
Eye movements during intentional car following

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Abstract. Does intentional car following capture visual attention to the extent that driving may be impaired? We tested fifteen participants on a rudimentary driving simulator. Participants were either instructed to follow a vehicle ahead through a simulated version of London, or were given verbal instructions on where to turn during the route. The presence or absence of pedestrians, and the simulated time of the drive (day or night) were varied across the trials. Eye movements were recorded along with behavioural measures including give-way violations, give-way accidents, and kerb impacts. The results revealed that intentional car following reduced the spread of search and increased fixation durations, with a dramatic increase in the time spent processing the vehicle ahead (controlled for exposure). The effects were most pronounced during nighttime drives. During the car-following trials participants were also less aware of pedestrians, produced more give-way violations, and were involved in more give-way accidents. The results draw attention to the problems encountered during car following, and we relate this to the cognitive demands placed on drivers, especially police drivers who often engage in intentional car following and pursuits.

1 Introduction

The limited capacity of visual attention has often been related to accidents that occur during driving (eg Staughton and Storie 1977). A recent analysis of accidents categorised by perceptual failures revealed that inattention, failure to look, and 'looked but failed to see' errors were among the most frequent causal factors involved in the accidents, as identified by investigating police officers (Brown 2002). These perceptual errors occur because attention must be selective.

When the context becomes too demanding, however, the priorities of selective attention change according to the nature of the demand. For instance, negotiating curves (eg Shinar et al 1977) places a greater demand on visual attention, as does increased traffic density (Rahimi et al 1990), increased speed (Cohen 1981), proximity to other vehicles (Hella et al 1996), and increasingly complex driving manoeuvres (Muir 1979). In all of these instances, fixation durations are decreased as the drivers attempt to sample more of the visual scene in order to maintain their situational awareness in an increasingly demanding situation. An increase in the sampling rate of visual search limits the amount of processing that can be done during any single fixation. It may be these occasions that are primarily responsible for 'looked but failed to see' errors. Drivers may know that they must check for cross-traffic at a junction, though a cursory glance in the appropriate direction may not be enough to verify that a manoeuvre is safe.

Other increases in demand can have the opposite effect upon visual search. The appearance of abrupt hazards, such as the car ahead suddenly braking, or a pedestrian stepping into the road, tend to capture attention, resulting in increased fixation durations and a reduced spread of search (Chapman and Underwood 1998; Velichkovsky et al 2002). These events may contribute to accidents where the driver has failed to look, or has been distracted.

The current study is concerned with one specific instance in which the context leads to an increase in demand on the attentional system: intentional car following. There has been considerable interest in engineering models of car-following behaviour (for a review,

see Brackstone and McDonald 1999). All such models, however, view car following as a passive activity, where car following is incidental to the task of getting from A to B. Here, we are concerned with a more active definition of car following, where it is the driver's intention to follow another vehicle rather than merely to travel to a new destination in a line of traffic. The impetus for this research has developed from current concerns in police pursuit driving, and therefore we focus upon how the drivers deploy visual attention in a driving scenario when they are required to follow a vehicle through a complex series of streets.

The UK Police Complaints Authority (PCA) recently reported a marked increase in serious injuries or fatal road-traffic incidents involving police vehicles. Of the 85 cases investigated between 1998 and 2001, over 75% were classified as 'pursuits' or 'follows' and 73 involved a total of 91 fatalities. The majority of incidents occurred at night, in an urban area with a 30 miles h⁻¹ speed limit and when the road was either quiet or deserted. 'Pursuits' and 'follows' involve following another vehicle containing a suspected law violator. The typical differences between the two are that 'pursuits' have a higher average speed, involve active attempts to stop the fleeing vehicle, and the mean distance between the vehicles is generally lower during 'safe follows' (PCA 2002). The most frequent source of collision during pursuits (in incidents referred to the PCA between 1998 and 2001) was that of the target car colliding with a fixed object (such as a tree) or with another vehicle or pedestrian. In contrast, the majority of collisions occurring during 'follows' involved the police vehicle. Though differences between 'follows' and 'pursuits' may lead to somewhat different search patterns, both situations are dominated by the necessity to attend to a lead vehicle.

On the basis of attentional focusing with abrupt hazards (Chapman and Underwood 1998; Crundall et al 1999, 2002), Crundall et al (2003) suggested that the prolonged hazard associated with chasing or following a suspect vehicle may also capture attention. If fixation durations are increased on a fleeing vehicle, and spread of search is correspondingly decreased, then the driver may be more prone to inattention blindness to peripheral stimuli, which may contribute to an increased accident liability. Alternatively, though a lead vehicle may increase fixation durations, the driver may attempt to compensate for the increased demand, by prioritising other important peripheral stimuli that may otherwise be missed. Mourant and Rockwell (1970) found both attentional capture and compensation (with increased glances to road markings) when drivers were instructed to maintain a specific headway between themselves and an incidental lead vehicle. Would such results occur under intentional following conditions?

Crundall et al (2003) asked police and normal drivers to watch video clips of police pursuits and found that, although police drivers did have a wider spread of search than normal drivers, all participants showed evidence of focusing, though this mainly occurred during nighttime clips. Daytime clips actually showed increased scanning during pursuits compared with control clips, as if participants were using a compensatory strategy (Mourant and Rockwell 1970).

A number of questions were raised by this study. First, it was questioned whether the basic results would be upheld if drivers had some motor interaction with the clips. It is known that certain steering actions require specific eye movements (eg Land and Lee 1994) and it is possible that the lack of interaction removed the need for certain visual strategies (such as strategies associated with car positioning relative to the lane and other road users).

A second issue was whether the level of information in each clip systematically affected search strategy. For instance, the nighttime clips in the Crundall et al (2003) study had fewer pedestrians and less traffic. This was a consequence of filming under natural conditions, and reflected the diurnal pattern of roadway activity. It is possible that drivers invest more attention in the suspect vehicle when they know there are

fewer other potential hazards. This has different safety implications compared with the possible explanation that the fleeing vehicle attracts more attention at night owing to the increased salience of the vehicle against the surroundings. The former explanation suggests that drivers could reallocate attention away from the suspect vehicle if they thought that the presence of other potential hazards required it. The latter explanation suggests that the drivers would not have this option. Though the use of real-world stimuli does provide fidelity and realism, the inherent nature of the experimental conditions means that it can be hard to tease apart such competing explanations.

In the current study, we address these issues using a non-police cohort in simulated car-following and control drives, in daytime and nighttime settings, with and without pedestrians. The use of a rudimentary driving simulator allowed the experimenters to include motor interaction whilst retaining a high degree of consistency across the participants' trials. It also allowed the manipulation of the number of peripheral distractors (in this case, the presence or absence of pedestrians) independently of the time of day. Two extra sources of information have also been added that were not available in the video clips used by Crundall et al (2003): a rear-view mirror and a speedometer.

On the basis of previous studies it was predicted that drivers would devote more attention to the car ahead in the car-following conditions compared with the control conditions (where participants were given verbal instructions on which route to take). This focusing should be apparent in the amount of time spent looking at the car ahead, longer fixation durations, and a decreased spread of visual search, and according to Crundall et al (2003) will vary according to the time of day.

There is evidence that mirror checking is generally reduced as the mental load during driving increases (Recarte and Nunes 2000; Robinson et al 1972). Schweigert and Bubb (2001) have additionally reported fewer fixations upon other non-essential objects during this time. The total duration of fixations upon the rear-view mirror and the speedometer are therefore expected to reduce during car following.

The presence of pedestrians is predicted to lead to an increase in visual search, at least in the control trials when the driver is not required to actively follow another car. If focusing does occur and is primarily due to a reduction in distractor stimuli rather than the increased salience or priority of the suspect vehicle, then the presence of pedestrians should reduce any focusing effect.

If focusing is prompted by a reduction of attentional requirements elsewhere in the scene (ie drivers only focus on the car ahead when it is safe to do so), then focusing should not occur at the expense of safety. Give-way violations, rear-end collisions, give-way collisions, and kerb impacts were all recorded to test this hypothesis. It was predicted that any focusing that occurs will be unavoidable and will therefore produce an increase in violations and accidents that are linked to inattention. Kerb impacts were included as a measure of lane maintenance, which is considered to be a peripherally monitored task (Land and Horwood 1995), and is therefore susceptible to reduced peripheral attention caused by focusing on a demanding central stimulus (Crundall et al 1999, 2002).

2 Method

2.1 Participants

Fifteen naïve participants (seven female, eight male) took part in this investigation. All participants held a full UK driving licence, and had normal or corrected-to-normal vision. Participants ranged in age from 19.3 to 31.3 years with a mean of 21.7 years. Driving experience ranged from 1 to 12.2 years from gaining a driving licence, with a mean of 3.8 years. None of the participants had any prior experience of the driving simulation used in this study.

2.2 Design

A $2 \times 2 \times 2$ within-groups design was employed. The first independent variable was driving type: participants were either required to follow a lead vehicle or were given verbal directions. The second factor split the drives according to whether they occurred within a midday or nighttime setting (which included streetlamps). The third factor manipulated the complexity of peripheral stimuli through the presence or absence of pedestrians during the drives.

A number of measures were recorded. Eye-movement recordings provided fixation durations, spread of horizontal and vertical search, and gaze durations within certain categories of stimuli (car ahead, speedometer, and rear-view mirror). As the amount of time there was a car ahead varied for each drive (especially when comparing car-following versus verbal-direction drives), gaze durations within the category of car ahead were calculated as a percentage of the amount of exposure to such stimuli. For the purpose of this study, a 'car ahead' is defined as any vehicle available to view directly through the windscreen and that is travelling in the same direction as the participant.

Driving violations and accidents were also recorded. Violations were restricted to obvious failures to give way at appropriate junctions. Three types of 'accidents' were recorded: rear-end shunts, give-way collisions, and kerb impacts. Each accident was given a number of points based on the severity of the incident. They were either classified as minor (1 point), moderate (2 points), or severe (3 points) accidents. Severity for rear-end shunts and give-way collisions was defined according to the speed at which collision occurs: 20 miles h^{-1} or below is classified as minor, since a pedestrian hit at this speed has over 95% chance of survival; between 21 and 30 miles h^{-1} is rated as moderate, when survival chances reduce to 55%; and 31 miles h^{-1} or more is regarded as severe as survival chances decrease further and this is also breaking the speed limit for the roads in the simulator (Department of Transport 1997). Kerb impacts are rated as minor for a clip, moderate if mounting the kerb with 2 or more tyres, and severe if also endangering pedestrians and/or crashing into pavement furniture (such as a lamppost).

2.3 Stimuli

The stimuli consisted of eight 2 min simulated periods of driving through the city of London using the 'cruise' option of *Midtown Madness 2*[®], a driving simulator produced by Microsoft. This provided a free-roaming driving simulation without any specific goals (see figure 1 for an example screen shot).

Participants were presented with a driver's viewpoint of the simulation (subtending 60 deg by 45 deg of visual angle). Mirror information was also available from a small section at the top-right of the screen (subtending 18 deg by 7.5 deg; mirror location was restricted by software limitations), and a digital speed display was available in the bottom left corner of the screen (subtending 5 deg by 3.3 deg). Drivers had the option of looking out of the left and right side windows of their car by pressing two buttons on the steering wheel. When either button was depressed, the view from the front of the car would change to a side view.

The simulated environment was urban and included junctions, traffic lights, stop signs, dual and single carriageways, hills, and parked cars. The cars that were followed drove relatively normally, abiding by traffic lights, etc, although they frequently broke the 30 miles h^{-1} speed limit.

Four routes were chosen around London. Each route was used twice, once during the daytime and once during the night. Two of the routes were used for car following and two were used for verbal instructions. The car-following routes had at least two lead vehicles which kept to the same route, providing a consistent drive for all participants. One of the vehicles was used as the lead car in the nighttime drive and the other was used in the daytime drive (counterbalanced across participants). Slight variations in the



Figure 1. A sample screen taken from a simulated drive. The rear-view mirror is represented at the top right of the screen. The number in the bottom left corner is a measure of speed (screen shot reprinted by permission from Microsoft Corporation).

route taken by the lead car occurred only if an unexpected event intervened (eg if the participant crashed into the lead car). To minimise the risk of such variations (and to limit the full testing session to 1 h to prevent fatigue), clip duration was set at 2 min.

All routes had either 6 or 7 bends or turns, with a minimum of at least 2 turns to the left or right, and between 4 and 6 junctions that the driver was required to pass through. At the start of each trial the participants were instructed to drive to the starting point of the route and park at the side of the road. Participants then waited at this location until either the target car passed by or until given their first instruction by the experimenter. All trials were presented in a random order.

2.4 Apparatus

The simulation software was run on a Pentium III computer. The screen had a resolution of 800 by 600 pixels and was projected through an Epson EMP-50 digital projector onto a large white projector screen. Participants were seated 1 m from the screen. A ThrustMaster steering wheel was attached to a table of approximately 73 cm in height, and ThrustMaster brake and accelerator pedals were positioned under the table to suit each individual participant. The centre of the steering wheel contained four buttons. Two of these buttons allowed the driver to look out of the left or right side windows (changing the forward view to a view left or right of the car). Two levers protruded from the steering column. The left-hand lever was assigned as a hand brake.

A head-mounted, SMI Eyelink eye tracker, with an accuracy of 0.5° and sampling at 250 Hz, recorded participants' monocular eye movements from the dominant eye. Video recordings were made of all participants' drives, with a cursor representing eye location overlaid on top of the simulated image.

2.5 Procedure

Before beginning the experiment, participants were required to fill in a short questionnaire regarding biographical information and their exposure to driving simulators in general, and specifically to the simulator used in this study.

Participants were then seated 1 m from the screen, and were acquainted with the steering wheel and the foot pedals. They then completed an initial practice drive involving various tasks, including an emergency stop, reversing, looking left and right at a junction, driving at 30 miles h⁻¹ and following another vehicle for a short period. The practice drive was self-paced but lasted no more than 10 min. Participants were then fitted with the eye tracker and completed calibration using markers on the projector screen.

Participants received standard instructions to drive as they would in reality and completed eight drives of 2 min duration. In the car-following scenario, trials were aborted early if participants lost the car-to-be-followed. Participants were informed of a 30 miles h⁻¹ speed limit and were instructed to drive normally on control drives. During the car-following drives they were told to drive as if they were a police vehicle following a suspect. The verbal directions given during the former conditions were delivered by the experimenter at appropriate times so that participants knew where to turn on a similar time scale as during car following.

3 Results

The results are divided into three sections. The first section reports participant's fixation durations and spread of search. The second section is concerned with gaze durations within the three categories of car ahead, rear-view mirror, and speedometer. The third section reports measures of driving behaviour including speed, violations, and accidents. Eye movement means can be viewed in table 1, while accident and violation means are recorded in table 2.

Unless otherwise stated, data were analysed with a 2 × 2 × 2 within-groups analysis of variance (ANOVA). These analyses were conducted across the two types of driving (control and car following), two times of day (night and midday), and two levels of

Table 1. Condition means for all eye-movement measures (with standard errors, in italics). Spread of search is calculated as the standard deviations of fixation locations in the horizontal and vertical meridians.

	Control				Car following			
	no pedestrians		pedestrians		no pedestrians		pedestrians	
	day	night	day	night	day	night	day	night
Fixation durations/ms	385 <i>(19)</i>	379 <i>(21)</i>	382 <i>(17)</i>	377 <i>(19)</i>	417 <i>(24)</i>	403 <i>(31)</i>	422 <i>(22)</i>	428 <i>(26)</i>
Horizontal spread of search/°	10.70 <i>(0.41)</i>	10.10 <i>(0.27)</i>	10.96 <i>(0.42)</i>	10.87 <i>(0.38)</i>	9.10 <i>(0.35)</i>	10.52 <i>(0.60)</i>	9.29 <i>(0.35)</i>	9.84 <i>(0.46)</i>
Vertical spread of search/°	4.47 <i>(0.38)</i>	4.19 <i>(0.30)</i>	5.14 <i>(0.80)</i>	4.68 <i>(0.84)</i>	4.27 <i>(0.55)</i>	4.26 <i>(0.54)</i>	4.68 <i>(0.44)</i>	3.59 <i>(0.35)</i>
Gaze duration on car ahead/% of exposure	39.81 <i>(4.18)</i>	39.18 <i>(3.40)</i>	n/a	n/a	76.81 <i>(2.84)</i>	80.81 <i>(2.04)</i>	n/a	n/a
Gaze duration on the rear-view mirror/ms	3259 <i>(738)</i>	2472 <i>(612)</i>	2251 <i>(532)</i>	1685 <i>(522)</i>	1621 <i>(500)</i>	1832 <i>(565)</i>	3485 <i>(1386)</i>	2195 <i>(813)</i>
Gaze duration on the speedometer/ms	3803 <i>(669)</i>	3632 <i>(1003)</i>	2699 <i>(511)</i>	3080 <i>(606)</i>	1341 <i>(651)</i>	923 <i>(530)</i>	1312 <i>(385)</i>	677 <i>(258)</i>

Table 2. The mean number of violation and accident occurrences for control and car-following trials (with standard errors, in italics).

Violation/accident	Control	Car following
Give-way violations	1.07 (<i>0.28</i>)	2.13 (<i>0.35</i>)
Rear-end shunts	0.40 (<i>0.24</i>)	6.67 (<i>1.48</i>)
Give-way collisions	0.40 (<i>0.16</i>)	1.47 (<i>0.43</i>)
Kerb impacts	0.87 (<i>0.29</i>)	3.87 (<i>1.12</i>)

peripheral stimuli (with and without pedestrians). Prior to each ANOVA, data were tested with the Kolmogorov–Smirnov test of normality and Mauchly’s test of sphericity. If data were not normally distributed, transformations were applied where appropriate; where sphericity was of concern, the degrees of freedom were modified with the Greenhouse–Geisser epsilon. The latter modifications did not affect any of the observed p values. Effect sizes were calculated by means of Cohen’s f and are reported where they aid interpretation.

3.1 Fixation analyses

Prior to analysis, all fixations below 50 ms and above 3 standard deviations from each participant’s mean were removed from the data.

A main effect of drive type was found for fixation durations ($F_{1,14} = 5.75$, $MSE = 7131$, $f = 0.64$, $p < 0.05$), with longer fixation durations during the car-following trials compared with the control trials. No other effects were found.

A similar ANOVA was conducted on the standard deviations of fixation locations in the horizontal axis, to compare a measure of horizontal search across conditions. A main effect of drive type was noted, with a smaller spread of search in the car-following conditions ($F_{1,14} = 12.2$, $MSE = 410.0$, $f = 0.93$, $p < 0.01$). Two interactions were also noted. The first interaction was found with drive type and time of day ($F_{1,14} = 4.4$, $MSE = 174.7$, $f = 0.56$, $p = 0.05$). The interaction reveals that the reduction in horizontal spread of search in the car-following trials is primarily due to less horizontal search during daytime drives. The reduction in horizontal search in the nighttime clips was minimal. The second interaction was found with drive type and the presence or absence of pedestrians ($F_{1,14} = 6.2$, $MSE = 372.7$, $f = 0.67$, $p < 0.05$). During control trials participants increased their horizontal search when pedestrians were present. During car-following trials, the presence or absence of pedestrians did not influence horizontal search, with both conditions showing reduced spread of search compared with control trials. It appears that the car-following task either demanded the resources that participants would normally allocate to monitoring the pedestrians (foveal attention), or removed the resources that made the drivers aware of the pedestrians in the first instance (peripheral attention).

It should be noted that the influence of car following on horizontal spread of search is an underestimate, as the analysis does not take into account the number of times the drivers looked out of the left-hand-side and right-hand-side car windows (using buttons on the steering wheel to momentarily change the view). Drivers made an average of 2.2 switches of view during control drives, compared with a much reduced 0.84 switches during car following. This further illustrates the decrement in horizontal search evident during car following.

A similar analysis conducted on the standard deviations of fixation locations in the vertical meridian showed no significant effects.

3.2 Gaze durations within categories

The durations of gaze within three key categories (car ahead, speedometer, and rear-view mirror) were taken from video recordings of each participant's drives. The videos had a cursor overlaid on the simulator display indicating what the participant was looking at during the drive. Gaze durations were calculated in milliseconds on the basis of the number of frames of video (25 Hz) in each drive when the cursor fell within the boundaries of one of the three categories.

The availability of a car ahead varied greatly between trials (especially when comparing car-following with control trials). To enable comparisons, the total number of frames in which a car ahead was present was summed for each drive for each participant. This provided a baseline measure of exposure to the category of car ahead for every trial. Gaze durations within the category of car ahead were then calculated as a percentage of the amount of time each driver was exposed to a car ahead in each trial.

Though the target cars used in the following conditions followed reasonably consistent routes, the other traffic on the road was less consistent in the routes taken. This resulted in less than half of the participants having a car ahead present for any of the control drives with pedestrians present. On this basis, analysis of the gaze durations on the category car ahead was conducted only upon the trials that did not contain pedestrians, requiring a 2×2 ANOVA across the two levels of driving (car following and control) and the two times of day (daytime and nighttime).

A significant main effect of drive type ($F_{1,14} = 200.4$, $MSE = 115.7$, $f = 3.78$, $p < 0.01$) was found. As predicted, total gaze duration upon the car ahead was greater during car following. When intentionally following a car, participants remained focused upon the vehicle for 79% of the time that it was available, compared with only 39.5% in the control condition.

A $2 \times 2 \times 2$ ANOVA was conducted on the gaze durations on the rear-view mirror. No differences were found, even after a square-root transform to correct slight deviations from normality.

The same analysis was conducted upon the speedometer by using a square-root transform to correct for deviations from normality. A significant main effect of drive type ($F_{1,14} = 29.3$, $MSE = 816.6$, $f = 1.45$, $p < 0.01$) was found with shorter gaze durations upon the speedometer during car-following trials. After transformation, the data fell short of suggesting an interaction between drive type and the presence or absence of pedestrians ($F_{1,14} = 4.3$, $MSE = 119.7$, $f = 0.55$, $p < 0.06$), though the trend was in the predicted direction, with lower gaze durations on the speedometer in the presence of pedestrians, but in control trials only. In the car-following trials, the gaze durations on the speedometer were reduced, and no distinction was apparent between the pedestrians-present and pedestrians-absent conditions.

3.3 Measures of driving performance

In addition to eye-movement measures and gaze durations within key categories, certain behavioural measures were also analysed. These included speed, give-way violations, rear-end shunts, give-way accidents, and kerb impacts (where the vehicle mounted the kerb).

Speed was recorded every 10 s throughout each trial and averaged to give an approximate mean speed. These mean speeds were analysed with a $2 \times 2 \times 2$ ANOVA. A main effect of drive type upon mean speed was found ($F_{1,14} = 56.3$, $MSE = 17.7$, $f = 2.01$, $p < 0.01$). As expected, mean speed was significantly higher during car-following (mean = 19.9 miles h^{-1}) than during control conditions (mean = 14.1 miles h^{-1}). Speed range was also analysed, with greater speed ranges occurring in the following conditions (44.6 miles h^{-1}) compared with control drives (29.4 miles h^{-1} , $F_{1,14} = 82.9$, $MSE = 83.6$, $f = 2.43$, $p < 0.01$).

Give-way violations, and the three different types of accident could not be analysed with ANOVAs because of the relatively low rate of occurrence. As such, violation and accident data were pooled across the conditions of daytime and nighttime, and the presence or absence of pedestrians, producing a series of within-groups *t*-tests comparing accidents and violations between the car-following and control conditions.

A give-way violation was defined as a failure to check for other vehicles at a junction where the participant did not have right of way. The number of give-way violations while intentionally following a car was greater than that during control trials (2.13 and 1.06, respectively; $t_{14} = 3.4$, $p < 0.05$).

Participants also had a higher accident rating for rear-end shunts ($t_{14} = 4.176$, $p < 0.01$, one-tailed), give-way collisions ($t_{14} = 2.694$, $p < 0.05$), and kerb impacts ($t_{14} = 2.728$, $p < 0.05$) when following a car compared with normal (control) driving. Accident ratings were calculated on the basis of frequency and severity (see section 2). The mean number of violations and accidents can be viewed in table 2.

4 Discussion

The results have revealed a clear focusing of overt attention during car-following compared with control trials during the simulated drives. When participants were instructed to follow a specific vehicle, fixation durations increased, spread of horizontal search decreased, and the proportion of time spent looking at a vehicle ahead was doubled. This suggests that attention was reallocated from a wider visual-search strategy to a narrower strategy that paid specific attention to the car in front.

The effects of the presence or absence of pedestrians upon visual-search strategies suggests that the focusing effect did not occur as the result of reduced peripheral stimuli (as could be argued in the case of the focusing noted in nighttime pursuits in Crundall et al 2003). During the control drives, the presence of pedestrians tended to increase visual search along the horizontal axis. When following the car ahead, however, horizontal search was reduced to such an extent that no distinction remained between the presence or absence of pedestrians. This suggests that in the control condition the lack of a central focus allowed participants to become aware of the pedestrians and then respond to their presence by fixating them. When following another car, however, participants were either less aware of the pedestrians, or they at least made fewer attempts to foveate these potential hazards.

Horizontal search was also influenced by the time of day. During the daytime clips, horizontal search was slightly greater than during the nighttime scanning. However, during car-following trials, horizontal search decreased dramatically in the daytime clips, with little decrement occurring during the nighttime drives. This result contrasts with the results of Crundall et al (2003) who found that nighttime clips produced the greatest reduction in scanning, while daytime clips actually produced a greater degree of horizontal scanning compared with the control clips. This surprising result will be returned to later in the discussion.

It was not surprising that vertical search was unaffected by car following, as there is very little variance in fixation locations in the vertical axis. As drivers develop their visual skills they quickly realise that the majority of the information that they need to attend to is distributed in the horizontal axis.

Gaze durations upon the categories of car ahead, rear-view mirror, and speedometer produced mixed results. As expected, participants spent longer looking at the car ahead if they were required to follow it, reducing the amount of time available to attend to other relevant stimuli. Gaze durations on the speedometer were found to decrease in the car-following trials suggesting that drivers were less aware of the speed that they were travelling at. Though this could be explained in terms of reallocating attention from the speedometer to the fleeing vehicle, it is also likely that the prioritisation of speed

regulation between car-following and control tasks may have had an effect. In the control trials participants were instructed to drive normally, whereas in the car-following trials participants were given the cover story that they were police officers following a suspect in a crime. Participants were made aware of the speed limit in both types of trial, though in the car-following trials their speed was regulated by the speed of the suspect vehicle. Thus, drivers may have had less reason to check the speedometer in the car-following trials, for if they were over the speed limit they would not be able to slow down without losing their target. Gaze durations upon the rear-view mirror did not reveal any reductions in a comparison of the car-following and control trials. Previous research suggested that increased mental load should reduce mirror checks (Recarte and Nunes 2000; Robinson et al 1972), though these studies used a secondary task that did not relate to the driving task. It is possible that the increased load produced by car following is not sufficient to induce a degradation in gaze durations upon the mirror. It seems unlikely, however, that the demand of car following reduced the ability of drivers to look at peripheral stimuli, such as pedestrians or cross-traffic at junctions, yet was not great enough to reduce mirror checks. It is possible, however, that the emphasis placed on mirrors while learning to drive results in mirror checking remaining a key activity long after search strategies out of the front of the car have degraded. There is a question how useful gaze durations on the mirror were during the car-following condition. If the mirror checks were simply the repetition of a highly practised pattern under conditions of high demand, then it is possible that very little of the information available in the rear-view mirror was actually processed. This could be another potential source of a 'looked but failed to see' error. The mirror data are supported by a previous study that demonstrated increased, and inappropriate, use of the rear-view mirror by novices in demanding driving conditions (Underwood et al 2002b).

The results of the car following upon other driving behaviours were quite apparent. Rear-end collisions were greatly increased, with misjudgments of speed in the car-following trials leading to the accidents (though it should be noted that rear-end collisions were not corrected for exposure to vehicles ahead). Give-way violations were greatly increased during car following, as were the number and severity of give-way collisions and kerb impacts. One cannot attribute the increase in these accidents solely to the attentional demands of car following, as a proportion of the increased accident liability may be due to an increase in the average speed of car-following trials compared with the control trials (a difference of nearly 5 miles h⁻¹). Additionally, when viewing these statistics, one should bear in mind all simulators will suffer from comparisons with real-world driving. For example, rear-end shunts may be affected by the particular braking and deceleration models used in the simulator. However, the fact that all behavioural measures tend to the same direction suggests a pattern that is distinct from any confounds caused by the simulator itself.

The increase in give-way violations is more directly linked to attentional demands, however, as they were defined by the driver failing to look for cross-traffic at junctions. These violations played a large part in the increased number of give-way collisions during car-following trials.

Overall the results suggest that car following does capture attention. The focusing effect cannot be explained by a reduction in the level of distracting stimuli competing for attention as drivers seem to be less aware of the pedestrians during the car-following trials. It is possible that automated routines to predictable locations, such as glances to the rear-view mirror, may continue despite the degradation of visual search for other hazards out of the front of the vehicle. The impact of car following on a number of violations and collisions is detrimental, and while kerb impacts and rear-end collisions may be partially explained by increased speed and exposure, give-way violations and collisions are directly linked to inadequate visual search.

The contradiction between the current research and that of Crundall et al (2003) regarding the narrowing of search either during the daytime (as found in the current study) or the nighttime (as noted in Crundall et al 2003) is difficult to solve. There are a considerable number of differences between the two studies. The previous study used real video clips of driving, whereas the current study used an interactive simulation. Thus, while the crisp delineation of objects in a simulator may overestimate the visibility of the visual scene during nighttime drives (which would reduce the contrast of a fleeing vehicle compared with the surroundings during the night), the inclusion of a motor component may place specific demands upon driving that interact with the increased sensitivity of peripheral vision during the night. There is no reason to believe that the difference between these two studies is due to one method being inherently more accurate than the other. Underwood et al (2002a) showed that actively viewing video clips of driving can produce similar eye-movement patterns to those noted on the real road, while other researchers working with simulators have reported that, though absolute measures of behaviour may not translate perfectly to the real world, relative measures of driving behaviour with a simulator study have greater validity (eg Toernros 1998). Though many conclusions from this study are readily apparent, the finer issue whether focusing occurs most during daytime or nighttime drives may only be solved by future on-road testing.

References

- Brackstone M, McDonald M, 1999 "Car-following: a historical review" *Transportation Research, Part F: Psychology and Behaviour* **2** 181–196
- Brown I D, 2002 "A review of the 'looked but failed to see' accident causation factor" *Behavioural Research in Road Safety* **11** 116–124
- Chapman P R, Underwood G, 1998 "Visual search of driving situations: Danger and experience" *Perception* **27** 951–964
- Crundall D, Chapman P, Phelps N, Underwood G, 2003 "Eye movements and hazard perception in police pursuit and emergency response driving" *Journal of Experimental Psychology: Applied* **9** 163–174
- Crundall D, Underwood G, Chapman P, 1999 "Driving experience and the functional field of view" *Perception* **28** 1075–1087
- Crundall D, Underwood G, Chapman P, 2002 "Attending to the peripheral world while driving" *Applied Cognitive Psychology* **16** 459–475
- Cohen A S, 1981 "Car drivers' pattern of eye fixations on the road and in the laboratory" *Perceptual and Motor Skills* **52** 515–522
- Department of Transport, 1997 *Killing Speed and Saving Lives* (London: The Stationery Office)
- Hella F, Neboit M, Laya O, 1996 "Perceptual demand and eye movements in driving", paper presented at the *International Conference on Traffic and Transport Psychology* Valencia, Spain, May 22–25
- Land M F, Horwood J, 1995 "Which parts of the road guide steering?" *Nature* **377** 339–340
- Land M F, Lee D N, 1994 "Where we look when we steer" *Nature* **369** 742–744
- Mourant R R, Rockwell T H, 1970 "Mapping eye-movement patterns to the visual scene in driving: an exploratory study" *Human Factors* **12** 81–87
- Mura T, 1979 "Visual behaviour in driving" *Bulletin of the Faculty of Human Sciences, Osaka University* **5** 253–289
- Police Complaints Authority, 2002 *Investigation of Road Traffic Incidents (RTI's) Involving Police Vehicles, 1998–2001: Identifying Common Factors and the Lessons to be Learned* (London: The Stationery Office)
- Rahimi M, Briggs R P, Thom D R, 1990 "A field evaluation of driver eye and head movement strategies toward environmental targets and distracters" *Applied Ergonomics* **21** 267–274
- 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 19–22

-
- Shinar D, McDowell E D, Rockwell T H, 1977 "Eye movements in curve negotiation" *Human Factors* **19** 63–71
- Staughton G C, Storie V J, 1977 *Methodology of an In-depth Accident Investigation Survey* Transportation and Road Research Laboratory Report LR761 (Crowthorne, Berkshire: Transportation and Road Research Laboratory)
- Toernros J, 1998 "Driving behaviour in a real and a simulated road-tunnel: a validation study" *Accident Analysis and Prevention* **30** 497–503
- Underwood G, Chapman P, Bowden K, Crundall D, 2002a "Visual search while driving: skill and awareness during inspection of the scene" *Transportation Research, Part F: Psychology and Behaviour* **5** 87–97
- Underwood G, Crundall D, Chapman P, 2002b "Selective searching while driving: the role of experience in hazard detection and general surveillance" *Ergonomics* **45** 1–12
- Velichkovsky B M, Rothert A, Kopf M, Dornhöfer S M, Joos M, 2002 "Towards an express-diagnostics for level of processing and hazard perception" *Transportation Research, Part F: Psychology and Behaviour* **5** 145–156

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