ERGONOMICS, 2002, VOL. 45, NO. 3, 167–185

An analysis of 'looked but failed to see' accidents involving parked police vehicles

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Keywords: Vehicle conspicuity; Police cars; Collisions; Hazards.

Drivers who collide with a vehicle that is parked on the hard shoulder of a motorway or dual-carriageway sometimes claim not to have seen it before the collision. Previous research into vehicle conspicuity has taken such 'looked but failed to see' claims at face value, and concentrated on attempting to remedy the problem by making vehicles more conspicuous in sensory terms. However, the present study describes investigations into accidents of this kind which have involved stationary police cars, vehicles which are objectively highly conspicuous. Two laboratory studies showed that experienced drivers viewing a film of dual-carriageway driving were slower to respond to a parked police car as a 'hazard' if it was parked directly in the direction of travel than if it was parked at an angle; this effect was more pronounced when the driver's attention was distracted with a secondary reasoning task. Taken together with the accident reports, these results suggest that 'looked but failed to see' accidents may arise not because the parked vehicle is difficult to see, but for more cognitive reasons, such as vigilance failure, or possession by the driver of a 'false hypothesis' about the road conditions ahead. An emergency vehicle parked in the direction of travel, with only its blue lights flashing, may encourage drivers to believe that the vehicle is moving rather than stationary. Parking at an angle in the road, and avoiding the use of blue lights alone while parked, are two steps that drivers of parked emergency vehicles should consider taking in order to alert approaching drivers to the fact that a stationary vehicle is ahead.

1. Introduction

Perceptual factors are often claimed to play an important role in many road traffic accidents (review in Hills 1980). Following an accident, one or both of the drivers often claim not to have seen the other vehicle until it was too late to avert a collision —the so-called 'looked but failed to see' (LBFS) error (Staughton and Storie 1977). Cairney and Catchpole (1995) estimated that 69–80% of all intersection accidents result from a failure by one driver to detect another's presence until it was too late to avoid a collision. Rumar (1990) has identified two important causes of LBFS errors: sensory limitations (the stimulus may fail to be detected because it falls below or near perceptual thresholds) and cognitive factors (e.g. failures of attention or inappropriate expectations about what is likely to happen next).

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Ergonomics ISSN 0014-0139 print/ISSN 1366-5847 online
http://www.tandf.co.uk/journals
DOI: 10.1080/00140130110115363

There has been a great deal of research into late detection errors within the context of drivers' problems in detecting motorcyclists and cyclists (Olson 1989). In this context, most research has tended to focus on sensory limitations as the root cause of the problem, rather than cognitive failures: motorcyclists and cyclists have been considered to be difficult to detect due to their small size compared to other vehicles (although see Olson 1989, Wulf *et al.* 1989, Hole and Tyrrell 1995, for alternative explanations). Researchers have tended to take at face value drivers' claims to accident investigators that they failed to see a motorcyclist or cyclist. Correspondingly the solution to the problem has been thought to be to make the motorcyclist or cyclist as physically conspicuous as possible (for example, by use of daytime headlights and bright clothing, e.g. Janoff and Cassel 1971, Fulton *et al.* 1980).

However late detection accidents are not confined to accidents involving motorcyclists and cyclists (Olson 1989, Rumar 1990): 'looking and not seeing' appears to have been a factor in accidents involving other types of vehicle as well, some of which one might expect to be easily detected, for example railway engines (Leibowitz 1985) and buses (Draskoczy 1989). Cercarelli *et al.* (1992) produce evidence from accident database studies to suggest that many crashes between cars can be interpreted as LBFS errors. The explanation of collisions purely in terms of sensory conspicuity problems does not therefore seem likely to provide a complete explanation of this type of accident (Olson 1989; Wulf *et al.* 1989).

Previous studies of vehicle conspicuity have often investigated situations where a lack of sensory conspicuity (small size, together with positioning within the peripheral visual field as opposed to foveal vision) and failure to detect have coincided, such as in the case of motorcyclists and cyclists: in these situations, it is difficult to rule out sensory limitations as a contributory factor in accident causation. In the case of collisions between cars and motorcycles or bicycles, one has to allow for the possibility that in some cases the behaviour of the motorcyclist or cyclist may have contributed to the accident. There is also the possibility that the offending driver is using the claim that they failed to detect the other vehicle as an excuse, rather than admitting that they had deliberately violated the other vehicle's right of way (e.g. in an attempt to force their way out at a junction rather than wait for a suitable gap to appear in the oncoming traffic).

However, what if one found a situation where an objectively conspicuous and relatively large object, appearing within the driver's central visual field, and which no sane person would want to collide with, was nevertheless not detected? Such failures would argue against an explanation of conspicuity failure purely in terms of sensory factors: the explanation must lie somewhere else. Such a situation does exist: sometimes objectively highly conspicuous vehicles are collided with by drivers who claim that they failed to see them. These include police vehicles and other emergency vehicles parked on the hard shoulder of a dual carriageway or motorway.

In the UK, a 'motorway' is usually a six-lane road (three lanes in either direction) with a speed-limit of 113 km/h (70 miles per hour), from which certain classes of road-user (e.g. cyclists and learner drivers) are excluded. A 'dual-carriageway' is usually a four-lane road (two lanes in either direction) with a 113 km/h speed limit. Both types of road usually have a 'hard shoulder' on which vehicles can stop only if they have broken down. There are numerous exceptions to these rules, since some dual-carriageways have six lanes, and some motorways have only four. The important points for the present discussion are that (a) both types of road are designed for high speed (so that the road generally lacks sharp bends or turns); (b) all traffic on a carriageway is moving in the same direction; and (c) stationary and very slow-moving vehicles are relatively rare, with stationary vehicles almost always confined to the hard shoulder (where one exists).

The initial motivation for the present study came from our local police force, who reported an increased number of accidents involving collisions with stationary police vehicles on motorways. There was concern that this increase was related to a change in parking practices: before 1996, UK police vehicles were parked across the carriageway in the lane that contained the hazard, so that the side of the vehicle was visible to oncoming drivers (hereafter referred to as 'echelon' parking). Since 1996, guidelines issued by the Association of Chief Police Officers (ACPO 1996) have required police vehicles to park so that the rear of the police vehicle is visible to the oncoming traffic (i.e. the vehicle's long axis is parallel to the lane's line markings, a practice hereafter referred to as 'in line'). This change was intended to increase the police vehicle's conspicuity by making the car's roof-mounted lighting strip more visible to the traffic than if the car were parked at an angle.

With the aid of the Institute of Traffic Accident Investigators, we mounted a nationwide campaign to solicit information from police forces about any accidents that they had experienced which involved a driver colliding with a stationary police car. Detailed descriptions of 47 collisions were obtained, from twelve UK police forces. After excluding reports for which an alternative explanation might exist (such as driver impairment due to fatigue or alcohol, poor weather, or the presence of a physical obstruction to the approaching driver's view) 29 reports remained of daytime accidents in which a stationary police car, fitted with conspicuity enhancements (reflective markings and flashing lights) had been crashed into by a driver who claimed either not to have seen the vehicle at all, or at least not in time to avoid an accident.

A total of 59% (17 of 29) of the accidents occurred when the police vehicle was definitely parked 'in-line'; in the case of the other reports, the orientation of the vehicle was not always explicitly recorded. All but one of the accidents occurred when there was only one police vehicle parked, due to it being either the first or last vehicle at the scene. The early deployment of warning signs and traffic cones did not guarantee detection of the parked vehicle.

Some 62% (18 of 29) of the accidents occurred within 15 km of the offender's home address, i.e. on roads that were presumably relatively familiar to the drivers concerned. (This finding has to be treated with caution, given the small size of the sample and the fact that familiarity is inevitably confounded with exposure to risk: drivers might be more likely to have an accident close to home because they spend more time driving in that area).

The offending drivers were over the age of 25 years except in one case, which tentatively suggests that that this type of accident can involve drivers of all ages and hence levels of experience.

Evidence from these reports suggests that in this type of accident the driver was not detecting the hazard too late, but was failing to detect it altogether. Some 39% of the reports (11 of 29) contain no evidence that the driver braked *at all* before the collision. A total of 70% (20 of 29) of the offending drivers' statements contained the phrase 'I did not see it'.

Interpretation of accident statistics is fraught with difficulties, especially when the sample is small and concerns events as uncommon as this particular type of accident. However, the data do enable us to make a number of observations. First, while this is not a common type of accident, it does occur with an appreciable frequency. It was suggested to us that many other cases had occurred, apart from the ones officially reported to us. Police forces evidently find this a sensitive issue to discuss, even when confidentiality is assured. If these claims are to be believed, it suggests that there may be as many as 150 such cases in the UK per year amongst the police alone. When one includes similar collisions with breakdown vehicles and the general public, this type of LBFS error may be more common than might be suggested by the statistics reported here.

Second, we have been able to isolate a core sample of reports that appear to demonstrate clearly that, despite being conspicuous in sensory terms, police vehicles were being hit by drivers who claimed not to have seen them. We have good reports concerning drivers who have, in broad daylight and with an unrestricted view of the road ahead, nevertheless failed to detect a parked vehicle covered in reflective stripes and using flashing blue and red lights.

The survey data, however, provide few clues to the cause of this detection failure. In order to try to identify contributory factors, we undertook two laboratory experiments in which we attempted to simulate the essential aspects of the drivers' situation before the accident took place.

2. Experiment 1: hazard detection as a function of vehicle parking orientation and drivers' experience

2.1. *Introduction*

The accident data suggested to us that one factor in these LBFS accidents might be that drivers collide with police cars that are parked 'in-line' because they are relying on certain expectancies about the road ahead. Experience may have taught the driver that the 'in-line' parked vehicle displaying blue lights is a moving vehicle rather than stationary. The accident data are inconclusive about whether or not 'echelon'-parked cars are more readily detectable as being parked than are cars parked 'in-line'. However, if this kind of accident is due to drivers having inappropriate expectations about their surroundings, then it seems likely that this would be the case: compared to cars parked 'in-line', the 'echelon'-parked car's orientation should present drivers with a clearer signal that they are approaching something which is out of the ordinary and which is unlikely to be a moving vehicle. If so, this effect should be affected by the driver's level of experience: inexperienced drivers may not have developed such strong expectancies about the road environment and hence should be more likely to recognize that a police car parked 'in-line' is stationary.

This laboratory experiment therefore investigated the ability of drivers to detect a parked police car in a video of a dual carriageway filmed from the driver's viewpoint, as a function of the parked car's orientation (in-line versus echelon) and the level of the driver's experience (inexperienced versus experienced).

Participants were asked to report any hazards they saw on the video. Towards the end of the video, a stationary police car came into view, parked either 'in-line' or 'echelon'. If detection of the parked vehicle is governed solely by sensory (physical conspicuity) factors, then there might be differences in detectability produced by the two different modes of parking, but there should be no difference in performance between experienced and inexperienced drivers. However, if drivers' expectancies are a factor in this kind of accident, there should be an effect of experience on detection performance: to an experienced driver, a car parked 'in-line' may look no different to any other car that is travelling in the same direction as the driver, and consequently experienced drivers should take longer to detect a stationary police car when it is parked 'in-line' than when it is parked at an angle ('echelon' fashion). In the absence of such well-developed expectancies, inexperienced drivers should detect either orientation equally well.

2.2. *Method*

2.2.1. *Design*: The experiment used an independent measures design. Experienced or inexperienced drivers viewed either a police vehicle parked 'in-line' or parked 'echelon' in one video clip amongst a series of clips that were otherwise identical for all participants. Participants therefore participated in one of four conditions:

(1) 'experienced in-line';
(2) 'experienced echelon';
(3) 'inexperienced in-line'; and
(4) 'inexperienced echelon'.

Participants' reaction times were recorded, together with their decision about whether or not each clip contained a 'hazard'.

2.2.2. *Participants*: A total of 59 participants (20 males and 39 females) were recruited by campus advertisement at the University of Sussex. Mean age was 27 years (range 17–49 years). 'Experienced' drivers were defined as drivers with more than 2 years' driving experience. 'Inexperienced' drivers were either learning to drive or had passed their test within the previous month. The experienced drivers had a mean of 13 years' driving experience.

2.2.3. *Preparation of stimulus materials*: Video-recordings were made of police cars parked in the left-hand lane of the west-bound carriageway of the A27(M), west of Chichester, West Sussex. This road is a dual-carriageway with motorway status: on each side of the road there are two lanes plus a hard shoulder, and usage is restricted to certain classes of road-user (e.g. learner drivers, cyclists, moped riders and invalid carriages are excluded). The site where the stimulus materials were collected had a gentle leftwards bend in the road, so that there was a well-defined point at which an approaching driver could first see the parked police vehicle. This site had been the location for two LBFS-like accidents in the past.

The video-filming of the parked cars was from the viewpoint of an approaching motorist. Filming was through the front windscreen, by means of the in-car 'Provid' video-camera system fitted to Sussex police cars. Recordings were made during September 1997 in fine weather between 06:00 and 09:15 h. A marked police car was parked in the left-hand lane of the dual carriageway in either an 'in-line' position or an 'echelon' position (figure 1). In the 'in-line' condition the vehicle was parked 1 m from the white line which designates the beginning of the hard shoulder. In the 'echelon' condition the vehicle was parked facing the central reservation, at an angle of 45° from the near-side of the road, with the rear left wheel on the white line of the hard shoulder. In both cases the front of the parked car faced the direction of traffic flow. The car was a white Volvo T5 Estate with the array of conspicuity enhancements which are becoming the UK standard for police vehicles used on high-speed roads: the so-called 'Battenberg' striping pattern of large blue and yellow squares on the vehicle's sides plus diagonal red and yellow retro-reflective stripes on the tailgate, together with flashing blue and red lights on the roof-mounted lighting-bar.

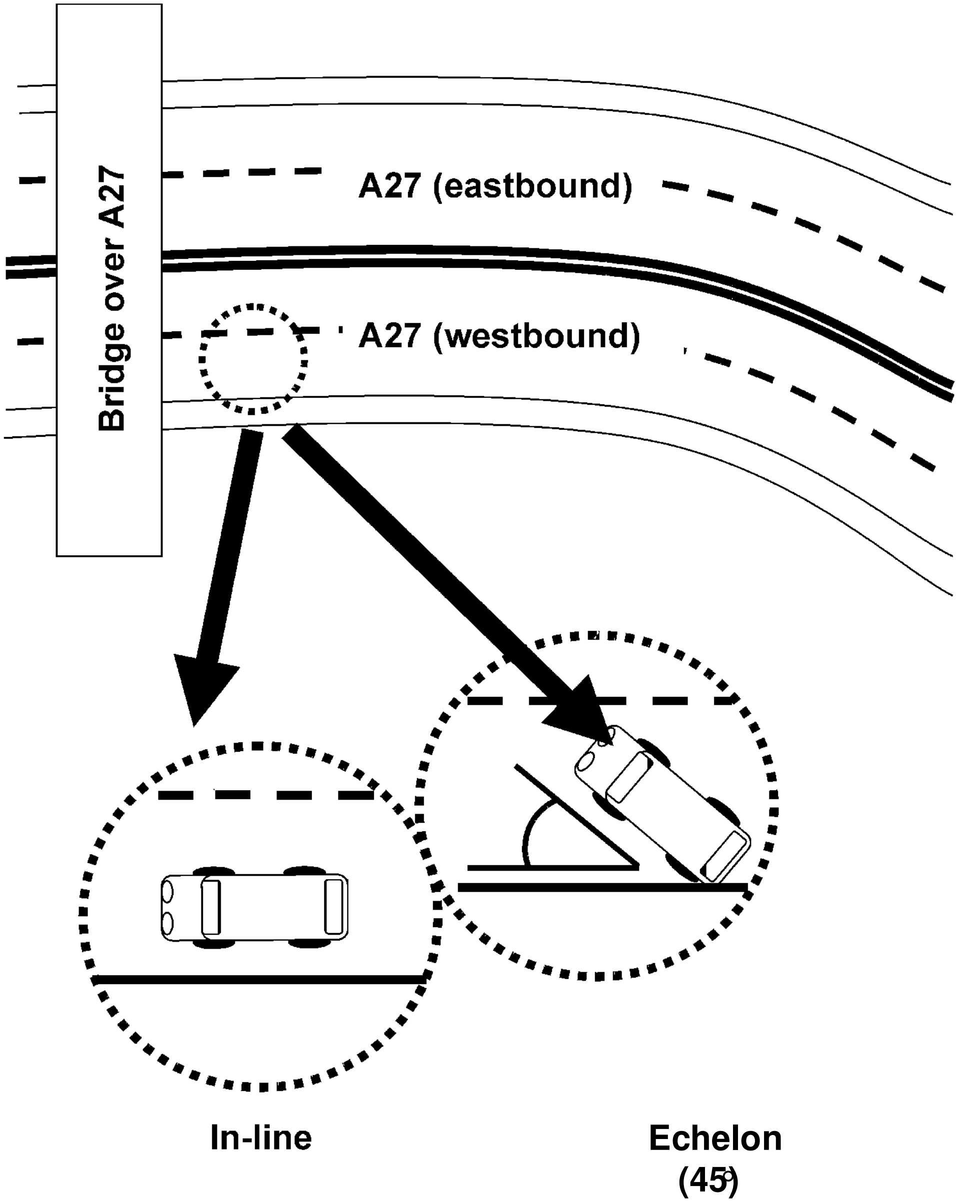

Figure 1. Plan of the experimental site used in Experiments 1 and 2, showing the approximate location of the parked police car on the west-bound carriageway of the A27. The plan is not to scale: in particular, the curvature of the road is exaggerated to emphasize how west-bound drivers were unable to see the parked vehicle before a reasonably well-defined point on the road.

Two police video vehicles preceded a rolling road block, produced by a marked police car which reduced traffic flow towards the parked police car. Traffic was stopped on the carriageway 4 km before the site of the parked car. When the road past the parked police car had become clear of traffic, the first police video vehicle drove towards the parked car, travelling in the left-hand lane of the carriageway. When 77 m away from the parked car, the moving car moved progressively into the right-hand lane. After the first video vehicle passed the parked car, the latter changed its parking orientation before being passed by the second video vehicle. After both video vehicles had passed the scene, the following police car escorted traffic past the parked car.

2.2.3.1. *Contents of video clips*: Participants were shown six video clips, each of which lasted 2 min. Five clips were the same for all participants: only the final clip contained the police vehicle, parked in either an 'in-line' or 'echelon' position depending on the experimental condition. In both cases this came into view 90 s after the beginning of the clip.

All of the video clips showed stretches of dual carriageway, filmed from the driver's perspective when travelling in the near-side lane. The first, third and sixth clips in the sequence contained 'hazards' (appendix 1). All clips showed the participant's vehicle travelling at 113 km/h (70 mph, the legal speed limit in the UK), except the fourth, which showed the participant travelling at speeds between 55 and 135 km/h. These speeds were the minimum and maximum speeds of traffic recorded on this stretch of road before testing commenced. The speed of approach was displayed in the lower section of the video screen and was visible throughout the experiment. Participants were made aware of this before the experiment began.

2.2.4. *Apparatus*: The video was projected onto a white screen situated in front of the participant by a Bell and Howell LCD10e projector (Lincolnwood, Illinois) and a Panasonic SVHS video player (Osaka, Japan). Participants viewed the video in a darkened room, seated 1.1 m in front of the screen. The resultant image was 31° horizontal and 22° vertical.

Participants indicated when a 'hazard' was present by pressing one of two buttons on a button box. A BBC microcomputer recorded each button-press, together with the time at which it occurred. All response-times were recorded with reference to time-pulses that were inserted onto the videotape at the beginning of each video-clip: every time a pulse occurred on the videotape, the computer's timing routine was reset to zero and the computer began timing again until it either encountered another pulse or the participant pressed a button.

For both versions of the final clip (containing a parked police car), the timing pulse occurred at the same fixed point, immediately before the parked vehicle first came into view. A period of 6 s then elapsed before the car from which filming took place began to move from the left lane to the right-hand lane, in order to avert a collision with the parked vehicle. Some 3.2 s later, the moving car passed to the right of the parked car.

2.2.5. *Procedure*: Each participant was tested individually. Before beginning the experiment, they read a short instruction sheet and completed details about their accident involvement and driving experience (these data will not be reported here, for reasons of brevity).

Participants were instructed to look for possible hazards, with the definition of what constituted a 'hazard' left for them to decide. Participants held a two-button response-box and pressed the left button if they believed a hazard was in the left lane or the right button if they believed a hazard was in the right lane. They were asked to respond as soon as they detected a hazard. It was explained to them that the video might contain many hazards, some or none at all.

Participants were allowed a short time to practice. The videotape took 12 min to view, but to minimize the possibility of an increase in vigilance near the end of the task, participants were not told how long the experiment would last.

2.3. *Results*

Data were collected from 60 participants. One participant's data were subsequently discarded because this participant experienced difficulty in using the button box at the same time as viewing the video.Two measures were taken for each participant: time (in seconds) to respond to the police vehicle as a hazard in the final video clip (measured from the timing pulse on the videotape, which occurred just before the parked car became visible); and the total number of 'hazard' responses for all clips.

2.3.1. *Time taken to detect the parked police car*: The reaction time data were analysed using a two-way ANOVA with independent measures on both variables. The independent variables were the orientation of the vehicle ('echelon' or 'in-line') and the driver's experience-level ('experienced' or 'inexperienced'). Main effects were found for vehicle orientation, $F(1,56) = 10.49$, $p < 0.01$, and driver experience level, $F(1,56) = 6.67$, $p < 0.05$. There was a significant interaction between the driver experience level and vehicle orientation, $F(1,56) = 6.39$, $p < 0.05$. This results from the fact that vehicle orientation significantly affected reaction-times only in the case of experienced drivers, who responded to 'echelon'-parked vehicles faster than 'in-line' parked vehicles, $t(28) = 4.22$, $p < 0.001$. Table 1 shows the mean time to respond by participants in each of the four experimental conditions.

All participants responded to the parked police car as a 'hazard', regardless of whether it was parked 'in-line' or 'echelon'. However, in evaluating these data, recall that approximately 9 s elapsed between the parked car first coming into view, and it being passed by the car from which filming took place. If these results can be generalized to real life, then most participants, even in the 'echelon/experienced' condition, would have had little time (6 s or less) in which to take action to avoid a collision with the parked car.

Table 1. Mean time to respond to the stationary police car in the final video clip (experiment 1)

Condition	Mean time to detect (s)		SD
Echelon/Experienced	3.12		0.57
In-line/Experienced	4.76	+1.64	0.99
Echelon/Inexperienced	4.56	+1.44	0.42
In-line/Inexperienced	4.50	+1.38	0.46

The figures preceded by + signs shows the difference between each condition's mean detection time and the shortest mean detection time (for the echelon/experienced condition).

2.3.2. *Overall number of 'hazard' responses*: Experienced drivers considered that the video clips contained fewer hazards than did the inexperienced drivers: the mean number button-presses for 'hazards' was 5 for experienced drivers (SD = 2), compared to 16 (SD = 17) for inexperienced drivers. There may be a number of reasons for this difference, but one interpretation is that the experienced driver appears to consider very little of a motorway environment to be hazardous.

2.4. *Discussion*

During a hazard detection task, experienced drivers were faster to respond to an 'echelon ' parked vehicle than they were to respond to one that was parked 'in-line'. For experienced drivers, but not for inexperienced drivers, the orientation of the vehicle appears to have facilitated recognition that it was stationary and hence a 'hazard'. Experienced drivers were 1.64 s faster to react to the 'echelon'-parked car. This represents a considerable difference, bearing in mind that at the UK speed-limit of 113 km/h on this type of road, a driver will cover approximately 31 m/s. None of the participants failed to respond to the parked car altogether, but it must be kept in mind that these participants were in an alert state in which they were actively looking for hazards for a comparatively short period of time.

3. Experiment 2: hazard perception as a function of vehicle parking orientation and drivers' level of attention

3.1. *Introduction*

This experiment attempted to more closely simulate the relative lack of attentiveness that may be characteristic of prolonged highway driving under normal conditions. The previous experiment was repeated, but with the addition of a secondary task that was intended to distract participants from attending exclusively to the hazard detection task and to encourage them to adopt a state of inattention that is perhaps more similar to that experienced during driving.

The task used was an adapted version of Baddeley *et al.*'s (1985) Working Memory Span Test, as used by Alm and Nilsson (1994) (appendix 2). Participants were presented with eight blocks of five sentences, some of which were meaningful (e.g. 'slippers are sold in pairs') while the rest were nonsensical (e.g. 'archbishops are made in factories'). They had to decide whether or not each sentence made sense, and also had to recall the last word of each sentence within a block, when prompted to do so. In terms of the demands placed on comprehension and memory, this task simulates some of the essentials of mobile telephone conversations while driving—the purpose for which it was used by Alm and Nilsson (1994).

3.2. *Method*

3.2.1. *Design*: The experiment used an independent measures design. Participants viewed either a police vehicle parked 'in-line' or parked 'echelon' in one video clip amongst a series of clips that were otherwise identical for all participants. Half of the participants performed this task under divided-attention conditions, while the other half were able to devote their undivided attention to the hazard-perception task. Each participant therefore participated in one of the following four conditions:

(a) ‘undivided-attention echelon’;
(b) ‘divided-attention echelon’;
(c) ‘undivided-attention in-line’; and
(d) ‘undivided-attention in-line’.

Participants’ reaction times were recorded, together with their decision about whether or not each clip contained a ‘hazard’.

3.2.2. *Participants*: 81 participants were recruited, principally staff and students at the University of Sussex. There were 40 males and 41 females. Mean age was 39 years (range 25–61 years). All participants held a full driving licence, with a mean of 17.8 years experience (range 5–43 years). Participants were randomly allocated to one of the four experimental conditions. There were 21 participants in the ‘undivided-attention echelon’ condition; 20 in the ‘divided-attention echelon’ condition; 19 in the ‘undivided-attention in-line’ condition; and 21 in the ‘undivided-attention in-line’ condition.

3.2.3. *Preparation of stimulus materials*: Participants saw five of the six video clips used in Experiment 1: the first clip was discarded in order to make the divided-attention task last as long as the video-clip sequence.

The first four clips were the same for all participants. The final clip contained the hazard of a marked police vehicle, parked in either an ‘in-line’ or ‘echelon’ position, depending on the experimental condition.

3.2.4. *Apparatus*: All details of video-clip display and measurement of participant responses were the same as for Experiment 1. The divided attention task was presented auditorily via an Hitachi TRK-640E cassette recorder (Tokyo, Japan).

3.2.5. *Procedure*: Each participant was tested individually. Before beginning the experiment, they read a short instruction sheet and completed details about their accident involvement and driving experience. Participants were instructed to look for possible hazards, with the definition of what constituted a ‘hazard’ left to them to decide. As in Experiment 1, participants held a two-button response-box and pressed the left button if they believed a hazard was present in the left lane or the right button if they considered there was a hazard in the right lane.

Participants in the two divided-attention conditions performed the Working Memory Span test at the same time as they performed the hazard-perception task. The Working Memory Span test was pre-recorded onto audiocassette tape. Forty sentences were presented auditorily to the participant, while the videotape was being shown. After each sentence was presented (e.g. ‘archbishops are made in factories’), there was a 4-s silence in which the participant had to respond ‘true’ or ‘false’. After each set of five sentences, a tone signalled the start of a 20-s period of silence, during which the participant was expected to recall the last word from each of the preceding 5 sentences. Each presentation of 5 sentences (including response breaks) took approximately 60 s. The participant’s responses were recorded by the experimenter.

3.3. *Results*

One measure was taken for each participant: the time (in seconds) to respond to the parked police vehicle in the final video clip. A total of 76 participants pressed a button in response to the parked police car: five failed to respond to it altogether.

3.3.1. *Time taken to respond to the parked police car*: The reaction time data for the 76 participants who made a response were analysed using a two-way ANOVA with independent measures on both variables. The independent variables were the orientation of the vehicle ('echelon'/or 'in-line') and the attention condition ('undivided attention' or 'divided attention'). Main effects were found for vehicle orientation ($F(1,72) = 13.33$, $p < 0.001$) and attention ($F(1,72) = 15.96$, $p < 0.001$). There was no significant interaction between orientation and attention ($F(1,72) = 0.006$, n.s.).

Table 2 shows the mean time to respond by participants in each of the four experimental conditions. Inspection of these means, together with the results of the ANOVA, suggests that there were two independent influences on participants' reaction times. First, performing the logical reasoning task markedly increased reaction times, regardless of the parked police car's orientation. Second, the police car's orientation affected reaction times, with participants slower to respond when the car was positioned in-line than when it was parked in the echelon position (replicating the main finding of Experiment 1).

3.3.2. *Frequency of hazard detection failures in the final video-clip*: Of the five participants who failed to respond to the parked police car as a 'hazard', four were in the in-line/divided attention condition, and one was in the in-line/undivided attention condition. No participants in the two echelon conditions failed to respond to the presence of the police car.

3.3.3. *Performance on the divided attention task, in relation to hazard-detection performance*: For each participant, a Working Memory Span test-score was computed: this consisted of the number of correct judgements on the logical reasoning task, added to the number of words correctly recalled. To assess whether there was a trade-off between performance on the divided attention task and performance on the hazard-detection task, the reasoning task measure was correlated with the participant's reaction time to respond to the parked police car. A significant positive relationship was found between the two measures (Pearson's

Table 2. Mean time to respond to the stationary police car in the final video clip (experiment 2).

Condition	Mean time to detect (s)		SD
Echelon/Undivided Attention	3.72		0.53
Echelon/Divided Attention	4.44	+0.72	0.77
In-line/Undivided Attention	4.38	+0.66	0.94
In-line/Divided Attention	5.13	+1.41	0.94

The figures preceded by the + signs show the difference between each conditions mean detection time and the shortest mean detection time (for the echelon/undivided attention condition)

$r = 0.67$, 75 df, $p < 0.01$): participants who scored highly on the logical reasoning task tended to take longer to respond to the parked police car.

3.4. *Discussion*

There was a highly statistically significant effect of attention-state on response-times: participants were significantly slower in the divided attention conditions than in the undivided attention conditions. There was also a highly statistically significant effect of orientation of vehicle: participants were slowest to identify the police car as a 'hazard' when it was parked 'in-line' than when it was parked at an angle. This experiment replicated the advantage of 'echelon' parking over 'in-line' parking that was found for experienced drivers in Experiment 1, although the difference in response-time was somewhat less than in the first study.

No participants in either of the 'echelon' parking conditions failed to respond to the police car; however, four participants in the in-line/divided attention condition, and one participant in the in-line/undivided attention condition, failed to identify it as a 'hazard'. These numbers are too small to perform any statistics on, but are suggestive—especially given that the experimental session was short and participants were alert, conditions which would tend to militate against detection failure.

4. General discussion

Any individual accident is likely to be the outcome of a number of contributory factors, and collisions with parked vehicles may occur for diverse reasons. Let us consider various explanations for this kind of accident in turn.

It seems highly unlikely that drivers were unable to detect the parked vehicles due to sensory limitations. Our accident reports were limited to collisions that had occurred during daylight conditions, when there was good unrestricted visibility. A parked police car presents a large, bright stimulus, with flashing multi-coloured lights and retro-reflective striping that are designed to enhance conspicuity and attract attention: it would be well above physical detection thresholds long enough for an approaching driver to see it, and take avoiding action—and yet at least some of the accident reports suggest that the driver failed to swerve or brake until just before impact. Moreover, the vehicle would have been directly ahead before the collision occurred, and hence located for some time in central as opposed to peripheral vision. While some collisions may occur because the driver failed to see a stationary vehicle due to sensory limitations (e.g. because of fog or because the view of the parked vehicle was obscured in some way), there remains a core sample of accidents that cannot be explained in these terms.

The results of our two experiments are also difficult to explain purely in terms of sensory conspicuity. First, the orientation of the parked police vehicle affected how quickly participants responded to it as a 'hazard', even though the two orientations of parked car were (objectively) similarly visible on the video. Second, experience affected response times: in Experiment 1, experienced drivers identified a parked police car as a 'hazard' faster when it was 'echelon'-parked than when it was parked 'in line'. This was not the case for inexperienced drivers. Neither of these findings can be accounted for by theories that account for conspicuity solely on the basis of the physical properties of the objects to be detected.

There are other explanations for these kinds of collisions which can also be ruled out: for example, while it might benefit a driver to attempt to force a motorcyclist or cyclist to give way to them at an intersection at which the latter has right of way, there is nothing to be gained by colliding with a stationary vehicle! Also, since the vehicle that was collided with is stationary, all of the responsibility for the accident falls on the driver of the moving vehicle; to some extent this simplifies interpretation of why the accident occurred, since one can rule out the possibility that the other party involved in the collision had contributed to the accident occurring.

The accident data that we collected are more consistent with the hypothesis that these LBFS accidents arise for 'cognitive' reasons. There are a number of possible explanations, all of which have some plausibility. First, there may have been a failure in vigilance on the part of the offending driver. Since Mackworth's studies in the 1950s (Mackworth 1957), it has been appreciated that a pronounced deterioration in vigilance performance may occur after as little as 20 min (see Cabon *et al.* 1993, Matthews *et al.* 1993, and Edkins and Pollock 1997 for discussions of vigilance failure in long-haul pilots and train drivers).

Motorway or dual-carriageway driving conditions may be ideal for promoting a decline in vigilance. Although motorway driving involves high speeds, it is relatively undemanding and unarousing most of the time. Due to advances in vehicle and highway design, together with the fact that everyone around the driver is travelling in the same direction and at similar speeds, little sensation of speed is obtained. Driving becomes largely a matter of monitoring one's lane position, maintaining a safe distance from the vehicle in front, and changing lanes to overtake slower-moving vehicles if necessary. Other vehicles are generally behaving quite predictably, and little attention has to be paid to them, other than cursorily registering their presence. Also, drivers very rarely encounter stationary vehicles on such roads (at least, not immediately in front of them), and so have no reason to look out for them. In terms of vigilance theory, the event which is to be detected occurs with a very low frequency amongst many other, fairly similar events. This militates against its successful detection (Lewis 1973).

Another factor that may contribute to these accidents is driver fatigue. In our accident data, there were some indications that collisions occurred most often in the middle of the day, with a peak around 14:00 h. One has to be wary of drawing conclusions from such a small sample, but if this is a valid observation, it is consistent with Mavje and Horne's (1994) finding that there is a propensity for sleepiness in the early afternoon, between midday and 16:00 h. Moreover, they claim that if a task lacks interest—as is the case with motorway driving—then the effects of this post lunch 'dip' in arousal are more noticeable.

Although it is possible to distinguish between fatigue and vigilance decrement on theoretical grounds, in practice their effects are likely to be difficult to disentangle: a tired driver is unlikely to be highly vigilant. An explanation entirely in terms of physical fatigue would not explain the results of our two laboratory studies, where participants were alert, performing for a relatively short period of time and (one hopes!) reasonably awake. As with explanations in terms of sensory conspicuity, a simple 'fatigue' explanation has difficulty in accounting for the effects of vehicle orientation and driver experience in these experiments.

One contributory factor in this type of accident may be that drivers *detect* the stationary vehicle in front of them, but *misinterpret* what they see. The driver who claims not to have seen a police car before colliding with it may have detected it but believed that it was moving. A stationary car on a motorway or dual-carriageway looks very similar to one that is moving in the same direction as oneself: there are no obvious cues that it is different to any of the other vehicles travelling on that road.

The flashing blue lights on a police car may actually *contribute* to this false impression, since police cars with flashing lights are normally seen moving rapidly on their way to an emergency (Shinar and Stiebel 1986). Therefore a driver may well adopt an erroneous hypothesis about the parked police car on the road ahead, based on their previous experiences of seeing police vehicles. By the time radial expansion of its retinal image occurs to any significant degree, it is probably too late for the driver to take evasive action. This is compounded by the fact that drivers' reaction times may be as long as 1.5 s when response is required to an unexpected hazard, and a lane-changing manoeuvre may take 8 s or more to complete (review in Olson 1996).

Davis (1958) used the concept of false hypotheses in an attempt to explain why train drivers sometimes failed to stop at a red light (see also Borowsky and Wall (1983) and Hurst and Hurst (1982) for an explanation of pilot error in terms of false hypotheses). Davis suggested that a false hypothesis is particularly likely to be adopted when the operator's expectancy is very high because of repeated exposures to the situation, and when attention is 'elsewhere' (i.e. the operator is distracted by another task). These conditions are likely to apply in the case of motorway and dual-carriageway driving. Once an operator forms a hypothesis about a given situation, it appears to be resistant to revision, despite information to the contrary. A driver who sees a police vehicle displaying lights might construct an initial hypothesis that it is moving, and retain this despite the subsequent development of conflicting cues such as looming, until it is too late to avert a collision. This explanation would account for the results of Experiments 1 and 2. Because it is at an angle in the road, the 'echelon'-parked police car not only provides an unusual stimulus to oncoming drivers, but one that is at odds with the hypothesis that the vehicle is moving. In the case of Experiment 1, this orientation cue appears to have been an aid only to experienced drivers who have extensive knowledge of what position a moving vehicle ought to have on the road ahead.

False hypotheses or vigilance decrements are possibly most likely to occur when the driver believes that he is 'as good as home' (Davis 1958). This may be reflected in our obtained accident data, given that many of these accidents occurred close to the offending driver's home (although there are problems in interpreting these data, as mentioned in the Introduction).

One of our reviewers suggested that drivers' perceptual sampling strategies, and their distribution of attention, might have a role to play in LBFS accidents. Drivers may base at least some of their behaviour on periodic 'samples' of the view ahead, rather than monitoring their surroundings continuously. The best evidence for this comes from Godthelp's (1985) measurements of lane-changing performance in drivers, under varying conditions of visual feedback. He found that even when an occluding visor prevented drivers from seeing the road ahead for 3 s, effects on lane-positioning were small. We do not know of any studies that have demonstrated a comparable sampling strategy in relation to other aspects of driving, such as interpretation of the surroundings. However, there are now numerous studies on 'change blindness' (Rensink *et al.* 1996), which demonstrate that individuals maintain remarkably impoverished representations of their surroundings, and may fail to notice highly marked changes to objects. This is well-documented when the changes occur to objects to which the individual is not attending, but can occur even when the objects are the focus of attention (Levin and Simon 1997). As one of our reviewers suggested, it is possible that a driver might detect a parked police vehicle, decide from the available cues (lighting and road position) that it is a moving vehicle, and not 'sample' it again until it is too late to avert a collision. It is clear to see how there might be an interaction between the adoption of a false hypothesis, faulty perceptual sampling of this kind, and change blindness.

Finally, the results of Experiment 2 are consistent with a growing body of data suggesting that driving performance may be impaired when the driver's attention is distracted, for example by the use of mobile telephones (Redelmeier and Tibshirani 1997). Using the same Working Memory Span task as we used in Experiment 2, Alm and Nilsson (1994) found that distracted drivers had lengthened reaction times and an increased subjective mental workload. Some studies (Briem and Hedman 1995) have found that the effects on performance of simulated mobile telephone use are greatest when the driving task is difficult. The present study suggests that distraction may have consequences even when the driving task is perceived as relatively undemanding, such as when driving on a motorway or dual-carriageway—precisely the kinds of conditions under which most drivers would consider using a mobile telephone. As Summala (personal communication, 2001) has pointed out, the increases in response times produced by a secondary task in our experiment are similar not only to those reported from the laboratory studies of Alm and Nilsson (1994), but also comparable to those found in real-life studies of the effects of mobile telephone use on drivers' responses to braking by the car in front of them (Brookhuis *et al.* 1991, Lamble *et al.* 1999).

So far, we have assumed that our experimental manipulations were a valid simulation of the conditions preceding a collision. However, laboratory studies cannot adequately simulate all of the properties of the real-world conditions under which this type of accident takes place. An obvious problem is that video very poorly reproduces the physical characteristics of the parked vehicle and its surroundings (ambient lighting, vehicle lighting, fluorescence and reflectivity of materials). Conditions are very far from those found in the real world, and video does not allow for the evaluation of the fluorescent properties of the materials fitted to police vehicles.

Second, objections might be raised to the extent to which our task was a valid simulation of 'driving', given that participants had an essentially passive role, with no control over the vehicle's movements. It might be thought that it would have been preferable to run our experiments in a driving simulator. However, driving consists of many different processes, including tactical decision-making, interpretation of perceptual input, and vehicle control. Most driving simulators emphasize vehicle control at the expense of perceptual realism. This may be satisfactory for investigating many aspects of driving, but it was felt that in the current context, we were justified in ignoring the motor control elements of driving, and focusing on the perceptual components of the task. Although our methods simulate only a small part of the driving task, they may be simulating the more important part of driving, at least as far as LBFS accident causation is concerned: since vehicle control is largely automatized in the experienced driver, it could be argued that removing this component of the driving task in our experiment is unlikely to make much of a difference to the cognitive 'overheads' of the driver's task.

Ideally, a complete simulation of the driving task would include all aspects of driving, but this is unfeasible at present: even the best driving simulators do not provide sufficiently realistic representations of the outside world, and even if they did, they would fail to provide the threat to personal safety that real-life driving provides. No laboratory experiment, no matter how effective the simulation, can adequately simulate the dangers of real-life driving: participants know that they are in an experiment, and that their mistakes have no important consequences for themselves or other road-users. The only way to test our hypotheses conclusively would be to run field experiments, with the vehicle under the participant's control, but there are obvious ethical objections to this; one should not underestimate the potential dangers that were involved in collecting our video footage, given that the road was open to the general public at the time.

A further problem concerns how our participants construed their task. It was left to them to define what might constitute a 'hazard' that needed a response. Although our main reason for this procedure was to enable us to present participants with an unexpected hazard (the parked car), we can also justify it on the grounds of ecological validity: in real life, each driver decides for themselves what represents a hazard, whether or not a response is required, and how urgently it must be executed. However, by leaving the participant's task so ill-defined, we may potentially have introduced some ambiguity into the interpretation of our results: participants may have responded slowly or not at all to the parked car, not because they did not see it for what it was, but because they did not consider it to be a 'hazard'.

In practice, given that the parked car occupied an entire lane, we believe that it is unlikely that participants did not include this stimulus in their personal definitions of 'hazards to be responded to', especially given the implicit demand characteristics of the experiment. Recall that we had asked participants to make different responses depending on whether a hazard was located in the left or right lane of the carriageway, a request which might be expected to give them a strong hint about how they should respond when confronted with a lane that was effectively closed to approaching vehicles. Also, this would not explain the differences in participants' responses in the 'in-line' and 'echelon' parking conditions, since in both cases, the parked car clearly blocked its lane to oncoming traffic, and required a similar urgency of response by the viewer.

With all of these limitations in mind, the results of this study have a number of implications. On a theoretical level, the accident data clearly demonstrate that high levels of conspicuity (in sensory terms) do not guarantee detection of a vehicle, a conclusion supported by the results of our two experiments. They also suggest that cognitive factors, such as drivers' expectations, may play an important role in causing this kind of 'looked but failed to see' accident. Precisely which cognitive factors are involved—fatigue, false hypotheses, inattention or a combination of all of these—remains to be determined by future studies.

On a practical level, the results suggest that drivers of all vehicles that are stationary on a high-speed road should try to draw attention to the fact that their vehicle is motionless: parking at an angle is one way to achieve this. However, since this is not foolproof as a means of avoiding collisions, the safest action civilian motorists could take is probably to wait in a place of safety, well away from their vehicle.

Acknowledgements

The authors are deeply indebted to the Traffic Division of Sussex Police, without whom this research could not have been conducted, and to the Institute of Traffic Accident Investigators and our anonymous survey respondents for their generous and enthusiastic help with this research. Thanks also to Heikki Summala and an anonymous reviewer for their constructive comments on an earlier version of this manuscript.

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Appendix 1. Summary of video clips.

Clip 1: this contained the hazard of a slow-moving motorcycle which appeared 30 s after the beginning of the clip.

Clip 2: this showed clear carriageway, with no hazards.

Clip 3: this contained two hazards, in the form of slow-moving vehicles in the near-side lane. The first vehicle, a truck, occurred 1 min after the start of the clip. The other, a car, appeared 90 s after the start.

Clip 4: this showed clear carriageway, with no hazards. The vehicle from which filming was being performed varied in speed between 55 and 135 km/h.

Clip 5: this showed clear carriageway, with no hazards.

Clip 6: this showed either a police vehicle parked 'in-line' or one parked 'echelon', coming into view 90 s after the beginning of the clip.

Appendix 2. Working memory span test items.

Slippers are sold in pairs.
The policeman ate the apple.
The train bought a newspaper.
The banker saw his car.
Rivers are crossed by bridges.
The girl sang the water.
The teacher spoke to the student.
The bird swallowed the worm.
Archbishops are made in factories,
The world divides the equator.
The letter spoke to the package.
The cat divorced the milk.
The man saw the woman.
The removal firm took a bed.
The boy brushed his teeth.
The farmer chased the dog.
The freezer was in the ice-cream.

The horse is riding the man.
The sailor beat the idea.
The jelly eats the screwdriver.
The plane swims in the sky.
Fish live in water.
The child reads the book.
The waiter served the food.
The man taught the cheese.
The cashier counted the money.
The brick threw the builder.
The soldier fought the battle.
The frog helped the vase.
The cow ate the grass.
The moon orbits the earth.
The cook sailed the kitchen.
The oven heats the food.
The dog wags its tail.
The artist flew the spider.
Elephants travel in cars.
The doctor examines the patient.
Thermometers tell the time.
Wine is bought in carpets.
Potatoes grow on trees.