation between fixation and recall is further investigated in
97 the present experiment, in which dynamic video sequences were shown prior to object-focused
98 recall questions. If recall is independent of fixation, then participants should perform as well when
99 they had previously fixated a target object as when they had not inspected it.

100 When watching dynamic video events a number of features will attract our attention more than
101 others, and these were varied systematically here. The video sequences were recorded from a
102 moving vehicle as it travelled along suburban and rural roads. Naturally occurring events, in-
103 volving other road users, were recorded during these video clips, and these provided the basis for
104 the recall questions, as well as details about static objects such as road markings and road signage.
105 What would attract the participants' eye fixations while they watched these video clips? Chris-
106 tianson and Loftus (1987) reported that central events shown in a video were more likely to be
107 recalled than incidental events, especially when the scene was traumatic, as in a scene from a road
108 traffic accident. It can be predicted that a central feature such as the colour of a car that crosses
109 our path would be more likely to capture attention than an incidental feature such as the colour of
110 clothing of a pedestrian walking on the pathway alongside the road.

111 Secondly, it can be predicted that dynamic events would capture attention more readily than
112 static events. The sudden appearance of an object in the visual scene provides an excellent example

113 of stimulus-driven attentional capture, in contrast with voluntary or goal-directed attentional
114 guidance that is exemplified by searching for a face in a crowd (Yantis, 1993). Hillstrom and
115 Yantis (1994) described the important distinction between attentional capture by an event and
116 detection of that event without attentional scrutiny, and have argued that it is not movement itself
117 that captures attention so much as the appearance of a new perceptual object. The segregation of
118 a moving object from its background would be sufficient to attract the perceiver's attention, by
119 this model, and Boyce and Pollatsek (1992) have reported that fixations are attracted by small
120 back and forth movements of an object in an otherwise static scene. Remembering details about a
121 cyclist who is being overtaken is therefore predicted to be more successful than remembering
122 anything about, for example, a parked vehicle or part of the road structure. Whereas some studies
123 of the detection of abrupt-inset targets suggests that attention will be captured (see, for example,
124 Theeuwes & Godijn, 2001, 2002), Theeuwes (1991) and Mortier and Theeuwes (2003) have also
125 shown that if attention is already focused on a specific location of space, then abrupt onsets may
126 fail to be so effective. If a driver is focused on the behaviour of a cyclist ahead, then the sudden
127 appearance of a pedestrian from behind a parked car may not capture attention and so detail not
128 encoded.

129 To determine the relationship between attention to an object and subsequent recall of infor-
130 mation about it, participants watched video clips recorded from the driver's perspective in a
131 moving vehicle. At unpredictable points in the recordings questions were asked about events
132 recently shown. Eye movements were recorded so that recall performance could be related to
133 whether or not the subject of the question had been fixated. Participants were expected to fixate
134 central events (e.g., other prominent road users) more than incidental events (e.g., other road
135 users not in the path of the moving vehicle), and they were expected to fixate dynamic events (e.g.,
136 moving vehicles) more than static events (e.g., road features and parked vehicles). These were
137 factors introduced to elicit systematic variations in fixations and recall questions were asked about
138 each of them. In addition, hazardous driving situations were contrasted with non-hazardous
139 situations, given that fixations are focussed on the object with a possible collision trajectory when
140 viewing hazardous sections of video recordings. The occurrence of a hazardous situation does not
141 produce equivalent fixation behaviour in experienced and novice drivers, and so two groups of
142 participants were tested, with several years and many miles of driving experience distinguishing
143 between them. Novice drivers have impaired detection of peripheral targets at the time that
144 hazardous situations are developing, and so we anticipated an interaction between the fixation of
145 central/incidental events and driving experience. Melcher and Kowler (2001) have questioned the
146 linkage between fixation and recall, and the experiment asks whether the pattern of fixation be-
147 haviour elicited by these stimulus features is reflected in the pattern of recall performance.

148 2. Method

149 2.1. Participants

150 Thirty University of Nottingham undergraduate students were each paid £5 for their partici-
151 pation in the experiment. They were recruited on the basis of their driving experience, with 15
152 novice drivers and 15 experienced drivers. The novices had no more than one year (average of 0.7

153 years) since acquiring their full driving licence, and reported having driven an average of ap-
154 proximately 1500 km in that time. The experienced drivers had held a full driving licence for at
155 least four years (average of 7.9 years), and reported that they had driven an average of ap-
156 proximately 100,000 km in total. All participants had normal or corrected-to-normal eyesight.

157 2.2. *Stimulus materials*

158 Participants were shown a series of video clips that had been digitised for projection onto a
159 large screen. Thirty four clips were used, each lasting between 10 and 90 s. The clips were recorded
160 from a vehicle moving along rural and urban roads. The clips have been previously described by
161 Chapman and Underwood (1998), and have the feature of each one of them containing at least
162 one event that can be described as hazardous in that if the event occurred during ordinary driving,
163 then the vehicle would have to be controlled to avoid a collision. For example, these hazardous
164 events include other road users (pedestrians, cyclists, motorised vehicles) crossing the path of the
165 vehicle from which the clips were recorded, or the vehicle directly in front of the camera braking.
166 In all cases the hazardous events selected in the video clips had abrupt onsets (as opposed to
167 gradual onsets, as we would describe the recognition of some object initially in the distance and
168 which, as the camera gets nearer, is recognised as something that represents a hazard and that
169 should be avoided, like a jogger running along the side of the road). At other times the video
170 recordings displayed the uneventful passage of the recording vehicle as it travelled along a range
171 of different roads. The experiment required that the video be paused at marked points, to allow
172 questions to be asked of the viewers. At the point when the video was paused, the object that was
173 the subject of the questions had been visible on the screen for between 4 and 8 s. Similar questions
174 were used after hazardous and non-hazardous situations, and target objects were on screen for
175 similar durations in each condition. The digitised MPEG clips were stored on an Apple Macin-
176 tosh laptop computer, and were displayed through the QuickTime Pro application.

177 The video clips were displayed on a white non-reflective screen placed at a distance of 1.85 m
178 from the participants, and with the image subtending 30° of horizontal angle. Participants' eye
179 movements were recorded with a NAC EyeMark VII eye-tracker, that was head-mounted and
180 allowed unrestricted head movements. A field-view camera was mounted on the eye-tracker to
181 record an NTSC video of the field of view directly before the participant. A second camera was
182 used to monitor a corneal reflection that was superimposed on the image from the field-view
183 camera, thereby generating a recording of the visual world seen by the participant together with a
184 marker of what they were looking at within that field. The eye marker was updated every 33 ms,
185 and the spatial accuracy of the eye-tracker was 2°.

186 2.3. *Procedure*

187 After calibration of the eye-tracker the set of video recordings was shown in two blocks, with a
188 short rest and re-calibration between blocks. Each trial consisted of the participant watching the
189 recording displayed on the screen, with instructions to watch the clips as if they were the driver of
190 the vehicle, and that when the recordings were stopped there would be questions about different
191 aspects of them. The order of clips was randomised for each participant, but the clips were paused
192 at the same point, and the same questions were asked of all participants. When the recording was

193 paused, the image was removed from display. Clips were paused in this way between 2 and 5
194 times, and either one or two questions asked at each pause. The length of the clips, the number of
195 pauses per clip, and the number of questions per pause were varied to introduce uncertainty about
196 the relationship between what was being shown and what would be questioned. Without this
197 uncertainty participants may have developed individual strategies in an attempt to anticipate the
198 questions. When clips were paused, the image on the screen was not available, so that participants
199 had to rely upon their memory of recent visual events. The questions asked about scenes shown in
200 the recording within the last 5 s. The recording was continued after each set of questions had been
201 answered.

202 Questions asked about events or objects shown in the video recordings, and were allocated to
203 one of eight conditions, in a $2 \times 2 \times 2$ factorial design that was used with both of the two groups of
204 participants. The first within-group variable was driving hazard: the recordings were paused
205 during or immediately after a hazardous event, or during a non-hazardous sequence. The second
206 variable was location of the targeted event or object: the question asked about a central or a
207 incidental aspect of the recording. Central events were those directly in front of the camera and
208 displayed centre screen (e.g., the colour of the vehicle that has just overtaken the camera vehicle),
209 and incidental (e.g., the colour of the vehicle parked at the side of the road). The third within-
210 groups variable was whether the subject of the question was moving (e.g., the colour of moving
211 vehicles or of clothing worn by pedestrians and cyclists) or static (e.g., parked vehicles, road signs
212 and road markings). There were nine questions in each of these conditions, with a randomised
213 order of presentation. Replies were spoken by the participants, and noted at the time.

214 3. Results

215 The questions answered correctly were determined, and related to the eye-tracking data that
216 indicated what the participant had been looking at immediately prior to the video being paused.
217 The data from questions answered incorrectly were analysed no further. Participants were re-
218 quired to contribute data to each cell, and one of the purposes of the study was to investigate the
219 relationship between fixating an event and reporting it. The study required that some of the events
220 that were to be the subject of a recall question should be not fixated. The data from three par-
221 ticipants were therefore excluded from all analyses, on the basis that they had fixated all of the
222 events and objects that were to be probed by recall questions. This process left 14 experienced
223 drivers and 13 novice drivers providing the data.

224 3.1. Recall of recent events

225 The mean percentages of correct recalls are presented in Table 1. A mixed design ANOVA was
226 used on the means of the correct recall responses, to look for effects of driver experience (expe-
227 rienced/novice), driving situation (hazardous/non-hazardous), target location (central/incidental),
228 and target movement (static/dynamic).

229 There were main effects of target location [$F(1, 25) = 124.85$, $MSe = 23587.4$, $p < .001$] and
230 target motion [$F(1, 25) = 76.08$, $MSe = 11858.9$, $p < .001$]. More questions were answered cor-

Table 1
Percentage of recall questions answered correctly (standard deviations in italics)

	Hazardous events				Non-hazardous events			
	Central		Incidental		Central		Incidental	
	Static	Moving	Static	Moving	Static	Moving	Static	Moving
Experienced drivers	83.33 <i>16.74</i>	83.72 <i>11.11</i>	43.51 <i>17.89</i>	76.30 <i>15.47</i>	75.82 <i>13.78</i>	84.82 <i>9.33</i>	62.83 <i>20.81</i>	77.04 <i>9.78</i>
Novice drivers	79.49 <i>12.71</i>	81.30 <i>10.52</i>	31.47 <i>16.85</i>	66.67 <i>19.77</i>	72.19 <i>15.24</i>	81.54 <i>14.05</i>	50.55 <i>17.12</i>	66.49 <i>11.80</i>

231 rectly when the target object had been central [80.3%] rather than incidental [59.6%], and when it
232 had been dynamic [77.3%] rather than static [53.8%].

233 The ANOVA also indicated three two-way interactions, each of which was inspected with
234 Tukey paired comparisons. These comparisons will only be mentioned, here and throughout,
235 when they were reliable at least at the $p < .05$ level. Driver experience interacted with target lo-
236 cation [$F(1, 25) = 4.36$, $MSe = 824.4$, $p < .05$]. The paired comparisons found no effect of driving
237 experience on the recall of central events, but experienced drivers [64.9%] recalled more incidental
238 events than novices [53.8%].

239 The second interaction was between driving situation and target location [$F(1, 25) = 18.67$,
240 $MSe = 2311.9$, $p < .001$]. This is attributed to fewer incidental events being reported during
241 hazardous situations [54.7%] than during non-hazardous situations [64.4%], but no effect of sit-
242 uational hazard upon the recall of central events.

243 The third interaction found that the main effect advantage of dynamic events was apparent
244 mainly for incidental events [$F(1, 25) = 42.81$, $MSe = 5078.9$, $p < .001$]. For central events, there
245 was a small recall advantage for moving [82.8%] over static objects [77.8%], but for incidental
246 events this advantage increased [71.8% vs. 47.3%].

247 There was also a three-way interaction between situation, location and movement
248 [$F(1, 25) = 14.39$, $MSe = 2461.4$, $p < .001$]. This interaction is illustrated in Fig. 1, where a large
249 disadvantage is seen, in hazardous situations, for incidental static objects. Further, there is an
250 interesting reversal in the recall advantages for static objects. Hazards give a 7% recall advantage
251 to central static events in contrast with a non-hazard, but there is 19% disadvantage for incidental
252 static events during a hazard. Hazardous situations focus the driver's attention on objects of
253 central interest at the expense of processing incidental objects. This applies only to stationery
254 objects, as dynamic objects have similar recall whether seen during hazards or not.

255 3.2. Fixation of events

256 The number of targeted objects that were fixated were recorded, and the means are presented in
257 Table 2. These were the events and objects that were the subject of the recall questions. An object
258 shown in the video recording was regarded as having been fixated if the analysis of frames from
259 the eye-tracker recordings indicated a fixation within 2° of a boundary of that object. A mixed

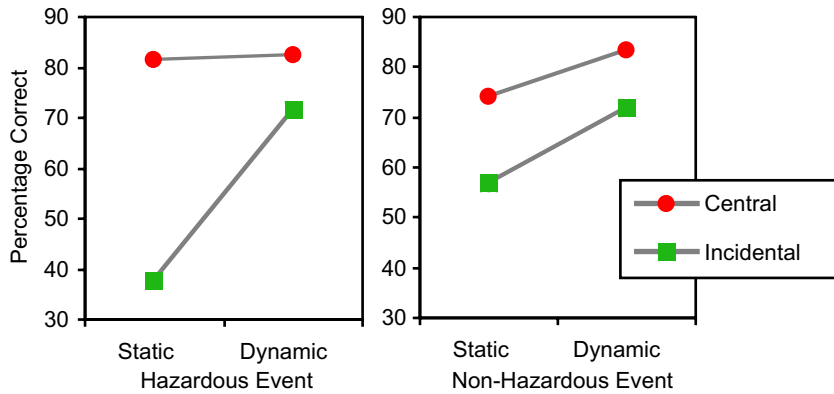


Fig. 1. Recall of recent events: the three-way interaction between driving situation, event location, and event movement.

260 design ANOVA was used to analyse these means, using the same factorial design as for the
261 analysis of recall accuracy.

262 There were three main effects, with hazardous events being fixated more often than non-haz-
263 arduous subjects [67.0% vs. 57.7%; $F(1, 25) = 21.00$, $MSe = 4604.3$, $p < .001$]. Central events were
264 fixated more often than incidental targets [74.9% vs. 49.8%; $F(1, 25) = 279.00$, $MSe = 34092.5$,
265 $p < .001$], and with dynamic targets being more likely to be fixated than static targets [69.2% vs.
266 55.6%; $F(1, 25) = 66.34$, $MSe = 10103.1$, $p < .001$].

267 Three two-way interactions emerged, and these were further inspected with Tukey compari-
268 sons. Driving situation interacted with location of the target [$F(1, 25) = 16.92$, $MSe = 2648.6$,
269 $p < .001$], with central hazardous events [83.1%] attracting more fixations than central non-haz-
270 arduous events [66.8%], but incidental targets attracted similar numbers of fixations whether they
271 were hazardous or not.

272 The second interaction involved driving situation and movement [$F(1, 25) = 10.76$,
273 $MSe = 2029.1$, $p < .01$], with dynamic events gaining more fixations when they were hazardous
274 [76.9%] than when they were non-hazardous [61.5%], but static events attracted similar numbers
275 of fixations in the two driving situations.

Table 2
Percentage of targeted objects fixated (standard deviations in italics)

	Hazardous events				Non-hazardous events			
	Central		Incidental		Central		Incidental	
	Static	Moving	Static	Moving	Static	Moving	Static	Moving
Experi- enced drivers	79.27 <i>12.90</i>	89.48 <i>8.80</i>	40.13 <i>8.33</i>	63.15 <i>18.00</i>	63.49 <i>15.12</i>	69.90 <i>18.37</i>	46.02 <i>21.32</i>	51.18 <i>15.02</i>
Novice drivers	76.07 <i>10.97</i>	87.47 <i>6.72</i>	32.87 <i>18.01</i>	67.52 <i>14.67</i>	64.65 <i>15.32</i>	69.25 <i>13.57</i>	41.76 <i>17.94</i>	55.79 <i>17.71</i>

276 Finally, location of the target interacted with movement [$F(1, 25) = 5.96$, $MSe = 1648.8$,
277 $p < .05$]. Dynamic targets always attracted more fixations than static targets, but the advantage
278 was smaller for fixations on central objects [79.0% for dynamic vs. 70.9% for static] rather than
279 incidental targets [59.3% vs. 40.3%, respectively].

280 3.3. Relating recall to prior fixation

281 The mean percentages of correct recalls are presented in Table 3. Participants were removed
282 from this analysis if they had fixated all of the objects that were the subject of the recall questions.
283 This procedure left the data from 10 experienced drivers and 12 novices for analysis. A mixed-
284 factors ANOVA was conducted, with one between-groups factor (driving experience) and four
285 within-groups factors (driving situation, target location, target movement, and target fixation).
286 All of the within-groups factors appeared as main effects. Hazardous events were recalled less
287 often than non-hazardous events [29.8% vs. 37.4%; $F(1, 20) = 10.10$, $MSe = 788.9$, $p < .05$],
288 central events were recalled more often than incidental events [41.4% vs. 30.3%; $F(1, 20) = 172.10$,
289 $MSe = 10730.6$, $p < .001$], dynamic objects were recalled more often than static objects [39.6% vs.
290 30.9%; $F(1, 20) = 85.96$, $MSe = 4913.8$, $p < .001$], and objects that had been fixated were recalled
291 more often than those that had not been inspected [50.8% vs. 20.8%; $F(1, 20) = 114.02$,
292 $MSe = 77391.2$, $p < .001$].

293 There were six two-way interactions from the ANOVA, and these were further analysed with
294 Tukey comparisons.

Table 3
Percentage of targeted objects recalled when they were fixated and when they were not fixated (standard deviations in italics)

	Hazardous events				Non-hazardous events			
	Central		Incidental		Central		Incidental	
	Static	Moving	Static	Moving	Static	Moving	Static	Moving
<i>Fixated events</i>								
Experi- enced drivers	69.86 <i>15.56</i>	74.29 <i>10.29</i>	25.46 <i>11.97</i>	52.22 <i>16.58</i>	48.53 <i>17.40</i>	68.64 <i>18.76</i>	37.73 <i>22.64</i>	40.00 <i>13.53</i>
Novice drivers	61.11 <i>12.04</i>	75.52 <i>93.38</i>	12.88 <i>11.27</i>	49.07 <i>4.69</i>	56.20 <i>14.59</i>	63.24 <i>16.85</i>	30.36 <i>15.56</i>	46.70 <i>17.71</i>
<i>Non-fixated events</i>								
Experi- enced drivers	16.67 <i>14.07</i>	6.25 <i>9.75</i>	21.82 <i>12.99</i>	23.33 <i>15.99</i>	22.73 <i>13.38</i>	23.71 <i>16.31</i>	28.83 <i>18.36</i>	37.86 <i>15.06</i>
Novice drivers	20.37 <i>13.23</i>	6.25 <i>4.58</i>	15.91 <i>15.56</i>	18.52 <i>11.92</i>	22.49 <i>12.37</i>	26.44 <i>15.49</i>	22.62 <i>11.70</i>	21.57 <i>15.23</i>

295 Driving experience interacted with target location [$F(1, 20) = 13.98$, $MSe = 871.5$, $p < .01$],
 296 with experienced drivers [41.6%] recalling more incidental objects than novices [27.2%] but there
 297 was no difference between drivers for the recall of centrally located objects.

298 Driving situation also interacted with target location [$F(1, 20) = 15.26$, $MSe = 684.2$,
 299 $p < .001$]. There was no difference in the recall of central objects from hazardous and non-haz-
 300 ardous situations, but incidental objects [32.9%] were recalled more often from non-hazardous
 301 situations [27.2%].

302 Driving situation interacted with prior fixation of the object [$F(1, 20) = 18.09$, $MSe = 3839.4$,
 303 $p < .001$]. The recall of objects that had been fixated was slightly better in hazardous situations
 304 [52.6%] than in non-hazardous situations [48.9%], but this advantage was reversed for the recall of
 305 non-fixated objects [non-hazardous: 25.8%; hazardous: 16.0%].

306 Target location interacted with target movement [$F(1, 20) = 26.24$, $MSe = 1544.1$, $p < .001$],
 307 with a stronger recall advantage for dynamic over static objects that were of incidental [36.1% vs.
 308 24.0%] rather than central interest [43.2% vs. 37.9%].

309 Prior fixation of the object interacted both with location [$F(1, 20) = 90.74$, $MSe = 24582.5$,
 310 $p < .001$], and with motion [$F(1, 20) = 37.97$, $MSe = 6221.0$, $p < .001$]. For non-fixated objects,
 311 there was a recall advantage for incidental [23.4%] over central objects [18.1%], but object motion
 312 was ineffective. However, for fixated objects the advantages were for central [64.8%] over inci-
 313 dental objects [36.7%] and also for dynamic [58.7%] over static objects [42.5%].

314 The ANOVA also revealed two three-way interactions, the first involving driving situation,
 315 target location, and target motion [$F(1, 20) = 29.29$, $MSe = 2088.9$, $p < .001$]. This interaction
 316 appeared in the analysis of recall that is illustrated in Fig. 1, and will not be considered again here.

317 The second three-way interaction involved driving situation, target location, and prior fixation
 318 [$F(1, 20) = 10.42$, $MSe = 1859.4$, $p < .01$]. This interaction illustrated in Fig. 2. For static inci-
 319 dental objects, there was a recall advantage for non-hazardous rather than hazardous objects, but
 320 for static central objects the recall advantage was for objects from hazardous situations. For
 321 dynamic incidental objects, there was no difference in the recall of objects from hazardous and
 322 non-hazardous situations, but non-hazardous objects were recalled more than those from haz-

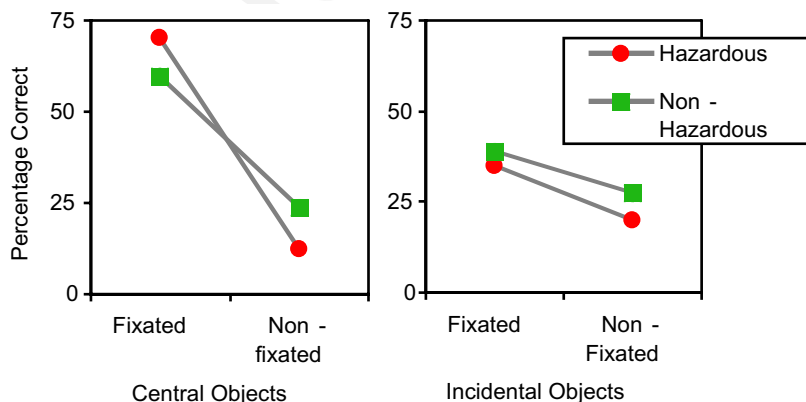


Fig. 2. Relating fixation to the recall of recent events: the three-way interaction between driving situation, event location, and fixation.

ardous situations. The second three-way interaction found that for central objects that had been fixated, more details were recalled from hazardous than from non-hazardous situations, but for incidental objects, more details were recalled from non-hazardous situations. For incidental and for central objects that had not been fixated, more were recalled from non-hazardous situations.

4. Discussion

After watching a short video recording, drivers answered questions about details of roadway events and objects that they had or had not fixated. In general, questions about objects that had been fixated were answered more successfully than those that had not been fixated, but there are caveats to this conclusion. It is not the case that only fixated objects are remembered, and it is not the case that recall will invariably be improved by fixation of an object. The central questions asked here concerned the relationship between experience and the effective perceptual field, and whether fixation determined retention of information about a natural, moving scene. Before discussing these relationships between experience, attention and memory we will first examine the features of the roadway that attract the driver's attention.

While viewers watched video clips of road scenes recorded from a moving vehicle, their eye fixations were tracked to determine the focus of their attention immediately before a recall test. Large effects were observed for dynamic objects (e.g., moving vehicles) attracting more eye fixations than static objects (e.g., parked vehicles). The camera that recorded the video clips was in motion itself, of course, and so "dynamic" and "static" refer to motion relative to that of the camera. There was also a large effect for objects in the centre of the screen and of central significance (e.g., a vehicle recently overtaken) being fixated more than incidental objects (e.g., a building). Incidental objects attracted more attention when they were moving, to a greater extent than the effect of movement had upon the attentional capture by central objects. The driving situation also influenced the fixation patterns of the novice and inexperienced drivers alike. Hazardous events occasionally occurred, such as other road users moving into the trajectory of the camera vehicle, giving the appearance of an imminent collision, or the vehicle in front starting to brake. When these events occurred, the conflicting road user, as well as a co-occurring object, were the subject of the recall test. The hazardous object was fixated more than equivalent objects seen in non-hazardous situations, and this difference was greater for central objects and for dynamic objects. These are the patterns of differences that would be expected on the basis of results from various paradigms: attention is attracted by the appearance of moving objects (see Hillstrom & Yantis, 1994), central objects (see Loftus et al., 1987), and hazardous objects in driving situations (see Chapman & Underwood, 1998). The patterns of recall of recently seen events followed this pattern of fixations, but with some important differences.

An attentional focussing effect during hazardous driving situations has been seen previously in the fixation behaviour of experienced and novice drivers presented with video recordings (Chapman & Underwood, 1998; Crundall et al., 1999, 2002; Underwood et al., 2002). In the present study there were no differences due to driving experience in fixation behaviour, but here we recorded attentional capture as the dependent measure whereas previously we have recorded the variance of fixation locations. There was evidence of attentional focusing independent of fixation behaviour, with novices tending to recall fewer incidental events once their attention had

364 been captured. This pattern of novices being aware of the the roadway to a lesser extent than
365 experienced drivers has been seen previously in their fixation patterns while driving (Crundall &
366 Underwood, 1998; Falkmer & Gregersen, 2001; Underwood, Chapman, Brocklehurst, Under-
367 wood, & Crundall, 2003). In laboratory tasks, eye fixations are clustered in centre screen, and
368 abrupt-onset targets are detected less readily than at other times. These effects are more pro-
369 nounced for novices than for experienced drivers, suggesting that as skill develops, attention can
370 be divided more easily between different sources of information without any detriment to the
371 processing of the main message (Underwood, 1974). There was some support for the hypothesis
372 that skill enables greater division of attention from the present study, with experienced drivers
373 recalling as much central detail as the novices, but more detail from incidental objects. Although
374 they successfully retrieved information from the focus of their attention, they also retrieved more
375 information about objects that were incidental to the main sequence of events. There were no
376 differences between patterns of fixation here, however, and no differences in the recall of fixated
377 and non-fixated objects. Novices were just as likely as experienced drivers to look at dynamic
378 objects or static objects, for example, and just as likely to recall them as experienced drivers when
379 they did look at them and when they did not.

380 Increased scanning of the roadway by experienced drivers is seen in its extreme when eye
381 movement recordings are taken from very skilled drivers. Crundall, Chapman, Phelps, and Un-
382 derwood (in press) showed roadway video recordings to police pursuit drivers, as well as to novice
383 and experienced controls. The police drivers had elevated scanning along the horizontal plane,
384 relative to matched-control drivers. When novices were shown recordings taken at night, their
385 horizontal was further restricted, whereas the police and experienced drivers were unaffected by
386 time of day. When the video recordings were taken from real pursuit drives, with the recording
387 vehicle following a pursued vehicle, increasing focussing was apparent, but mainly in novice
388 drivers. Accordingly, the fixation durations of the police and experienced drivers were shorter,
389 corresponding to an increase in the sample rate. As skill and experience increase, drivers increase
390 their sampling of events in the environment and they sample from more locations.

391 The consequences of attentional focussing have been reported previously for events depicted in
392 photographs of stressful events such as road traffic accidents (Christianson et al., 1991). The
393 present study also reports fewer fixations and reduced recall of details that are incidental and not
394 the focus of central interest. This effect of the subject of the viewer's attention also gaining better
395 recall than incidental detail is especially pronounced for the recall of details from hazardous,
396 attention-capturing events. The recall of detail from incidental objects can be improved, however,
397 when those objects are moving. This is most likely an effect of the potency of moving objects in
398 capturing attention, as the same effect was seen in recall and in fixation. Incidental objects that
399 were moving were both fixated and recalled more frequently than static objects.

400 Recall of the detail of an object mirrored the fixation upon the object in a number of ways.
401 There was greater recall as well as greater fixation for central rather than incidental objects and
402 for dynamic rather than static objects, and for both measures incidental objects were more de-
403 tectable if they were moving. Hazardous situations resulted in more fixations and improved recall
404 for central objects and for dynamic objects. When we list the patterns of effects for fixation and
405 recall performance they are essentially identical, suggesting that there is a strong relationship
406 between fixating an object and remembering some detail about it. This conclusion is not so well
407 supported when the analysis of recall data separates those objects that were fixated from those

408 that were not. There were a number of interactions between the main effects of driving situation
409 and object prominence that involved whether or not the object had been fixated, and these qualify
410 the general conclusion that successful recall follows fixation.

411 There was a robust overall main effect of fixation. The data in Table 3 show that details about
412 fixated objects were recalled on around 50% of occasions, but details about non-fixated objects
413 were recalled approximately 20% of the time. So, of the details that were recalled, approximately
414 70% of them came from fixated objects, a figure comparable with that reported by Melcher and
415 Kowler (2001) from a study using static images of scenes. Melcher and Kowler questioned the
416 linkage between fixation and recall, however, on the basis that they found that non-fixated objects
417 were often recalled at their 1 s exposure duration, and sometimes with the 4 s exposure. The video
418 recordings used in the present study made the target objects available for at least 4 s, and we also
419 found that participants were sometimes able to recall details from objects that had not been
420 fixated directly. This was particularly so with objects tested after non-hazardous sequences when
421 there was less attentional focussing upon the central action. This pattern of results supports
422 Melcher and Kowler's caution in the use of eye movement measures to infer cognitive states in-
423 volving the development of memories of recent events.

424 For fixated and for non-fixated objects, there was greater recall for dynamic objects, for central
425 objects, and for objects in hazardous situations. Differences in the recall of fixated and non-fixated
426 objects emerge during hazardous driving situations, when attention is focussed upon a central
427 object that starts on a collision trajectory with the viewer. The recall advantage gained by fixation
428 was enhanced during hazardous sequences, possibly as a consequence of the extent of attentional
429 focussing upon the unfolding events involving, for example, a child pedestrian running out in
430 front of the moving vehicle, or a cyclist riding out of a side road at the moment that the camera
431 vehicle approaches the junction. The effects of focussing are also seen in an interaction involving
432 driving situation, target location, and whether or not the target had been fixated. There was a
433 general tendency for more details to be recalled from non-hazardous situations, but this pattern
434 was reversed for fixated central objects. In hazardous and non-hazardous situations there was the
435 greatest level of recall of detail from objects in the centre of the screen, and of the central objects
436 that had been fixated, more details were recalled from hazardous situations than from non-haz-
437 ardous situations. Better recall was evident from central objects that had been fixated in haz-
438 ardous than non-hazardous situations, in contrast with any non-fixated objects and in contrast
439 with details from incidental objects in the two situations. The on-going hazard had focussed the
440 viewer's attention, attracting more fixations on the central object than in non-threatening situa-
441 tions, resulting in better recall of detail about the central object. The usual advantage for recall
442 from non-hazardous situations was reversed for the single case of central objects that had been
443 fixated.

444 When objects had not been fixated, there was an unexpected advantage for the recall of inci-
445 dental detail over the detail of objects that were presented centrally. There is no obvious expla-
446 nation of this effect, and as it was a small recall advantage relative to the overall advantage of
447 central objects and that of fixated objects, it may not be reliable.

448 In preparation for questions about roadway events unfolding in the video recordings, observers
449 looked at objects and followed their paths. To a lesser extent they also looked at features of the
450 roadway landscape such as buildings, signs and stationary vehicles. As other road users started to
451 move towards the camera's viewpoint, as if on a collision trajectory, their eyes were drawn to these

452 new objects. Using a study of eye fixations made to line-drawings of natural scenes, Henderson,
453 Weeks, and Hollingworth (1999) developed a model of fixation control in which a saliency map is
454 built of regions within the scene. Findlay and Walker (1999) have also suggested that a topo-
455 graphic map of the saliency of objects determines the order of fixations in visual search. The
456 saliency model can be extended to viewing natural scenes such as photographs and may be useful
457 in understanding the control of eye movements while watching video recordings of natural scenes.
458 The model accounts for the location of fixations by assuming that the viewer must first develop a
459 map of visually differentiated regions using low-level information. Variations in contrast, colour,
460 luminance and contour density are used in this initial map, with greater salience being allocated to
461 closer regions, as suggested by Rayner and Pollatsek (1992). Chapman and Underwood (1998)
462 also found a dominant pattern of fixations in centre field, when viewers watched video recordings,
463 attesting to the saliency of location. When viewing video recordings or other stimuli in which
464 objects have the capability of movement, then motion would be a significant part of the saliency
465 map. At the end of this process the viewer has available a map of the features of the scene with
466 saliency weightings that can be used to determine their initial fixations. There are reports of initial
467 fixations being captured by the meaning of parts of the scene (Loftus & Mackworth, 1978), but
468 data from De Graef, Christiaens, and d'Ydewalle (1990) and from Henderson et al. (1999) suggest
469 that it is the stimulus characteristics of the scene that are used to guide the first few fixations. As
470 the objects in the scene are identified with the aid of direct fixation, then the saliency weight is
471 reduced and attention released, enabling attention and then fixation to be relocated on the region
472 with the highest saliency weight. The viewer's eyes remain on each region until processing is
473 completed, and this will depend both upon the complexity of stimulus features, and upon the
474 viewer's task. Saliency is initially determined by the low-level visual features of the scenes, but as
475 inspection progresses then the weighting for a region will come to be based on its meaning. As we
476 look at a scene and develop an understand of what is being portrayed, then our future fixations
477 will be determined by its semantic content, and more attention will be allocated to objects of
478 cognitive saliency.

479 The saliency map model of scene inspection developed by Henderson et al. (1999) describes the
480 capture of attention by events in video recordings very well. More attention was allocated to
481 central objects and to moving objects, and this was also reflected in memory performance. When
482 new objects appeared on trajectories that suggested a collision may occur, then they captured
483 fixation, suggesting that the saliency map model should not include motion as a low-level stimulus
484 factor that is used in the initial parse of the scene, but that a time-to-contact calculation also
485 contributes to the map. Once an object has been fixated then details about it can be recalled, but
486 this is a generalisation, and the present experiment demonstrates that not all objects that are
487 fixated can be used to support memory performance, and that it is possible to recall details about
488 objects that are not fixated.

489 **Acknowledgements**

490 This study was supported by ESRC Project R000223311 on 'Experiential differences in scene
491 perception'. We are grateful to Jean Underwood for helpful comments during the development of
492 this paper.

References

- 493
494 Boyce, S. J., & Pollatsek, A. (1992). Identification of objects in scenes: The role of scene background in object naming.
495 *Journal of Experimental Psychology: Learning, Memory and Cognition*, 18, 531–543.
- 496 Chapman, P., & Underwood, G. (1998). Visual search of driving situations: Danger and expertise. *Perception*, 27, 951–
497 964.
- 498 Christianson, S.-V., & Loftus, E. F. (1987). Memory for traumatic events. *Applied Cognitive Psychology*, 1, 225–239.
- 499 Christianson, S.-V., Loftus, E. F., Hoffman, H., & Loftus, G. R. (1991). Eye fixations and memory for emotional
500 events. *Journal of Experimental Psychology: Learning, Memory and Cognition*, 17, 693–701.
- 501 Crundall, D., Chapman, P., Phelps, N., & Underwood, G., (in press). Eye movements and hazard perception in police
502 pursuit and emergency response driving. *Journal of Experimental Psychology: Applied*.
- 503 Crundall, D., & Underwood, G. (1998). Effects of experience and processing demands on visual information acquisition
504 in drivers. *Ergonomics*, 41, 448–458.
- 505 Crundall, D., Underwood, G., & Chapman, P. (1999). Driving experience and the functional field of view. *Perception*,
506 28, 448–458.
- 507 Crundall, D., Underwood, G., & Chapman, P. (2002). Attending to the peripheral world while driving. *Applied*
508 *Cognitive Psychology*, 16, 459–475.
- 509 Cutting, J. E., Vishton, P. M., & Braren, P. A. (1995). How we avoid collisions with stationary and moving obstacles.
510 *Psychological Review*, 102, 627–651.
- 511 De Graef, P., Christiaens, D., & d'Ydewalle, G. (1990). Perceptual effects of scene context on object identification.
512 *Psychological Research*, 52, 317–329.
- 513 Falkmer, T., & Gregersen, N. P. (2001). Fixation patterns of learner drivers with and without cerebral palsy (CP) when
514 driving in real traffic environments. *Transportation Research F*, 4, 171–185.
- 515 Findlay, J. M., & Walker, R. (1999). A model of saccade generation based on parallel processing and competitive
516 inhibition. *Behavioral and Brain Sciences*, 22, 661–721.
- 517 Henderson, J. M., Weeks, P. A., & Hollingworth, A. (1999). The effects of semantic consistency on eye movements
518 during complex scene viewing. *Journal of Experimental Psychology: Human Perception and Performance*, 25, 210–
519 228.
- 520 Hillstrom, A. P., & Yantis, S. (1994). Visual motion and attentional capture. *Perception & Psychophysics*, 55, 399–411.
- 521 Lee, D. N. (1976). A theory of visual control of braking based on information about time-to-collision. *Perception*, 5,
522 437–459.
- 523 Loftus, E. F., Loftus, G. R., & Messo, J. (1987). Some facts about weapon focus. *Law and Human Behavior*, 11, 55–62.
- 524 Loftus, G. R., & Mackworth, N. H. (1978). Cognitive determinants of fixation location during picture viewing. *Journal*
525 *of Experimental Psychology: Human Perception and Performance*, 4, 565–572.
- 526 Melcher, D., & Kowler, E. (2001). Visual scene memory and the guidance of saccadic eye movements. *Vision Research*,
527 41, 3597–3611.
- 528 Mortier, K. D., & Theeuwes, J. (2003). Attentional capture within and between objects. *Acta Psychologica*, 113, 133–
529 145.
- 530 Rayner, K., & Pollatsek, A. (1992). Eye movements and scene perception. *Canadian Journal of Psychology*, 46, 342–376.
- 531 Shinoda, H., Hayhoe, M. M., & Shrivastava, A. (2001). What controls attention in natural environments? *Vision*
532 *Research*, 41, 3535–3545.
- 533 Theeuwes, J. (1991). Exogenous and endogenous control of attention: The effect of visual onsets and offsets. *Perception*
534 *& Psychophysics*, 49, 83–90.
- 535 Theeuwes, J., & Godijn, R. (2001). Attentional and oculomotor capture. In C. Folk & B. Gibson (Eds.), *Attention,*
536 *distraction, and action: Multiple perspectives on attentional capture* (pp. 121–149). Amsterdam: Elsevier.
- 537 Theeuwes, J., & Godijn, R. (2002). Irrelevant singletons capture attention: Evidence from inhibition of return.
538 *Perception & Psychophysics*, 64, 764–770.
- 539 Underwood, G. (1974). Moray vs. the rest: The effects of extended shadowing practice. *Quarterly Journal of*
540 *Experimental Psychology*, 26, 368–372.
- 541 Underwood, G., Chapman, P., Bowden, K., & Crundall, D. (2002). Visual search while driving: Skill and awareness
542 during inspection of the scene. *Transportation Research F*, 5, 87–97.

- 543 Underwood, G., Chapman, P., Brocklehurst, N., Underwood, J., & Crundall, D. (2003). Visual attention while driving:
544 Sequences of eye fixations made by experienced and novice drivers. *Ergonomics*, *46*, 629–646.
- 545 Underwood, G., Crundall, D., & Chapman, P. (1997). Visual attention while performing driving and driving-related
546 tasks. *Behavioural research in road safety* (Vol. 7, pp. 60–74). Crowthorne, UK: Transport Research Laboratory.
- 547 Yantis, S. (1993). Stimulus-driven attentional capture. *Current Directions in Psychological Science*, *2*, 156–161.

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