Does Familiarity breed inattention? Why drivers crash on the roads they know best

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Abstract

This paper describes our research into the nature of everyday driving, with a particular emphasis on the processes that govern driver behaviour in familiar, well-practiced situations. The research examined the development and maintenance of proceduralised driving habits in a high-fidelity driving simulator by paying 29 participants to drive a simulated road regularly over three months of testing. A range of measures, including detection task performance and driving performance were collected over the course of 20 sessions. Performance from a yoked control group who experienced the same road scenarios in a single session was also measured. The data showed the development of stereotyped driving patterns and changes in what drivers noticed, indicative of inattentional blindness and "driving without awareness". Extended practice also resulted in increased sensitivity for detecting changes to foveal road features associated with vehicle guidance and performance on an embedded vehicle detection task (detection of a specific vehicle type). The changes in attentional focus and driving performance resulting from extended practice help explain why drivers are at increased risk of crashing on roads they know well. Identifying the features of familiar roads that attract driver attention, even when they are driving without awareness, can inform new interventions and designs for safer roads. The data also provide new light on a range of previous driver behaviour research including a "Tandem Model" that includes both explicit and implicit processes involved in driving performance.

Key words: Driver attention; inattention blindness; automaticity; driving simulator.

1. Introduction

The phenomena of selective looking and inattention blindness, the failure to consciously notice many otherwise prominent changes in the environment, have been known for over 100 years (Bálint, 1907, cited in Simons & Chabris 1999; James, 1890). In what have become well-known demonstrations of the phenomena, observers instructed to count the number of times a basketball is passed between players often fail to notice a woman with an umbrella or a person dressed as a gorilla walking through the midst of the players (Neisser, 1979; Simons & Chabris 1999). These and similar findings have been taken as evidence for the selectivity of attention, and the importance of attention for conscious perception. Even otherwise conspicuous events and objects may go unnoticed if they are unexpected or not relevant to observers engaged in an on-going task.

In recent years, the effect of selective looking and inattention in driver behaviour has been the subject of considerable interest. Part of the reason for this interest is due to the high rate of "looked-but-failed-to-see" crashes, collisions in which a driver fails to detect another road user or object despite looking at it (Kousanaï, Boloix, van Elslande, & Bastien, 2008). A recent taxonomy of driver inattention and distraction has used the term driver neglected attention to characterise errors of this type (Regan, Hallett, & Gordon, 2011). The issues of inattention and distraction, however, are difficult to untangle in that distractions such as conversations appear to contribute to looked-but-failed-to-see errors (White & Caird, 2010). In New Zealand, inattention and poor observation are associated with nearly half of all injury crashes, and crashes categorised as attention diverted (distraction) add another 10-13% (MoT, 2011).

Drivers' active engagement in a secondary, non-driving task appears to lead to withdrawal of attention from the forward scene, producing a form of inattention blindness (Strayer, Drews, & Johnston, 2003). Increasing the cognitive demands associated with non-driving tasks also results in change blindness, reducing drivers' sensitivity to changes in the visual environment regardless of their relevance to driving safety (Lee, Lee, & Boyle, 2007). Some aspects of the environment appear to be more likely to go unnoticed depending on the driver's amount of experience. Experienced drivers, for example, are less likely to detect important traffic signs when they are placed in unusual locations (Borowsky, Shinar, & Parmet, 2008). This form of selective looking has been proposed to result from the development of well-learned schemata for scanning the roadway which guide experienced drivers' search for task relevant information (Borowsky, Shinar, & Oron-Gilad, 2010).

Experience appears to affect where drivers search and look for information in the environment. An interesting issue in this regard is how selective looking and inattention blindness are affected by repeated exposure and familiarity with a particular route or road. With repeated exposure to a particular road, drivers may experience the phenomenon of driving without awareness. Or more correctly, they may experience the cessation of the driving without awareness state, returning to the driving task with the experience of a time gap in their awareness (Chapman, Ismail, & Underwood, 1999). Just as the direct experience of driving without awareness is unavailable to many drivers, the phenomenon has also eluded most theoretical models of driver behaviour. Most models of driver behaviour have regarded driving without awareness as an exception to "normal" driving; an undesirable state that occurs when a driver becomes distracted (Charlton & Starkey, 2011).

One of the exceptions to this point of view, the Tandem Model, has described driving as being dependent on two interlinked processes; a conscious, intentional level of task engagement referred to as an "operating process", and an unconscious "monitoring process" continuously engaged with the driving task; its function to compare incoming stimuli to stored representations of previous instances of driving, particularly instances indicative of potential errors or hazards (Charlton & Starkey, 2011). When incoming stimuli are congruent with stored representations of familiar or benign situations the monitoring process alone is sufficient to maintain most aspects of the driving task without active attention, in essence, a driving without awareness mode. The Tandem Model suggests that repeated practice results in a broadening and refinement of the templates (schemata) used by the monitoring process to the point where a wide range of familiar situations and circumstances can be handled with little or no activation of the operating process.

With regard to selective looking and inattention blindness, it is an interesting question whether extended practice is associated with an increase or a decrease in the detection of changes to the driving environment. In the original selective looking experiments, observers who were practiced at selectively tracking the passes made by one of the two basketball teams were twice as likely to notice the unexpected umbrella woman as were novice observers (Neisser & Dube, 1978, cited in Most et al, 2005). In contrast, research using the change blindness paradigm suggests that experience may lead to greater inattention blindness in that experienced drivers are less likely to attend to non-essential stimuli or stimuli located in unusual places (Borowsky, Shinar, & Parmet, 2008).

In one experiment explicitly investigating the effects of repeated practice on detection, Martens and Fox (2007) found that although five days of practice led to better recollection of traffic signs along the route, there was a decrease in recognition accuracy when a target sign was changed from a priority crossing to a yield sign on the final day of the experiment, an apparent failure to detect important changes to the road environment. From a practical perspective, it would be useful to know to what extent this finding generalises to other familiar driving situations and other kinds of traffic stimuli. From a theoretical perspective it would be interesting to know what sorts of road and traffic stimuli are more likely to receive conscious attention and which sorts may be processed implicitly by the monitoring system, and which others may remain attentionally "neglected" or unprocessed.

The experiment reported in this paper was intended to explore these possibilities by examining detection and driving performance as participants repeatedly drove a single road in a driving simulator in 20 sessions spread over three months. Performance from a yoked control group who experienced two road scenarios in a single session was also measured.

2. Method

2.1. Participants

Two groups of participants were recruited for this study via posters placed on university notice boards and word of mouth (i.e., a convenience sample). The first group of 29 participants, 13 males and 16 females, were assigned to the "Expert" group who were recruited to drive in the driving simulator regularly over a period of approximately 3 months. The Expert group participants' ages ranged from 17 to 49 years of age (M = 30.17 years, SD = 11.52), and reported that they regularly drove between 10-500 km per week (M = 138.93 km, SD = 138.55) and on average had 15 years of driving experience (range 2-35 years, SD = 11.46). A second group of 30 participants, 14 males and 16 females, formed the "Casual" group and were recruited to participate for a single experimental session only. Their mean age was 32.27 years (SD = 10.88, range 18-53 years), they reported driving between 5 and 850 km per week (M = 203.45 km, SD = 179.42) and had 1 to 38 years driving experience (M = 9 years, SD = 10.93). All of the participants were required to possess a current New Zealand driver licence and were asked to wear any corrective lenses during the experiment if they were required to do so as a condition of their driver licence. The mean ages and years of driving experience were not significantly different for the two groups ($F(1, 57) = .239$, $p = .627$ and $F(1, 57) = .516$, $p = .476$ respectively).

Twenty-four of the participants in the Expert group completed all 20 experimental sessions. Two of the participants withdrew after Session 6, one withdrew after Session 11, one after Session 12, and one after Session 14. Non-completion by these participants was due to time constraints or medical reasons. (Data from the participants who completed only six sessions were not included in subsequent analyses). All of the participants in the Casual group completed their experimental session. In recognition of their participation in the study, participants received a $10 gift voucher for each experimental session they attended.

2.2. Apparatus

The experimental apparatus was the University of Waikato driving simulator consisting of a complete automobile (BMW 314i) positioned in front of three angled projection surfaces producing a 175˚ (horizontal) by 41˚ (vertical) forward view of the simulated roadway from the driver's position. In addition, two colour LCDs were mounted at the centre rear-view mirror and driver's wing mirror positions to provide views looking behind the driver's vehicle. The details of the driving simulator have been previously described elsewhere (Charlton & Starkey, 2011).

2.3. Simulation scenarios

The simulation scenarios were based on a 24 km-long section of rural road containing a combination of straights and gentle horizontal and vertical curves. The road geometry was based on the surveyed 3-dimensional road geometry of a rural two-lane state highway in New Zealand. The simulated road was divided into two 12 km halves, each half containing eight intersections. Each half of the simulated road could be driven in either direction (northbound or southbound), with a village marking the central point of the simulated road. Drivers could start at either the north end of the road and finish in the village, start in the village and drive either north or south, or start at the southern end of the road and drive to the village. The speed limits were 100 km/h, apart from a 400 m section which passed through the village and had a speed limit of 60 km/h. Each half of the road contained a range of prominent landmarks (e.g. houses, shops, farms, a bridge, a 400 m tunnel, overtaking lanes, and directional signs) to facilitate participants' recognition of their surroundings as they became familiar with the road over repeated sessions (see Figure 1).

Figure 1: Scenes from the simulated road. Clockwise from top left: Volkswagen detection target; tunnel; road works; unfamiliar road

Using the simulated northern and southern road sections described above, 38 distinct scenarios were created and presented across 20 experimental sessions (as shown in Table 1). Most of the scenarios differed only in the placement of other traffic on the roads. A representative mixture of cars, light trucks, and heavy vehicles, were in each scenario (25 vehicles in each half) heading toward the driver. In addition, one Volkswagen beetle was placed into each road scenario (heading towards the driver and becoming visible 280 m away), which the participants were required to identify in a vehicle detection task described later. In order to minimize the influence of traffic on the participants' speed and lateral positioning, no leading vehicles were placed within 750m ahead of the driver.

Table 1: The simulation scenarios presented in the 20 sessions

Session 1	**Session 2**	**Session 3**	**Session 4**	**Session 5**
A-South	B-North	A-North	B-South -- RW	B-North
B-South	A-North	A-South -- CD	B-North -- RW	A-North
Session 6	**Session 7**	**Session 8**	**Session 9**	**Session 10**
A-South	A-North	A-South -- UR	B-South	B-North
B-South	A-South	B-South -- UR	B-North	A-North
Session 11	**Session 12**	**Session 13**	**Session 14**	**Session 15**
A-South	A-North	B-North	B-South	B-North
B-South	A-South -- CD	A-North	B-North	A-North
Session 16	**Session 17**	**Session 18**	**Session 19**	**Session 20**
A-South	B-South -- RW	A-South -- UR	A-North,	B-North
B-South	B-North -- RW	B-South -- UR	A-South -- CD	A-North

CD = change detection, RW = road works, UR – unfamiliar road

In three scenarios (termed Change Detection scenarios) changes were made to roadside buildings (e.g., a prominent farm silo was removed, rural sheds were added), warning signs (addition of unique pedestrian, horse, or children warning, removal of road dip warning), road markings (removal of edgelines or centrelines for 160 m, addition of three white dots placed across the driver's lane, change to solid white centreline for 160 m), a prominent directional sign was changed from English to German wording, and an oncoming police car was added. Two Road Works scenarios contained a 200m section of unsealed road, warning signage, 30 km/h speed restriction signs, road cones, and associated construction equipment. Finally, an Unfamiliar Road scenario (presented during two sessions) was created by changing the appearance of the landscape, types of trees used, and removing all landmarks such as buildings, tunnels, bridges, etc (although the road geometry remained identical to that used for the other scenarios).

2.4. Procedure

At the start of the first session, each participant was given an overview of the activities involved in the experiment, asked to complete an informed consent agreement, and allowed to practice until they felt comfortable driving the simulator (5 – 10 mins). At the start of every session the participants were instructed to drive in the simulator as they would normally drive in their own car. They were also instructed to sound the horn (by moving the headlight control stalk on the right side of the steering column) whenever they noticed anything interesting, unusual, hazardous, or a Volkswagen beetle, and name it aloud. The detection task was adapted from a previous study (Charlton, 2006) in which moving the headlight control (producing a single horn beep) was found to be an effective method for participants to indicate detection of objects and other vehicles. It should be noted that the same instructions were given at the start of each session and that the participants were not alerted to the possibility of changes to the scenarios or given any special instructions for the Change Detection, Road Works, or Unfamiliar Road scenarios.

There was a short (2 – 5 min) rest break between the two 12 km scenarios in each session during which participants got out of the car for a stretch and a drink of water or short conversation with the experimenter. The sessions were structured to mimic a plausible real-life drive; for example, a participant starting at the one end of the road would finish their first drive in the village and after a short break, would either continue in the direction they had been travelling, or begin driving in the opposite direction to their point of origin.

After practicing, the participants in the Casual group drove two of the 12 km scenarios during their only experimental session. The first scenario they drove was the Road Works scenario that the Expert group received during the first half of Session 17. The second scenario was the Change Detection scenario that the Experts received during the second half of Session 19. At the end of each scenario all participants were asked to rate the difficulty of driving the simulated road on a seven-point driving difficulty scale ranging from 1 = easy; no difficulty at all to 7 = extremely difficult; unsafe (adapted from Charlton, 2004).

3. Results

Ratings of driving difficulty decreased throughout the experiment, reaching asymptote by Session 7. The exceptions to this were the Unfamiliar Road and Road Works sessions which were rated as being more difficult and mentally demanding (see Figure 2). A repeated measures Anova indicated a linear trend for decreasing difficulty ratings across 13 sessions (all sessions excluding Unfamiliar Road, Road Works & Change Detection), $F(1, 20) = 24.18$, $p< .0001$, $\eta_p^2 = 0.547$, with no difference between the first and second roads of each session, ($F(1, 20) < 1.0$, $\eta_p^2 = 0.017$) or interaction between session and road order ($F(12, 240) < 1.0$, $\eta_p^2 = 0.040$). The difficulty ratings were significantly lower than those of the Control Group on the matched roads ($F(1, 58) = 22.26$, $p< .01$, $\eta_p^2 = 0.277$). The difficulty ratings during the two Unfamiliar Road sessions were significantly higher than the ratings from adjacent sessions, $F(1, 23) = 99.71$, $p< .0001$, $\eta_p^2 = 0.813$ and $F(1, 23) = 41.81$, $p< .0001$, $\eta_p^2 = 0.645$).

Detection of the Volkswagen beetle targets quickly became very accurate; at least 90% of the participants reliably detected both of the Volkswagens (one in each scenario) by the third session. The distance at which the participants detected the Volkswagens, however, changed over the course of the experiment; the average distance decreased over the first few sessions (to an average of approximately 44 m by Session 5) and then increased to over 140 m during the first road of Session 10 and to nearly 200 m during the second road. A 2 x 5 repeated measures Anova comparing the detection distances across the two roads during five equivalent sessions (Sessions 2, 5, 10, 15 and 20) indicated a significant interaction ($F(4, 60) = 3.15$, $p= .02$, $\eta_p^2 = 0.174$) reflecting equivalent distances for the first and second roads during the early sessions but longer distances for the second road by the second half of the experiment (see Figure 3). The Control Group detected a significantly lower proportion of Volkswagens on the same roads (Pearson $\chi^2(1) = 7.86$, $p < .005$) but detection distances were not reliably shorter ($F(1, 51) = 3.05$, $p= .087$, $\eta_p^2 = 0.056$).

Figure 2: Ratings of driving difficulty (cognitive demand)

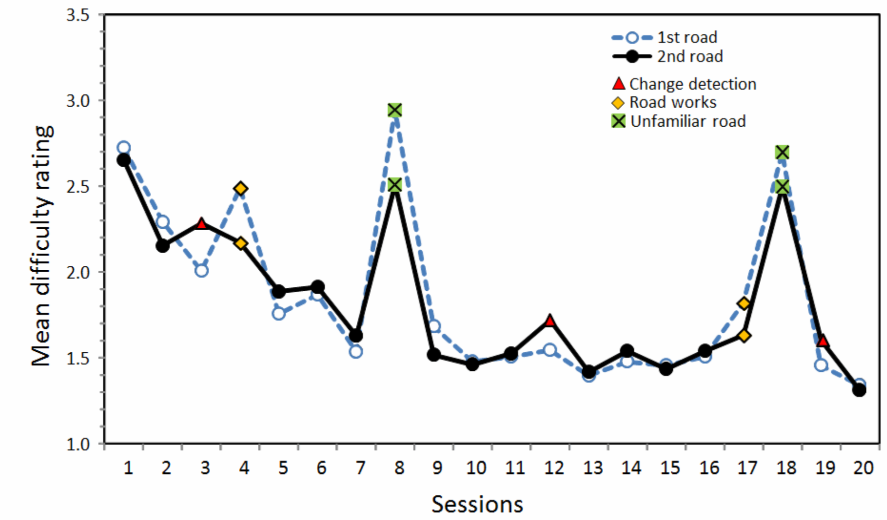


Figure 3: Vehicle detection distances

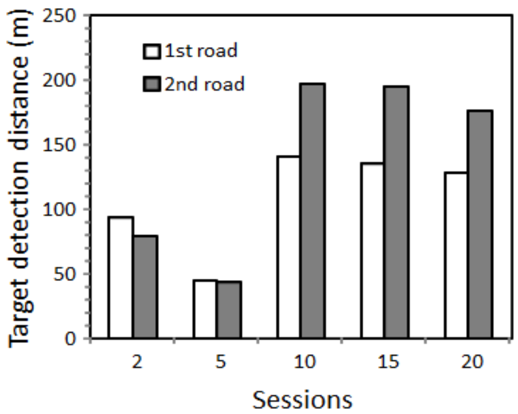
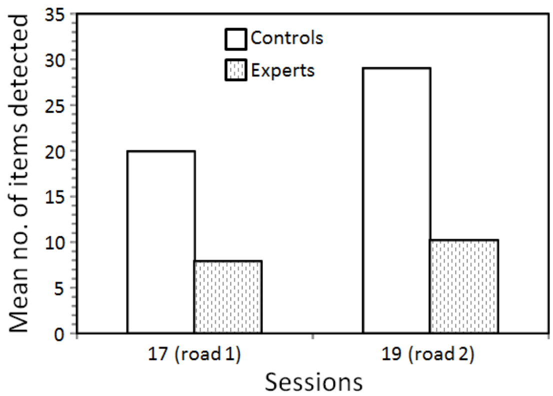


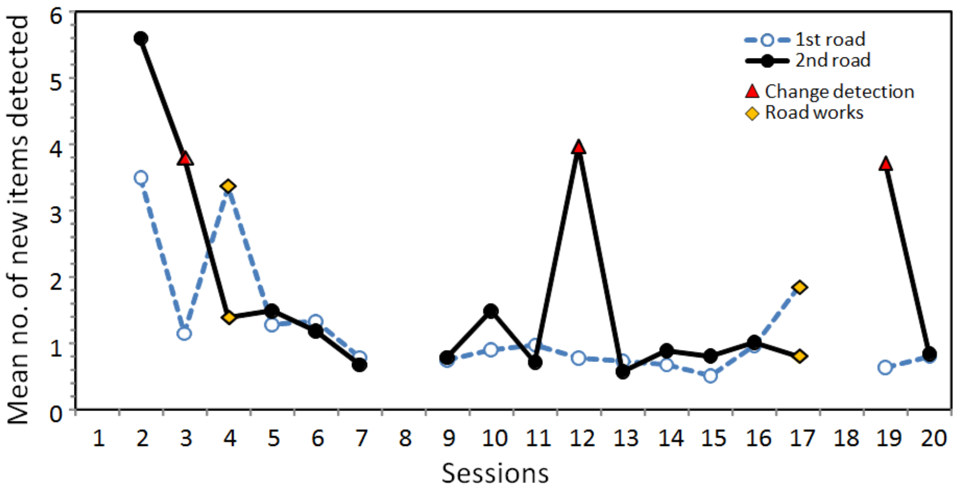
Figure 4: Total items detected



The number of times the participants indicated that something caught their attention tended to decrease over the course of the experiment (with the exception of the Unfamiliar Road and Change Detection sessions). A 2x2 mixed design Anova comparing the number of items detected by the Expert and Control groups during the equivalent sessions (as shown in Figure 4) indicated a significant difference between the two groups ($F(1, 52) = 25.62$, $p < .001$, $\eta_p^2 = 0.330$), as well as a difference between the two roads ($F(1, 52) = 23.16$, $p < .001$, $\eta_p^2 = 0.308$), and an interaction of road and group ($F(1, 52) = 8.72$, $p = .005$, $\eta_p^2 = 0.144$). As can be seen in Figure 4, the significant interaction resulted from an increase in the number of items reported by participants in the Control Group during the second road of their session.

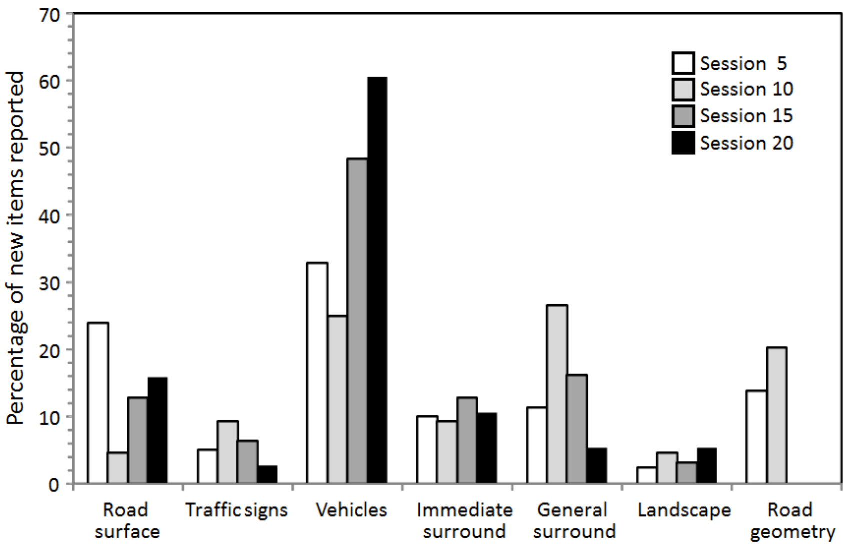
During the experiment participants developed a stereotyped repertoire of items they reported as they drove; the items were somewhat different from participant to participant, but individual participants tended to report the same items in every session. For example, on each drive a participant might point out “a bump in the road there”, “a green road sign ahead”, or “tunnel coming up”. The number of these repeated items reported was very stable from session to session. The number of new items reported (items not reported on the preceding drive on the same road) decreased rapidly over the first six sessions (see Figure 5). Change Detection scenarios were an exception and contained a relatively high number of items reported. A repeated measures Anova comparing all sessions except Session 1 and the Unfamiliar Road, Change Detection, and Road Works sessions indicated a significant linear decrease in items reported ($F(1, 21) = 26.88$, $p < .001$, $\eta_p^2 = 0.561$), as well as a smaller main effect of road ($F(1, 52) = 25.62$, $p < .001$, $\eta_p^2 = 0.330$), such that across all sessions there were more new items reported during the second road of the session.

Figure 5: New items reported (not reported on the preceding drive)



Analysis of the type of items the participants reported noticing (of the new items reported) was performed using categories adapted from Hughes and Cole (1986). Figure 6 shows the percentage of items falling into each of seven categories across Sessions 5, 10, 15, and 20. The single largest category of new items reported were vehicles, and grew to constitute an increasing proportion of the items over the course of the experiment (60.53% of the items by the end of the experiment) as compared to traffic signs, road geometry, and the general surround (e.g., buildings). It should be noted, however, that although vehicles represent a large proportion of items reported, the total numbers of reported items is rather small (over half of the participants reported no vehicles at all in the second half of the experiment).

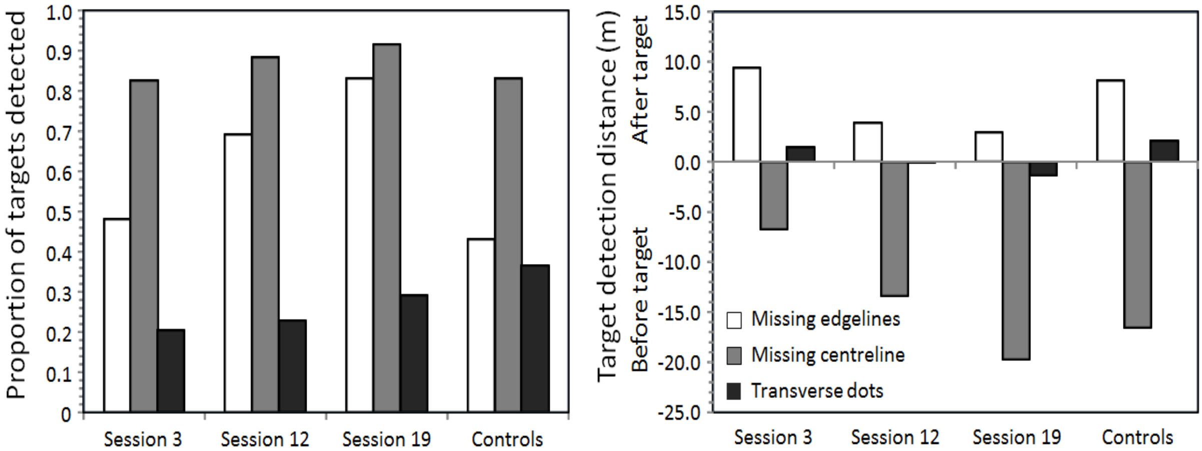
Figure 6: Types of new items reported



During the Change Detection scenarios (Sessions 3, 12, and 19) few of the participants noticed changes to buildings; fewer than 10% noticed the addition of a shed and none noted the removal of a large farm silo. Only one participant reported noticing the removal of a warning sign for a road dip (on Session 12), and only two noticed that the wording of an information/distance sign was changed from English to German (one each in Sessions 12 and 19). In comparison, three participants in the Control Group reported German wording on the sign in their session. The rate at which participants reported noticing the addition of new, unusual warning signs decreased across the sessions; 41.38% of drivers noticed the addition of a horse and rider warning (Session 3), 34.62% noticed a new children warning (Session 12), and 20.83% noticed a new pedestrian warning sign (Session 19), far fewer than the 63.3% of control participants reporting noticing the pedestrian sign in their session.

The changes with the greatest conspicuity were changes in road markings (removal of centrelines for 160 m, removal of edgelines for 160m, and the addition of three white transverse dots in the driver's lane). The detection rates and distances for these three road marking changes are shown in Figure 7. The removal of the centreline was the most frequently reported change; 82.76%, 88.46%, and 91.67% of the participants reported this change on Sessions 3, 12, and 19 respectively. Removal of the edgeline was next (reported by 48.28%, 69.23%, and 83.33% of participants across the three sessions). The addition of three white transverse dots was reported by fewer participants; 20.69%, 23.08%, and 29.17%. One change to the road markings went relatively unnoticed; only one participant reported noticing the dashed white centre line was changed to a solid white line for 160m (reported for Session 19).

Figure 7: Road marking changes detected



The mean detection distances (from the start of the road marking) are shown in the right panel of the figure (for those participants detecting a change). Detection distances steadily increased for all three changes, with the greatest change occurring for the absent centreline; increasing from an average 6.77m to the start of the change in Session 3 to 13.34m in Session 12, and 19.66 m by Session 19. The control participants showed the same general pattern of reporting as the Expert Group; highest conspicuity and earliest detection for the missing centreline followed by missing edgelines and white dots.

One other change introduced in the Change detection scenarios was the addition of a marked police car. The percentage of participants in the Expert Group reporting the police car was approximately the same across the three Change detection sessions; 62.01% in Session 3, 69.23% in Session 12, and 62.5% in Session 19. In comparison, only 34.03% of the participants in the Control Group reported seeing the police car; a marginally significant difference between the Control participants and the Experts in Session 19 (Pearson $\chi^2(1) = 3.56$, $p = .059$). Although these detection rates were better than for many of other changes, they were not as good as the detection of the Volkswagen beetle targets, which the participants had been explicitly instructed to look for and practised in every session.

4. Conclusions

Over time, the participants reported fewer items as attracting their attention, and the items they did report noticing became increasingly stereotyped and concentrated on vehicles rather than road signs, buildings, or landscape features. Participants were also relatively insensitive to changes in these features during the Change Detection scenarios, not noticing the removal or addition of buildings, or the change from English to German wording on a direction sign. Some participants did notice the addition of unusual warning signs, but their likelihood of detecting them decreased as their familiarity with the road increased.

By the fifth and sixth sessions of the experiment participants began volunteering that they were "driving without thinking about it", "zoning out" or "going on autopilot", comments indicative of driving without awareness. It was apparent that familiarity with the visual features of the road was most closely tied to the participants' feelings of driving without awareness; when the visual features were changed and familiar landmarks removed during the Unfamiliar Road scenarios, the participants' ratings of driving difficult returned to levels as high, or higher, than the first session of the experiment. The sense of driving "on autopilot" was also apparently associated with some degree of inattentional blindness given the lower rates of change detection for individual elements of the environment, particularly when contrasted with participants in the yoked control group.

Driving without awareness, however, did not mean that drivers were insensitive or change blind to all elements of the driving environment. Removal of lane guidance cues (i.e., centrelines and edgelines) was readily detected, and the participants' sensitivity to their removal increased over the course of the experiment. Similarly, participants quickly became proficient in the vehicle detection task, and the targets (Volkswagen beetles) were detected further away in the second half of the experiment, and during the second drive of those sessions, presumably when participants were most likely to be driving without awareness.

Considering these results in the light of the Tandem Model described earlier, they suggest that explicit or conscious involvement in the simulated driving task (the operating process) was withdrawn relatively early in the experiment, and its withdrawal was associated with a lower rate of reporting "interesting, unusual or hazardous" items. The very good detection performance for cues related to guidance suggests that the implicit monitoring process quickly becomes "tuned" to these sorts of cues, and their absence is rapidly detected. In the later sessions, when the participants' conscious involvement in driving was lower, the detection distances for these guidance cues were furthest, suggesting the implicit detection system was even more efficient when participants were not consciously involved.

For most drivers, the implicit monitoring process is apparently not tuned to detect changes in non-essential cues such as buildings and many types of signs. The performance on the Volkswagen detection task, however, suggests that with practice drivers become conditioned or tuned to automatically detect a range of different of visual elements. Interestingly, several participants commented that they often flashed their headlights (or found themselves reaching for them) when they saw Volkswagen beetles while driving their own cars, suggesting some generalisability of detection schemata from one situation to another. The detection of Police cars followed a similar pattern (poorer detection by the Control Group), and adds support to the suggestion that rapid detection for some meaningful cues may actually be more efficient when drivers are relying primarily on the implicit monitoring process rather than the explicit operating process.

As has been suggested elsewhere, withdrawal of attention and inattentional blindness may be inevitable for tasks that we repeat often; "IB (inattentional blindness) may be a pervasive aspect of visual perception…we do not realize the degree to which we are blind to unattended and unexpected stimuli and we mistakenly believe that important events will automatically draw our attention away from our current task or goals. Although such events might implicitly capture attention, thereby affecting the performance of our current task, they might not explicitly capture attention" (Simons, 2000, p154).

Epidemiological data have long shown that drivers are most likely to crash at locations very near their homes (Chen, et. al. 2005; Durand, 1980). As for why drivers crash on the roads they know best, it is clear that with repeated exposure many elements of familiar visual environments are neglected or not consciously processed. For them to be detected by the implicit monitoring system, they need to be regularly practised cues of some consequence for dynamic task performance. The good news is that efficient and rapid detection of a wide range road and traffic information is possible, even when drivers are not paying attention. The challenge for road safety practitioners is to develop training strategies that foster the development robust hazard detection schemata, and road designs that place important cues in locations that are most likely to be scanned and detected by drivers (e.g., road markings).

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