Transportation Research Part F 14 (2011) 456–471

Contents lists available at ScienceDirect

Transportation Research Part F

journal homepage: www.elsevier.com/locate/trf

Driving without awareness: The effects of practice and automaticity on attention and driving

Samuel G. Charlton *, Nicola J. Starkey

Traffic & Road Safety Research Group, School of Psychology, University of Waikato, New Zealand

ARTICLE INFO

Article history:
Received 15 August 2010
Received in revised form 22 April 2011
Accepted 28 April 2011

Keywords:
Driving simulator
Driver attention
Perception of speed
Speed variability
Vehicle detection

ABSTRACT

This research examined the development of proceduralised "driving without awareness" in a driving simulator by paying participants to drive a simulated road regularly over 12 weeks of testing. This longitudinal research paradigm is a significant departure from previous studies which have examined drivers in a conscious attentional mode using short experimental sessions or cross-sectional designs comparing expert and novice performance. During each session, participants took two "trips" on the simulated road; sometimes travelling on a "to and from" journey on one half of the road, sometimes traversing the entire road in one direction. A range of measures, including driving performance, vehicle detection, perceptual speed regulation, and hazard reactions were collected. The results showed the development of driving patterns and changes in object detection performance indicative of proceduralised driving. Speed and lane position variability quickly decreased with practice, as did participants' subjective experiences of driving difficulty. Performance on an embedded detection task appeared to become a proceduralised part of the driving task, becoming highly efficient in later stages of the experiment. The changes in attentional focus and driving performance over time provide new light on previous research findings and allow us to critically re-examine several established models of driver behaviour.

It is a general principle in Psychology that consciousness deserts all processes where it can no longer be of use… We grow unconscious of every feeling which is useless as a sign to lead us to our ends, and where one sign will suffice others drop out, and that one remains, to work alone (Wm James, 1890, p. 496)

1. Introduction

The sense of driving without awareness is an experience familiar to most drivers; a sudden realisation that you have no recollection of the past several minutes of driving, and that you have arrived at this point in the journey with little or no conscious attention to the surrounding traffic. As with other areas of skilled performance, many aspects of driving become automated with practice (Ranney, 1994). Variously referred to as driving without attention (Kerr, 1991) or driving without awareness (Brown, 1994), the driver performs in a state in which he or she has no active attention for the driving task and performs on 'autopilot'. Subjectively, the driving without attention state may not be experienced until it has ended, when the driver encounters an apparent time gap in their awareness of the drive (Chapman, Ismail, & Underwood, 1999; Galpin,

* Corresponding author. Address: Traffic & Road Safety Research Group, School of Psychology, University of Waikato, Private Bag 3105, Hamilton, New Zealand. Tel.: +64 7 838 4466x6534; fax: +64 7 858 5132.

E-mail address: samiam@waikato.ac.nz (S.G. Charlton).

1369-8478/$ - see front matter
doi:10.1016/j.trf.2011.04.010

Underwood, & Crundall, 2009; Reed, 1979). Recent examinations of crash data have suggested that this state is not without substantial risks, the most common crash modes appear to indicate failures in this automatic or proceduralised mode of driving (Iden & Shappell, 2006; Stanton & Salmon, 2009). In spite of its prevalence, many questions remain unanswered about this aspect of driver behaviour.

The role of automaticity in skilled performance was recognised early on by experimental psychologists (James, 1890) and is represented in several theories of knowledge representation, problem solving, and manual control (Calderwood, Klein, & Crandall, 1988; Norman, 1981; Shiffrin & Schneider, 1977). Automatic performance has generally been characterised as efficient, unintentional, and unconscious behaviour that has become proceduralised through extensive practice (Bargh & Chartrand, 1999; Moors & De Houwer, 2006; Shiffrin & Schneider, 1977). In this context the term proceduralised is used to refer to cognitive and motor skills that become automatised and tuned to the degree that they can be performed without being mediated by conscious attention or declarative knowledge (Anderson, 1982; Fitts & Posner, 1967). Once proceduralised, these automatic behaviours are stimulus-driven, i.e., they are initiated and continued autonomously in response to external stimuli (Trick, Enns, Mills, & Vavrik, 2004). Automaticity in skilled performance is also defined by distinguishing it from explicitly controlled, attentionally demanding, effortful, knowledge-based performance (Logan, 1988). It has even been proposed that most of our everyday life is controlled by proceduralised mental processes that operate outside of our conscious awareness; an effortless self-regulation system continually guiding the individual through the day (Bargh & Chartrand, 1999). Yet, because the process of proceduralisation itself is automatic we are often unaware of how the process operates or the extent to which automaticity determines our behaviour.

Driving would appear to provide an excellent domain for the investigation of cognitive automaticity, both because it is a well-practiced skill in the general population and because it is composed of a diverse range of components including attention, perception, decision making, and motor tasks. Driving has often been identified as an example of behaviour that becomes proceduralised or automated with extended practice (Fitts & Posner, 1967; MacKay, 1982; Norman, 1981; Shiffrin & Schneider, 1977). In the early 1960s researchers began investigating the phenomenon by measuring the 'spare mental capacity' available to experienced drivers as they drive (Brown, 1962). Subsequent investigators made a clear differentiation between two distinct modes of driving: (1) a 'top-down' mode involving conscious deliberation and effort while performing the driving task such as experienced by learner drivers or experienced drivers in an unfamiliar environment or while concentrating on a demanding manoeuvre such as overtaking; and (2) a 'bottom-up' mode composed of well-rehearsed perception–action units that enable experienced drivers to maintain their speed, lane position, following distances, and negotiate traffic with little or no conscious attention or effort (Ranney, 1994; Summala, 2000).

While it is generally acknowledged that driving requires both bottom-up (automatic) and top-down (conscious) modes (Charlton, 2004; Summala, 1988; Trick et al., 2004), most theories of driver behaviour have focussed on descriptions of the conscious mode (Fuller & Santos, 2002; Fuller, 2005; Gibson & Crooks, 1938; Michon, 1989; Wilde, 1982; Wilde, 1988). While these models have made valuable contributions to date in guiding research and engineering practices, many important questions have gone unanswered: whether drivers in the automatic mode have different information requirements then while in the conscious mode; whether different cognitive resources are required by the two modes of driving; and how frequently drivers switch between the two modes. Although applications of visual search and attentional resource theories to the domain of driver distraction offer some insights into these questions (Wickens & Horrey, 2008) most conceptualisations of driver behaviour treat the automatic mode as an exception to "normal" driving; an undesirable state that occurs when a driver becomes distracted (Lee, Regan, & Young, 2008). Other researchers have offered tantalising suggestions of what circumstances might occasion drivers to switch from the bottom-up mode to top-down processing (Lewis Evans & Rothengatter, 2009; Martens & Fox, 2007; Summala, 1988). However, when researchers have looked for evidence of automaticity in the driving of highly experienced drivers, the variability seen in the performance of tasks such as gear-changing have led some to question whether any component of the driving task can be considered truly automatic in the strictest sense of the term; i.e., effortless, unintentional, and impervious to secondary task disruption (Duncan, Williams, & Brown, 1991; Groeger & Clegg, 1997; Shinar, Meir, & Ben-Shoham, 1998).

It is an open question whether the participants in these sorts of studies can reasonably be expected to demonstrate anything other than the conscious (top-down) attentional mode as they adapt to novel driving experiences with the knowledge that their performance is being observed and analysed. In fact, much of the driver research completed over the past 50 or so years has been conducted using experimental protocols in which drivers perform for relatively short, hour-long experimental sessions in an unfamiliar instrumented vehicle or driving simulator (Groeger, 2002). Notable exceptions have been recent studies of naturalistic driving in which vehicle sensors and unobtrusive video cameras have been used to record drivers' behaviour over periods ranging from 1 week to 1 year (Dingus et al., 2006; Stutts et al., 2005). These studies have focussed on identification of precursors to crashes, and near crashes (Dingus et al., 2006) or the occurrence of driver distractions (Stutts et al., 2005).

In one recent longitudinal study, Martens and Fox (2007) investigated the influence of practice on top-down scanning and attention in a desk-top simulator over a period of 5 days. The participants in this study were reported as increasing their speeds and decreasing their glance duration as the study progressed, with the largest changes taking place on the first day of practice. Interestingly, more practice led to better recollection of the traffic signs along the route but poorer driving performance and post-drive recognition accuracy when a target sign was changed from a priority crossing to a yield sign. The researchers concluded that the effects of practice were to establish top-down control over visual scanning patterns that resulted in a failure to detect changes to the road environment. The researchers also posed the intriguing question of what type of stimulus would prompt drivers to switch back to an active information processing state and proposed that future research should investigate this aspect.

The purpose of the pilot experiment described in the present paper was to examine the development of automaticity in driving by asking participants to repeatedly drive the same road in a driving simulator over a period of approximately 3 months. The principal research questions were: (1) can proceduralised (automatic) driving be produced and detected in a driving simulator?; (2) how is automaticity reflected in drivers' behaviour?; and (3) do existing conclusions about driver behaviour generalise to proceduralised driving? The development of driving without awareness was assessed by examining participants' ratings of the difficulty of the drive and their performance on embedded visual detection tasks while the development of proceduralised behaviour was assessed by examining drivers' speed and lane position over the course of the experiment. Finally, drivers' responses to a road hazard (road works) and perceptual speed regulation (a tunnel) were included to assess the generalisability of established driver reactions to proceduralised driving performance. To further gauge the characteristics of driver automaticity, a separate group of participants, with no prior experience of the driving simulator, were recruited to drive simulation scenarios identical to those encountered in the later sessions allowing a yoked comparison of driving behaviour with and without the development proceduralised responses.

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. The first group of nine participants, 4 males and 5 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 20 to 50 years of age (mean = 31.25 years, SD = 11.84), and reported that they regularly drove between 10 and 900 km per week (average = 191 km, SD = 289.55) and on average had 15.29 years of driving experience (range 4.5–35 years, SD = 11.81). A second group of 12 participants, 5 males and 7 females, formed the "Casual" group and were recruited to participate for a single experimental session only. Their average age was 25.83 years (SD = 8.43, range 20–50 years), they reported driving between 20 and 500 km per week (mean = 171 km, SD = 147.94) and had 1.8–31.0 years driving experience (mean = 9.0 years, SD = 8.15). 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.

All but three of the participants in the Expert group completed 20 experimental sessions. Two of the participants completed 15 sessions and one completed six sessions. Non-completion by these participants was due to time constraints. (Data from the participant 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 (as shown in Charlton, 2009). The centre projection surface was located 2.42 m in front of the driver's seat with two peripheral surfaces connected to the central surface at 62° angles. The entire projection surface was angled back away from the driver at 14° (from the bottom to the top of the projection surface) and produced a 175° (horizontal) by 41° (vertical) forward view of the simulated roadway from the driver's position. The image projected on the central surface measured 2.64 m wide by 2.10 m high (at a resolution of 1920 by 1200 pixels) and each of the two peripheral images measured approximately 2.65 m by 2.00 m (at resolutions of 1024 by 768 pixels). In addition, two colour LCDs with an active area of 12.065 cm by 7.493 cm each at a resolution of 640 by 480 pixels were mounted at the centre rear-view mirror and driver's wing mirror positions to provide views looking behind the driver's vehicle. The simulated vehicle's dashboard displayed accurate speed and engine RPM data and vehicle performance was determined by a multi-body vehicle dynamics model configured as an automobile with automatic transmission, 3 l engine (making 170 kW power), and power steering. The projected images and vehicle model were updated at a minimum rate of 100 frames per sec. The steering wheel provided tactile feedback to simulate the forces produced when steering the vehicle. Four speakers located inside the car and a sub-woofer underneath the car presented realistic engine and road noises as appropriate. The simulation software recorded the participant's speed, lane position, and control actions automatically throughout designated sections of the simulation scenario. Digital video cameras were mounted in the rear seat and dashboard of the simulated vehicle to record the participants' behaviour during the experimental sessions.

2.3. Simulation scenarios

The simulation scenarios used for this study 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 an accurate representation of a rural two-lane

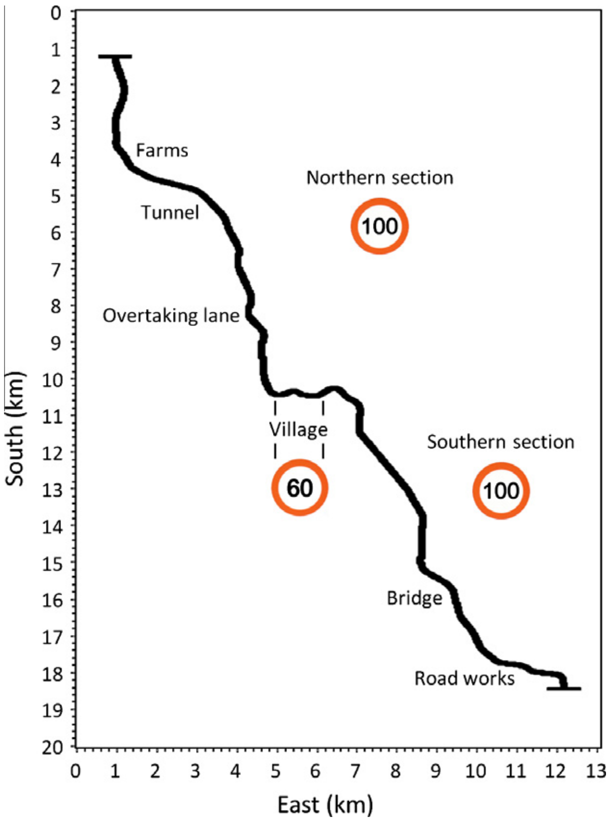

Fig. 1. Map of the simulated road.

state highway in New Zealand and was based on the surveyed 3-dimensional road geometry of the highway. Lane widths were based on road survey data obtained from the road controlling authority, and road markings were consistent with New Zealand Transport Agency (NZTA) guidelines. Road signs and roadside objects were modelled as 3-dimensional objects and placed in the simulation at appropriate locations. The simulated road was divided into two equal 12 km halves (northern and southern), 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 the 400 m section of simulated road which passed through the village, which had a speed limit of 60 km/h. Each half of the road also contained a range of prominent landmarks (e.g. houses, shops, farms, a 400 m bridge, a 400 m tunnel, overtaking lanes, and directional signs) to facilitate participants' recognition of their surroundings as they became familiar with the roads over repeated sessions (see Fig. 1).

One of these landmarks, the tunnel, was included to assess the effects of perceptual speed regulation. Drivers entering a tunnel have previously been observed to decrease their vehicle speeds, presumably due to an increase in optical flow rate and inflation of perceived speed (Denton, 1980; Manser & Hancock, 2007; Törnros, 1998). Perceptual speed regulation of this sort is the basis for many speed management treatments known as perceptual countermeasures (Godley, Triggs, & Fildes, 2004; Retting, McGee, & Farmer, 2000), and thus speed reduction in response to the tunnel was included in the present experiment to assess the generalisability of established driver reactions to proceduralised driving.

Using the simulated northern and southern road sections described above, 38 distinct scenarios were created to be 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 and light trucks, buses, and heavy goods vehicles, were placed into each simulation scenario (25 vehicles in each half) heading toward the driver. The vehicles were selected from 55 different vehicle types, each of which could be rendered in one of 45 possible colour schemes. In addition, one Volkswagen beetle was placed into each road scenario (at randomised locations with randomised colour), which the participants were required to identify in the 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 750 m ahead of the driver.

Several other scenarios included changes to the physical features in the road environment. In two scenarios involving the northern half of the road (termed Change Detection scenarios) road markings were removed from a 400 m section of road, a

Table 1
The order of the experimental scenarios for each group.

Session	First scenario	Second scenario
	Expert group	
1	Northern section, southbound	Southern section, southbound
2	Southern section, northbound	Northern section, northbound
3	Northern section, northbound	Northern section, southbound
4	Southern section, northbound	Southern section, southbound
5	Roadworks – southern section, southbound	Roadworks – southern section, northbound
6	Northern section, southbound	Roadworks – southern section, southbound
7	Northern section, southbound	Change detection – northern section, northbound
8	Unfamiliar road – northern and southern sections, southbound	
9	Northern section, northbound	Northern section, southbound
10	Southern section, northbound	Northern section, northbound
11	Southern section, northbound	Southern section, southbound
12	Northern section, southbound	Northern section, northbound
13	Roadworks – southern section, northbound	Roadworks – southern section, southbound
14	Northern section, southbound	Conversation – southern section, southbound
15	Southern section, northbound	Change detection – northern section, northbound
16	Unfamiliar road – northern and southern sections, southbound	
17	Southern section, northbound	Southern section, southbound
18	Northern section, southbound	Southern section, southbound
19	Northern section, northbound	Conversation – northern section, southbound
20	Southern section, northbound	Northern section, northbound
	Casual group	
1	Roadworks – southern section, northbound (same as Session 13 above)	Change detection – northern section, northbound (same as Session 15 above)

Fig. 2. Scenes from simulation scenarios (clockwise from top left): typical scenario containing Volkswagen beetle, Unfamiliar road scenario, Road works scenario, and the tunnel in the northern road section.

prominent farm silo was removed from the drivers' side of the road, a sign warning of an upcoming road dip was added, two of the directional signs were changed from English to German wording, an oncoming police car was added, and a speed camera van was parked along the road edge. Two Road works scenarios were created by introducing a 200 m section of road works (warning signage, 30 km/h speed restriction signs, road cones, and associated construction equipment) to the southern half of the road. Each Road works scenario was run in both northbound and southbound directions, making a total of four experimental scenarios. Finally, an Unfamiliar road scenario was created by changing the appearance of the landscape, types of trees used, and removing all landmarks such as buildings, tunnels, and bridges (although the road geometry remained identical to that used for the other scenarios). A scene from the Unfamiliar road scenario is shown in Fig. 2. The Unfamiliar road scenario was 24 km in length (it was run without a break in the middle) and was presented during two experimental sessions albeit with different traffic each time.

2.4. Procedure

As previously described, two groups of participants were recruited for this study: an Expert group ($n = 9$; 4 males and 5 females) who drove the simulation scenarios approximately twice a week for a period of up to 12 weeks and a yoked control group (the Casual group) of drivers ($n = 12$; 5 males and 7 females) who completed only one session in the simulator containing two 12 km scenarios. Upon arrival, each participant was given an overview of the activities involved and the time required for the experiment, and was asked to complete an informed consent agreement and a brief questionnaire about their driving background. After completion of the questionnaire each participant was given general instructions about the simulated road and allowed to practice driving until they felt comfortable operating the simulator (5–10 min). The participants were then instructed to drive in the simulator as they would normally drive in their own car. That is, to drive at an appropriate speed, and overtake other vehicles if they would normally do so in a real driving situation. They were also instructed to sound the horn (by moving the headlight control stalk located on the right side of the steering column) whenever they noticed anything interesting, unusual, hazardous, or a Volkswagen beetle, and name it aloud. The time and road position for each detection action was logged by the computer and the item named was recorded manually by the experimenter and verified with the video record of the session. The detection task was adapted from a previous study of road sign conspicuity (Charlton, 2006) in which moving the headlight control (which produced a single horn beep) was chosen as a less disruptive method for participants to indicate their detection of objects and other vehicles than the alternative of actually pressing the horn in the centre of the steering wheel (which required removing one hand from the wheel).

Once the participant was ready to start, the video cameras were switched on and a simulation scenario was begun. Two 12 km scenarios were completed in each session with a short (2–5 min) break in between. During the break, 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 north 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 (northbound or southbound), or begin driving in the opposite direction to their point of origin. During two experimental sessions (Sessions 8 and 16) the participants encountered the Unfamiliar road scenario described earlier. These sessions involved one drive of the full 24 km length of road with no mid-way break. During another two experimental sessions (Sessions 14 and 19) the second 12 km scenario in each session was designated a Conversation scenario. During these scenarios, the participants were engaged in a hands-free cell phone conversation with the experimenter (located in an adjacent room). The participants were free to converse about any topics they chose to, in order to promote a realistic free-flowing discussion and ecologically valid driving situation (Charlton, 2009). Each conversation continued throughout the experimental scenario.

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 13. The second scenario was the Detection scenario that the Experts received during the second half of Session 15. For all participants each experimental session took approximately 30 min to complete (excluding the familiarisation/practice drive). At the end of each experimental session 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). Finally, participants were asked if they had any other comments about their drive, and were given a $10 gift voucher to thank them for their participation.

3. Results

3.1. Driving difficulty ratings

Shown in Fig. 3 are the driving difficulty ratings collected from the participants at the end of each experimental session. As can be seen in the top panel of the figure, the participants in the Expert group rated the driving difficulty of the 20 sessions progressively lower as the experiment continued. The exceptions to this were the two sessions in which the visual appearance of the road was changed (Unfamiliar road) and the two sessions in which they engaged in a hands-free cell phone conversation as they drove (Conversation scenarios). Shown in the lower panel of the figure are difficulty ratings for the participants in the Casual group compared to the ratings for the Expert group obtained for the same driving scenario (Session 15). The ratings from the Expert group (mean = 1.19) were significantly lower than those from the Casual group (mean = 3.00) as indicated by a one-way analysis of variance; $F_{(1,\ 18)} = 18.962$, $p < 0.001$, $\acute{\eta}_p^2$ (Partial eta squared) = .513.

3.2. Detection tasks

Shown in Fig. 4 are the results from the vehicle detection task (identifying the Volkswagen beetle); the probability of detection, and the participants' distance to the targets at the time detection was reported. In the top panel of the figure it can be seen that the average probability of detection by the Expert group generally increased across the 20 sessions (although there was a notable decline in detection performance in the last session). In the lower panel of the figure the mean detection distances are shown along with a polynomial trend line for the detection distances for the first scenario presented in each experimental session (dashed line) and the second scenario of each session (solid line). Detection distances generally

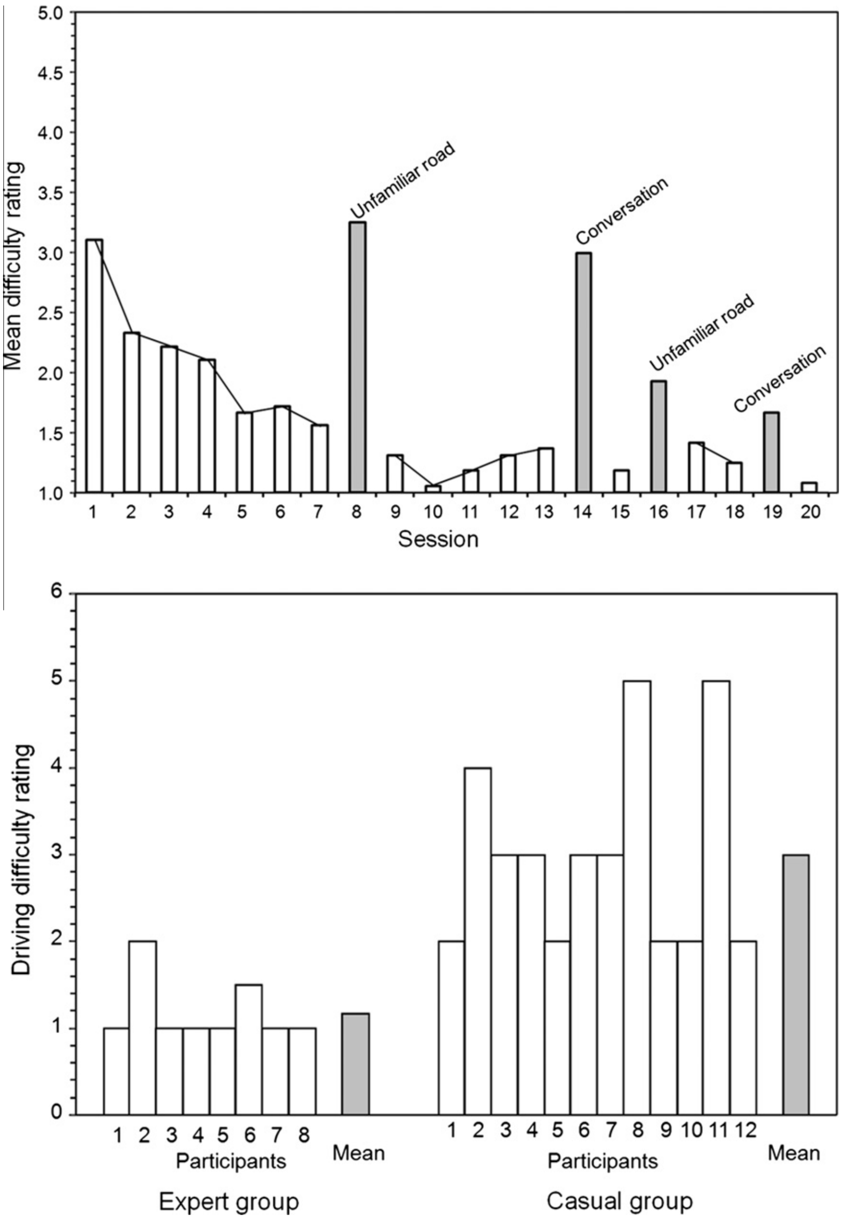

Fig. 3. The top panel shows the mean ratings of driving difficulty (1 = no difficulty; 7 = extremely difficult) by participants in the Expert group for each session. The bottom panel shows the Expert group participants' ratings during Session 15 compared to the Casual group's ratings of the same driving scenario in their first session.

increased across the 20 sessions, but the polynomial trend lines indicated that although the distances steadily increased for the first scenario presented in each session (sometimes a northern scenario, sometimes a southern scenario), detection during the second scenario decreased initially then reached, and exceeded, the first scenario distances towards the latter sessions. A 2×5 repeated-measures multivariate analysis of variance comparing the detection distances for each scenario during five equally-spaced sessions (Sessions 3, 6, 9, 12, and 15) produced a significant scenario $\times$ session interaction [Wilks' Lambda = .064, $F_{(4,\ 4)} = 14.529$, $p < 0.01$, $\acute{\eta}_p^2 = .936$] and a significant effect of session [Wilks' Lambda = .066, $F_{(4,\ 4)} = 14.094$, $p < 0.01$, $\acute{\eta}_p^2 = .934$], confirming that the significant increase in detection distances across the 15 sessions was different for the first and second scenarios seen by the participants each session. The main effect of scenario however did not meet the criterion for statistical reliability [Wilks' Lambda = .724, $F_{(1,\ 7)} = 2.670$, $p > 0.10$, $\acute{\eta}_p^2 = .276$].

Fig. 5 shows another aspect of the detection task, the number of objects and vehicles identified by the participants during each scenario of the experimental sessions. In the top panel of the figure the average number of items detected in each session by the participants in the Expert group is shown alongside the average number of new items they detected each session

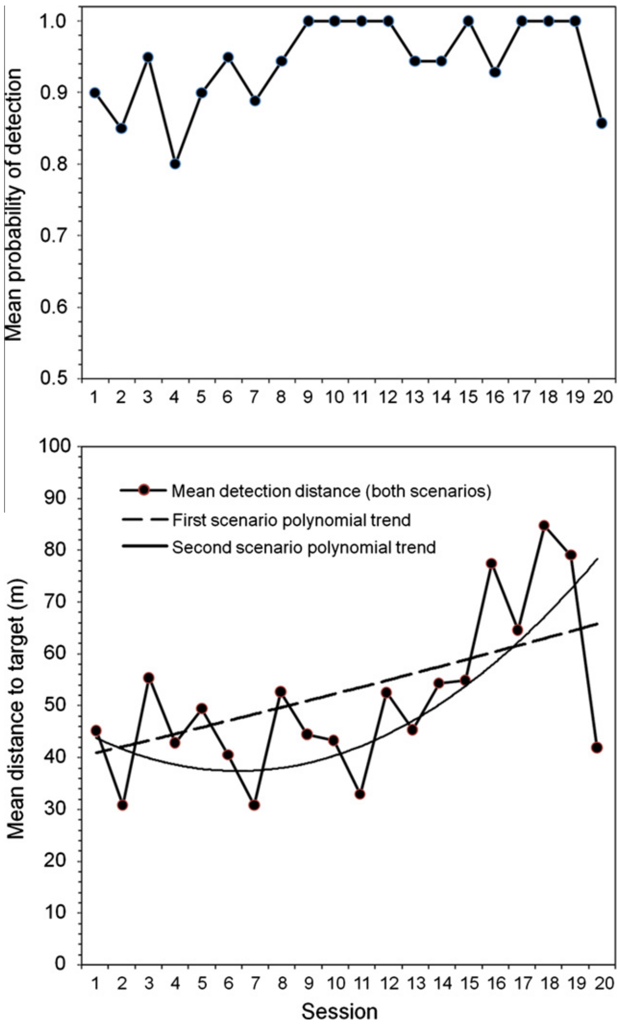

Fig. 4. Probability of vehicle detection (top panel) and detection distances (lower panel) across sessions.

(i.e., excluding items reported in previous sessions and any Volkswagens detected). As can be seen in the figure, the number of items reported decreased steadily during the course of the experiment, except when the scenarios were physically changed for the Road works, Detection, and Unfamiliar road sessions. The lower panel of the figure shows the average number of items reported (excluding Volkswagens) by the participants in the Casual group as compared to the participants in the Expert group on the corresponding scenarios. A mixed 2 × 2 multivariate analysis of variance comparing the two groups' performance across the two scenarios (within-subjects) indicated a significant group × scenario interaction [$F_{(1, 18)} = 11.210$, $p < 0.01$, $\acute{\eta}_p^2 = .384$] and a significant main effect of scenario [$F_{(1, 18)} = 5.064$, $p < 0.05$, $\acute{\eta}_p^2 = .220$] but did not yield a significant main effect of group [$F_{(1, 18)} = 1.542$, $p > 0.10$, $\acute{\eta}_p^2 = .079$]. The pattern of results showed that overall more items were reported by the Casual participants, but during the Road works scenario (presented first) the participants in the Expert group reported many fewer items than the Casual participants, but during the Detection scenario (presented second) they reported more than the Casual participants.

3.3. Vehicle speed and lane position

The average speeds taken from three equally distributed 100 m sections of the southern section of the simulated road are plotted in the top panel of Fig. 6 for those sessions containing a southern road scenario. As can be seen in the figure, there were few, if any substantial increases in the participants' average speeds over the duration of the experiment. To evaluate any changes in the participants' speeds, the mean speeds from one early southbound southern road scenario (Scenario 2 of Session 1) were compared to the same sections of road from a late southbound southern road scenario completed by eight of the Expert participants (Scenario 2 of Session 13) with a repeated-measures analysis of variance. The analysis did not indicate any reliable differences in speed across sessions [$F_{(1, 7)} = 2.132$, $p > 0.10$, $\acute{\eta}_p^2 = .233$]. To more closely examine the data for

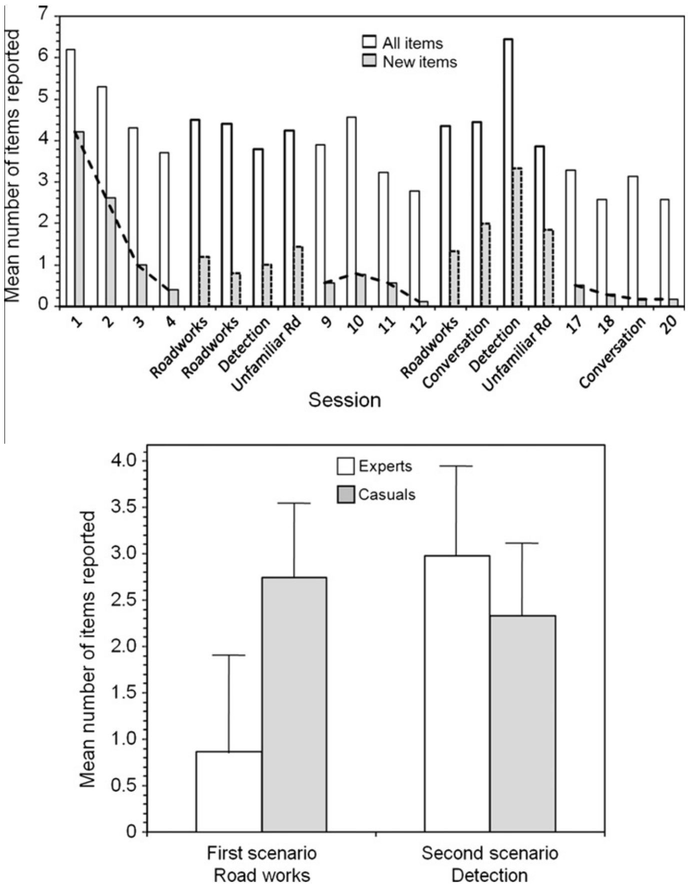

Fig. 5. Mean number of total number of items reported, and the number of new items (not reported in the preceding session) reported by the Expert group in each session (top panel). The bottom panel shows the mean number of items (excluding Volkswagen targets) reported by the Casual group compared to the number of items reported by Expert group during equivalent scenarios (the first scenario of Session 13 and second scenario of Session 15). Error bars show 95% confidence intervals.

any early changes in speed, the lower panel of the figure shows the mean speeds for the first half of the first experimental session (the northern section of simulated road) to their mean speeds for the second half of the same session (the southern section) for all nine Expert group participants (including the participant who did not complete the experiment). As shown in the figure, the participants displayed an average speed increase of 2.92 km/h from the first scenario to the second. A repeated-measures analysis of variance indicated that this change was a reliable difference [$F_{(1,\ 8)} = 6.304$, $p < 0.05$, $\acute{\eta}_p^2 = .441$].

The top panel of Fig. 7 shows the Expert group's speed variability (average absolute deviation in km/h) for a 100 m straight section of road located midway between the start and end of the southern road section, plotted for all of the sessions containing southern road scenarios.[1] As shown, the participants' speed variability decreased rapidly in the early sessions and remained low except for the Unfamiliar road and Conversation scenarios. Inspection of the individual participants' data, however, revealed that one of the participants had a distinctly opposite reaction to these scenarios; their speed variability generally increased over the sessions, and was lowest during the Unfamiliar road and Conversation scenarios. Removing that participant's data from the group resulted in the middle panel shown in Fig. 7; a distinct and rapid decrease in mean speed variability, and a return to first session levels during the Unfamiliar road and Conversation scenarios.

The bottom panel of the figure shows the participants' lane position variability (average absolute deviation in m) across the course of the experiment. In a manner similar to the speed variability results, there was a tendency for the participants' lane positions to become less variable across sessions, with peaks of high variability during the Unfamiliar road and Conversation scenarios. There was not, however, any indication of substantially different lane position variability for the participant with the unique speed variability characteristics, nor by any of the other participants.

A multivariate repeated-measures analysis of variance was used to determine the statistical reliability of the speed and lane position variability results, the first southern road scenario (Session 1) was compared to the last southern road scenario

[1] (With the exception of one session, Session 6, in which the Volkswagen for the embedded detection task was placed inside this data collection area. The data from Session 6 were thus left out of the figure and subsequent analyses.)

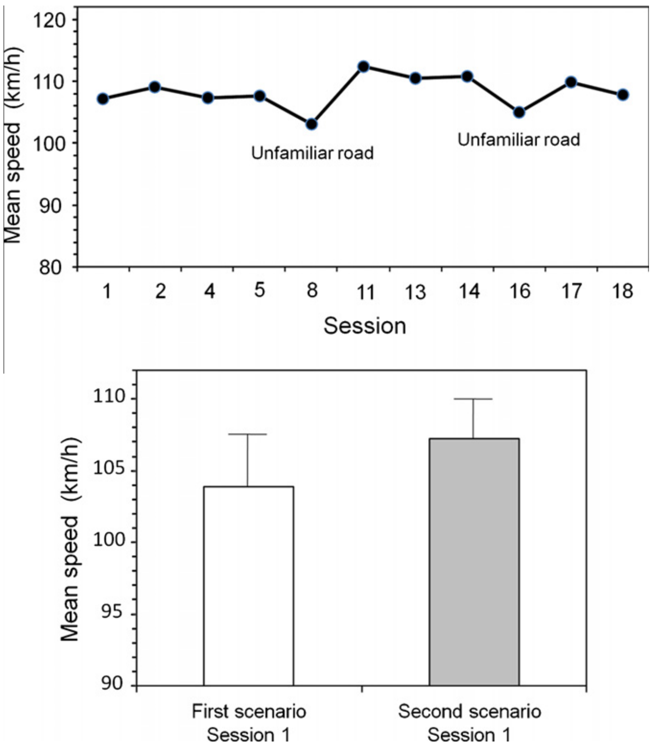

Fig. 6. Mean speeds from the southern road scenarios are shown for sessions throughout the experiment (top panel). The lower panel shows the mean speeds in the first and second scenarios of Session 1. Error bars show 95% confidence intervals.

(Session 15) completed by the Expert participants (calculated for seven of the participants for the reasons described above). The analysis indicated that the decrease in variability was significant for the speed variability and lane position variability measures [Wilks' Lambda = .317, $F_{(2,\ 5)} = 5.392$, $p < 0.056$, $\acute{\eta}_{\mathrm{p}}^{2} = .683$]. The univariate analyses for these measures separately indicated that the significant difference between early and late sessions was predominantly due to the speed variability measure [$F_{(1,\ 6)} = 4.258$, $p < 0.08$, $\acute{\eta}_{\mathrm{p}}^{2} = .415$] as compared to the lane position variability measure [$F_{(1,\ 6)} = 0.148$, $p > 0.10$, $\acute{\eta}_{\mathrm{p}}^{2} = .024$].

In Fig. 8 the speed and lane position variability for the participants in the Casual group (first scenario) is compared to that of all eight Experts during the equivalent road scenario (first scenario of Session 13). Participants in the Expert group displayed lower speed and lane position variability than did participants in the Casual group. Statistical analysis with a one-way multivariate analysis of variance indicated a significant difference between the two groups across the two measures [Wilks' Lambda = .666, $F_{(2,\ 17)} = 4.270$, $p < 0.05$, $\acute{\eta}_{\mathrm{p}}^{2} = .334$], with univariate tests again indicating this was largely due to the speed variability measure [$F_{(1,\ 18)} = 5.251$, $p < 0.05$, $\acute{\eta}_{\mathrm{p}}^{2} = .226$] rather than the lane position variability measure [$F_{(1,\ 18)} = 1.947$, $p > 0.10$, $\acute{\eta}_{\mathrm{p}}^{2} = .098$].

3.4. Perceptual speed regulation

Fig. 9 shows the participants' perceptual speed regulation (reduction in speed) as they progressed through the 400 m tunnel located in the northern road section. The speed change measure was calculated as the reduction in speed between the tunnel entry and the tunnel end. The top panel of the figure shows the speeds for the Expert group during their southbound northern road scenarios. As can be seen in the figure, the participants displayed larger speed reductions as their experience with the tunnel increased. During the Unfamiliar road scenario no tunnel was present and no changes in speed were observed for the corresponding section of road. Session 19 was a Conversation scenario and, as shown, produced the largest speed reductions in response to the tunnel. A repeated-measures analysis of variance comparing Session 1 to Session 14 indicated that the participants decreased their speeds at the tunnel significantly more during the late session as compared to the first session [$F_{(1,\ 7)} = 33.198$, $p < 0.001$, $\acute{\eta}_{\mathrm{p}}^{2} = .826$].

The lower panel of the figure shows the comparison of the Expert and Casual participants' speed reductions at the tunnel (northbound). Participants in the Casual group showed little or no speed decrease (mean = 1.30 km/h) as compared to the Experts' speed reductions during Session 15 (mean = 6.05 km/h decrease). A one-way analysis of variance indicated that the difference between the two groups on this measure was statistically reliable [$F_{(1,\ 18)} = 9.826$, $p < 0.01$, $\acute{\eta}_{\mathrm{p}}^{2} = .353$].

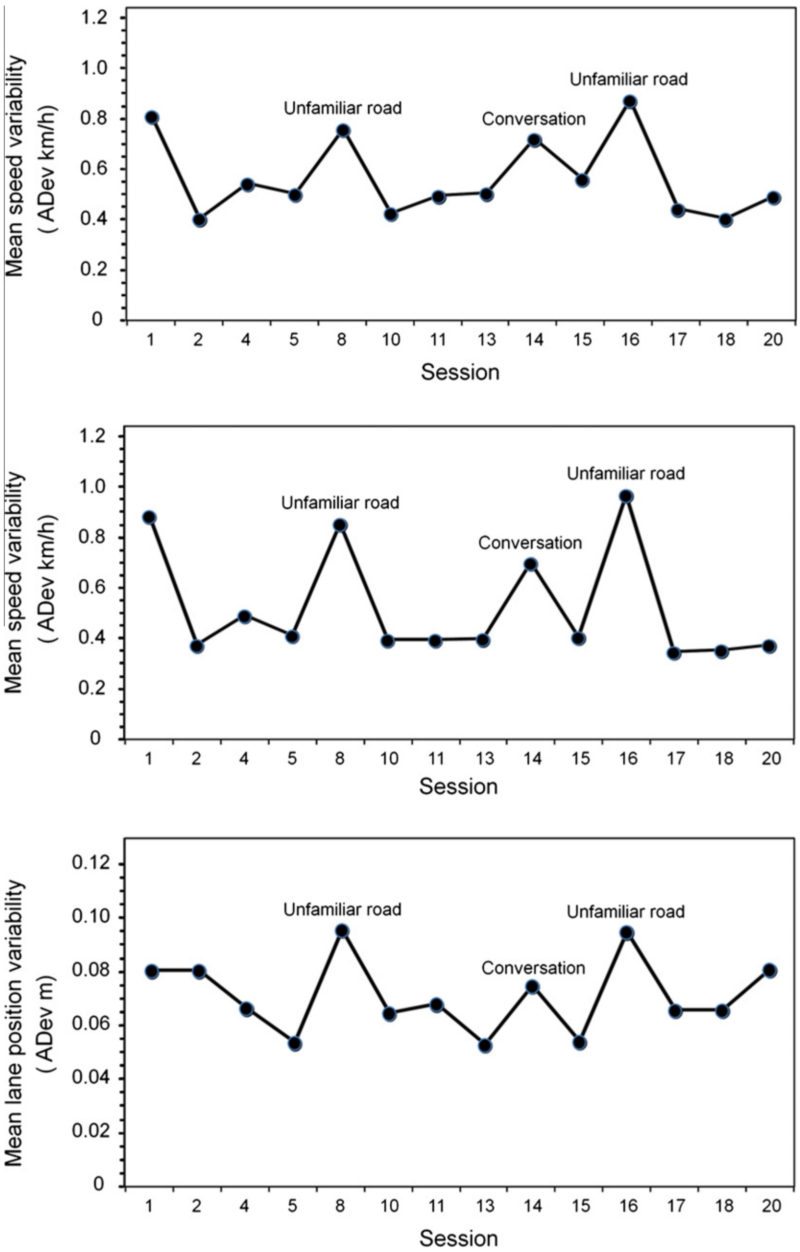

Fig. 7. Speed variability across a 100 m section of the southern road scenarios is shown in the top panel for all participants in the Expert group, and again with one participant removed in the middle panel. Lane position variability across sessions for all participants in the Expert Group is shown in the bottom panel.

3.5. Reactions to a road hazard

As described previously, during three sessions (5, 6, and 13) participants in the Expert group encountered road works on the southern road scenarios. Participants in the Casual group encountered the road works during the first scenario of their only experimental session. Fig. 10 shows the participants' brake reaction times (sec) to the road works warning sign and vehicle speeds (km/h) at the point of reaching the beginning of the road works (first scenario for the Casual group and first scenario of Session 13 for the Expert group). Participants in the Expert group displayed somewhat shorter reaction times than the Casual group. Even more noteworthy, however, was the difference in speeds as the participants arrived at the road works. The Casual participants decreased their speed to an average of 38.94 km/h, what might be considered an appropriate level as the road works had a posted speed limit of 30 km/h. Participants in the Expert group, however, were still travelling an average speed of 69.57 km/h as they reached the road works. A one-way multivariate analysis of variance indicated a

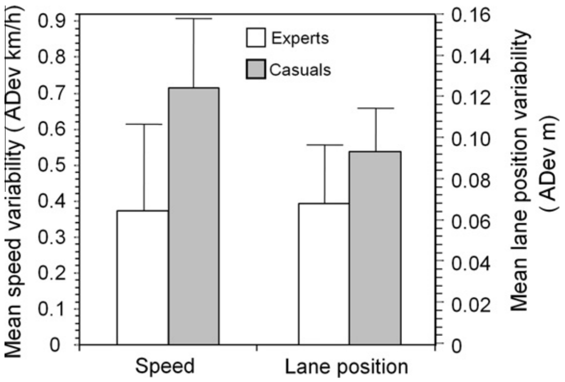

Fig. 8. Mean speed variability and lane position variability mean speed variability and lane position variability for the first scenario driven by the Casual group compared to the Expert group on the equivalent scenario (the first scenario of Session 13). Error bars show 95% confidence intervals.

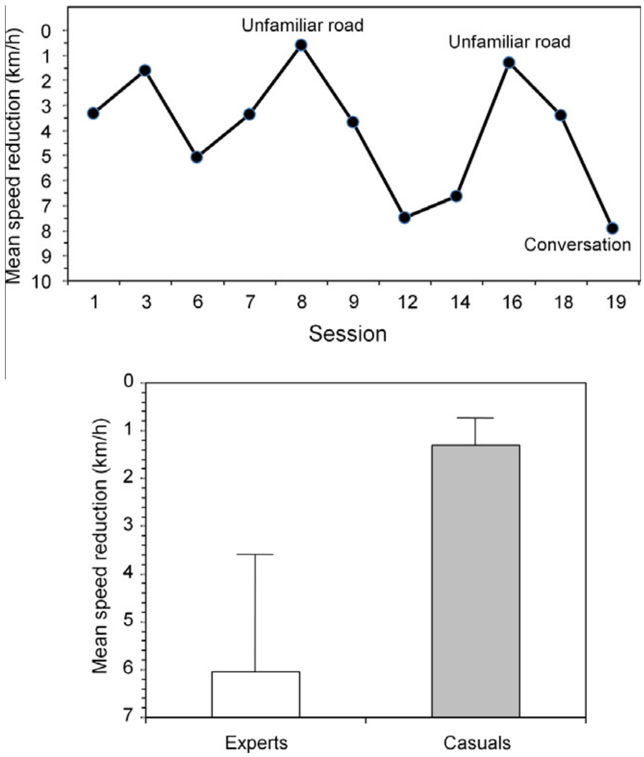

Fig. 9. The top panel shows the mean speed reductions in the tunnel across sessions for the Expert group (no tunnel was present during the Unfamiliar road scenarios and speed changes shown are for the same section of simulated road). The lower panel shows the mean speed reductions in the tunnel for the Expert and Casual groups compared for equivalent scenarios (Session 15 for the Expert group and Session 1 for the Casual group). Error bars show 95% confidence intervals.

significant difference between the two groups across the two measures [Wilks' Lambda = .505, $F_{(2,\ 17)} = 8.348$, $p < 0.01$, $\acute{\eta}_p^2 = .495$], with univariate tests indicating this was largely due to the speed measure [$F_{(1,\ 18)} = 14.792$, $p < 0.001$, $\acute{\eta}_p^2 = .451$] rather than the reaction time measure [$F_{(1,\ 18)} = 1.915$, $p > 0.10$, $\acute{\eta}_p^2 = .096$].

4. Discussion

To return to the first question posed at the outset of this study: can proceduralised (automatic) driving be produced and detected in a driving simulator? The participants' ratings of driving difficulty suggest that the answer is yes. The sessions were progressively rated as less difficult and comments such as "*I found myself going into auto, not paying attention to what I was doing*" (Participant 2, Session 5), "*Feels very normal, just like the drive home; thinking mostly about food*" (Participant 3,

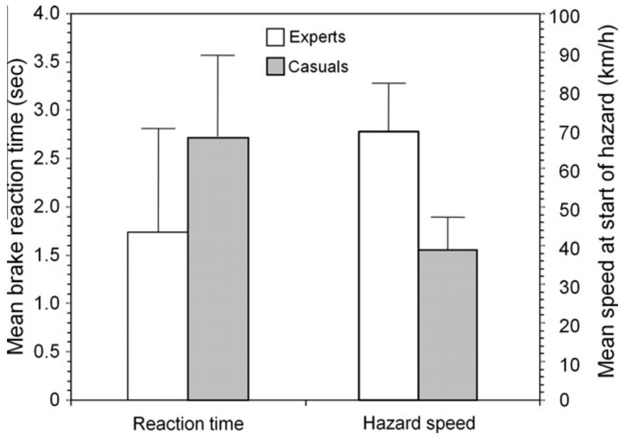

Fig. 10. Mean brake reaction times to the road works sign and subsequent speeds at the road works location for Expert and Casual groups. Error bars show 95% confidence intervals.

Session 6) and "*Was daydreaming, a lot on my mind*" (Participant 8, Session 7) indicated that some proceduralisation was occurring with extended practice. Of particular interest were the high difficulty ratings obtained for the Unfamiliar road scenario (Sessions 8 and 16). Even though the road was geometrically identical to the other scenarios, participants rated it as much more difficult and suggested it was because it contained more curves or traffic.

As regards the second question, how automaticity is reflected in drivers' behaviour, some of the principal changes noted were the reductions in speed variability and lane position variability. It must be emphasised, however, that the present research was originally conceived as a pilot study, and the small sample size does limit the generality of these conclusions. Indeed, as described in the Results, one of the eight participants displayed a substantially different pattern of changes in their speed variability as the experiment progressed. Similar to the findings of Martens and Fox (2007), some increase in the participants' vehicle speeds were observed in the first experimental session. The increased speeds, however, were limited to the earliest part of experiment and did not continue to increase.

The participants' performance on the detection tasks provides another insight into proceduralisation. During the early experimental sessions the participants' Volkswagen detection performance was best during the first scenario of each session, whereas during the second scenarios the participants reported that they were more likely to "let their mind wander" and detection performance appeared to suffer as a result. With extended practice, however, detection performance during the second scenario actually became superior to the first, suggesting that the detection task itself became proceduralised, and that detection in this automatic mode was faster than the effortful top-down detection that was more likely to occur in the first scenarios of the sessions. In fact, more than one participant related that they often flashed their headlights (or found themselves reaching for them) when they encountered Volkswagen beetles in their own cars.

Similarly, the finding that detection rates during the second Detection scenario were higher than the first Detection scenario and higher than the detection rates of the Casual participants suggests that, once proceduralised as part of the driving task, detection of some types of changes to the roadway environment becomes highly efficient. It is worth noting in this regard that although some changes were readily detected, other items were apparently not as noticeable; changes to signage and removal of a roadside building were not reported by any of the participants in either of the Detection scenarios. This failure to detect changes to road signs is similar to the finding reported by Martens and Fox (2007) where participants did not detect changes to intersection priority signs and may simply reinforce previous findings that participants have a general attentional neglect for familiar road signs (Charlton, 2006).

Answering the question of how long it took for the participants' driving to become proceduralised appears to depend on which aspect of the driving task is considered. Changes in speed variability appeared first, followed by lane position variability and verbal reports of "being on autopilot", and ultimately the performance on the detection tasks appeared to become a proceduralised part of the driving task. In addition to the vehicle and change detection performance described above, many of the participants developed what can best be described as stereotyped detection responses. With extended practice, some participants routinely sounded the detection horn and reported their every encounter with a few specific items (e.g., road bumps, an intersection, the tunnel, or large trucks), the same items during every scenario. An aspect of this can be seen in the decline in the number of new items reported in each session to nearly zero, while the total number of all reported items remains at levels above that required for successful detection of the two Volkswagen beetles present in each session.

In order to address the third question of whether existing conclusions about driver behaviour generalise to proceduralised driving one needs to examine the participants' behaviour at the tunnel and the road works site. With practice, the participants displayed increased amounts of perceptual speed regulation at the tunnel. In other words, their vehicle speeds were observed to decrease by progressively greater amounts during the first 200 m of the tunnel. One interpretation of this finding is that in the early sessions when the participants were deliberately and consciously attending to the driving task, they were more likely to use the speedometer to keep their speed within a band of tolerance around some (personal) set point. As the driving task became proceduralised and their explicit attention to the driving task was reduced the participants appeared to make greater use of implicit perceptual speed cues, and were more susceptible to the effects of increased optic flow information at the tunnel. Looking at the conversation scenario (the second scenario of Session 19) the average speed reduction was even greater; perhaps as a result of the participants' attention being more comprehensively drawn away from the driving task.

For the Road works scenario, participants in the Expert group were faster than the Casual participants at detecting and reacting to the hazard warning, but their reaction was not optimal, few participants slowed to meet the required speed restriction. It is not clear whether this difference was because the Expert participants had become desensitised to the Road works scenario in a previous session or because they found it more difficult to alter the proceduralised speeds that had been established for that section of road. Although a note of caution should be raised here with regard to using a driving simulator to assess reactions to road hazards, inasmuch as the consequences of a simulated crash cannot be equated to that of a real crash (Lewis Evans & Charlton, 2006), the Experts' performance would appear to correspond with the poor compliance with speed restrictions observed at many road works sites generally (Allpress & Leland, 2010; Morgan, Duley, & Hancock, 2010).

We believe that the patterns of driving behaviour displayed in the present experiment are indicative of two different modes of driving. The first, a 'top-down' mode, involves conscious deliberation and effort while performing the driving task. This mode is experienced by drivers in an unfamiliar environment or while concentrating on a demanding manoeuvre such as overtaking. While in this mode, drivers can experience a higher degree of driving difficulty and may be resource limited with regard to the cognitive resources available for the task. The second mode, 'bottom-up', is composed of well-rehearsed perception–action units that enable experienced drivers to maintain their speed, lane position, following distances, and negotiate traffic with little or no conscious attention or effort. The subjective experience of this mode is one of little or no difficulty, and resource competition from other tasks may produce little or no impairment in its execution. It must be said that the participants in the present study were already experienced drivers and as such the proceduralisation we are describing refers to the adaptation of an established driving skill to a new environment rather than the acquisition of an entirely new skill.

It is also important to note that our use of the terms 'top down' and 'bottom-up' here are substantially different than that of Martens and Fox (2007). These authors referred to proceduralised scanning patterns as being a top-down influence, whereas we would regard the same proceduralised patterns as bottom-up and reserve the term top-down for conscious, active information processing of the driving environment. We have previously used the term "attentional" and "perceptual" to differentiate these modes (Charlton, 2004) and other authors have used a range of other terms such as "open-loop vs. closed-loop", "skill-based" vs. "knowledge-based", "implicit" vs. "explicit" and "automatic" vs. "controlled". We believe that none of these terms adequately reflect the phenomenon at hand, in part because driving performance may not be governed by two dichotomous processing states in an "either – or" fashion.

As an alternative, we propose that two processing states work in tandem to guide and maintain driver behaviour; an "operating process" and a "monitoring process". We conceptualise the operating process as a conscious, intentional level of task engagement that is required when a driver lacks experience or for an unusual or dynamically changing traffic situation. In contrast, the monitoring process is an unconscious error monitoring system that requires relatively little cognitive effort and continues until an error is detected or it is terminated by a conscious choice. The monitoring process is continuously engaged with the driving task, its function is to compare incoming stimuli to stored representations of previous instances of driving, particularly instances indicative of potential errors or hazards. When the 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. When elements of the driving situation do not match stored representations, or when stimuli associated with failed control or potential hazard are detected, the activation of attentional pathways is increased, increasing the likelihood that the items will surface in consciousness and the operating process can be applied to the situation. The process of proceduralisation represents 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.

Our conceptualisation of two processes working in tandem is similar to Wegner's (1994) account of Ironic processes in self-control of mental states. As described by Wegner, an effortful, intentional operating process searches for mental contents consistent with an intended state and an unconscious monitoring process tests whether the operating process is needed by searching for mental contents inconsistent with the intended state. The idea that transient activation of incoming stimuli by an unconscious monitoring process can trigger a shift to sustained, explicit attention is also a feature of current conceptualisations of selective attention and attentional blindness (Most, Scholl, Clifford, & Simons, 2005). Similarly, the suggestion that unconscious activation of incoming stimuli previously associated with negative affective states can unconsciously guide performance and produce greater attentional capture for these stimuli is an integral part of the Somatic-Marker Hypothesis of decision-making (Damasio, 1994; Damasio, 1996). Our proposal of a tandem model of driver behaviour also appears to be congruent with the concept of a Behavioural Inhibition System (BIS) developed to account for the neuropsychological basis of anxiety. This system is believed to be constantly acting in a monitoring capacity, influencing behaviour when a conflict or threat is detected (Gray, 1976). Animal research has since confirmed the key role of the septo-hippocampal pathway and the hippocampus in detecting mismatches between ongoing behaviour and environmental threats or novelty (e.g., Gray & McNaughton, 1983; Gray & McNaughton, 2003) and given the hippocampus' role in processing spatial information would appear ideally suited for hazard detection and redirection of behaviour and attention while driving.

Thus, in the present experiment the early sessions required a considerable degree of control by the operating process, there being relatively little stored information available to enable the monitoring process to guide performance. With experience, enough information was accumulated in the templates to allow the participants to rely increasingly on the unconscious monitoring process to guide moment-to-moment control. We contend that this development was reflected in the participants' progressively lower variability of speed and lane position. Another indication of this change was the participants' speed reductions in the tunnel; instead of consciously monitoring their speeds with the speedometer, drivers in the later sessions unconsciously reduced their speed as a consequence of the monitoring process erroneously "matching" the increased rate of optic flow produced by the tunnel to cues associated with a higher velocity than was actually the case.

The increasingly stereotyped visual detection patterns noted in the present experiment as well as by Martens and Fox (2007) could be interpreted as an indication that drivers' visual scanning has been left largely to the automatic monitoring process; a circumstance which can lead to attentional blindness for changes to some types of environmental stimuli (Galpin et al., 2009). The progressive improvement in target (Volkswagen) detection, as well as its generalisation to situations outside the laboratory, could also be interpreted as evidence of modifications to the templates used by the monitoring process through the process of proceduralisation. Rapid detection of important stimuli as well as automatic execution of stored responses may both be important characteristics of the monitoring process.

We believe this conceptualisation complements and reconciles many of the existing models of driver behaviour (e.g., Summala, 1988) by suggesting that the monitoring process is responsible for unconsciously detecting potentially important stimuli, and activating the operating process (which engages after some threshold has been reached) and is experienced consciously as feelings of driving difficulty (Fuller, 2005), risk (Wilde, 1982), discomfort (Lewis Evans & Rothengatter, 2009), or even a time gap (Chapman et al., 1999). The main point of departure from existing models of driver behaviour is that the monitoring process is viewed as a continuously functioning background process which is used to guide and control driver behaviour in most situations rather than a highly stereotyped motor program that is triggered in exceptional circumstances or a degraded level of performance that remains when a drivers' conscious attention is occupied elsewhere. Clearly much additional work remains on how these processes interact, how frequently and broadly the monitoring process samples different driving situations, and what effect contextual cues or motivational conditions may have on thresholds for attentional activation during performance.

Acknowledgements

The authors would like to thank the volunteer drivers who participated in this project; it would not have been possible without their dedication.

References

Allpress, J. A., & Leland, L. S. (2010). Reducing traffic speed within roadwork sites using obtrusive perceptual countermeasures. *Accident Analysis & Prevention, 42*, 377–383.
Anderson, J. R. (1982). Acquisition of cognitive skill. *Psychological Review, 89*, 369–406.
Bargh, J. A., & Chartrand, T. L. (1999). The unbearable automaticity of being. *American Psychologist, 54*, 462–479.
Brown, I. D. (1962). Measurement of the 'spare mental capacity' of car drivers by a subsidiary auditory task. *Ergonomics, 5*, 247–250.
Brown, I. D. (1994). Driver fatigue. *Human Factors, 36*, 298–314.
Calderwood, R., Klein, G. A., & Crandall, B. W. (1988). Time pressure, skill, and move quality in chess. *The American Journal of Psychology, 101*, 481–493.
Chapman, P. R., Ismail, R. B., & Underwood, G. (1999). Waking up at the wheel: Accidents, attention and the time gap experience. In A. G. Gale et al. (Eds.). *Vision in vehicles* (Vol. VII). North Holland: Elsevier.
Charlton, S. G. (2004). Perceptual and attentional effects on drivers' speed selection at curves. *Accident Analysis & Prevention, 36*, 877–884.
Charlton, S. G. (2006). Conspicuity, memorability, comprehension, and priming in road hazard warning signs. *Accident Analysis & Prevention, 38*, 496–506.
Charlton, S. G. (2009). Driving while conversing: Cell phones that distract and passengers who react. *Accident Analysis & Prevention, 41*, 160–173.
Damasio, A. R. (1994). *Descartes error: Emotion, reason and the human brain*. New York: Putnam.
Damasio, A. R. (1996). The somatic marker hypothesis and the possible functions of the prefrontal cortex. *Philosophical Transactions of the Royal Society of London, Series B, 351*, 1413–1420.
Denton, G. G. (1980). The influence of visual pattern on perceived speed. *Perception, 9*, 393–402.
Dingus, T. A., Klauer, S. G., Neale, V. L., Petersen, A., Lee, S. E., Sudweeks, J., et al (2006). *The 100-car naturalistic driving study, Phase II – Results of the 100-car field experiment (DOT HS 810 593)*. Washington, DC: National Highway Traffic Safety Administration.
Duncan, J., Williams, P., & Brown, I. (1991). Components of driving skill: Experience does not mean expertise. *Ergonomics, 34*, 919–937.
Fitts, P. M., & Posner, M. I. (1967). *Human performance*. Belmont, CA: Brooks/Cole.
Fuller, R. (2005). Towards a general theory of driver behaviour. *Accident Analysis & Prevention, 37*, 461–472.
Fuller, R., & Santos, J. A. (2002). Psychology and the highway engineer. In R. Fuller & J. A. Santos (Eds.), *Human factors for highway engineers* (pp. 1–10). Oxford: Pergamon.
Galpin, A., Underwood, G., & Crundall, D. (2009). Change blindness in driving scenes. *Transportation Research Part F, 12*, 179–185.
Gibson, J. J., & Crooks, L. E. (1938). A theoretical field-analysis of automobile-driving. *The American Journal of Psychology, 11*, 453–471.
Gray, J. A. (1976). The behavioural inhibition system: A possible substrate for anxiety. In M. P. Feldman & A. M. Broadhurst (Eds.), *Theoretical and experimental bases of behaviour modification* (pp. 3–41). Wiley: London.
Gray, J. A., & McNaughton, N. (1983). Comparison between the behavioural effect of septal and hippocampal lesions: A review. *Neuroscience and Biobehavioural Reviews, 7*, 119–188.
Gray, J. A., & McNaughton, N. (2003). *The neuropsychology of anxiety: An enquiry into the functions of the septo-hippocampal system* (2nd ed.). Oxford: Oxford University Press.
Godley, S. T., Triggs, T. J., & Fildes, B. N. (2004). Perceptual lane width, wide perceptual road centre markings and driving speeds. *Ergonomics, 47*, 237–256.

Groeger, J. A. (2002). Trafficking in cognition: Applying cognitive psychology to driving. *Transportation Research Part F, 5*, 235–248.
Groeger, J. A., & Clegg, B. A. (1997). Automaticity and driving: Time to change gear conceptually. In T. Rothengatter & E. Carbonell Vaya (Eds.), *Traffic and transportation psychology: Theory and application* (pp. 137–146). Oxford: Pergamon.
Iden, R., & Shappell, S. A. (2006). A human error analysis of US fatal highway crashes 1990–2004. In *Proceedings of the human factors and ergonomics society 50th annual meeting. Posters* (pp. 2000–2002). Santa Monica, CA: Human Factors and Ergonomics Society.
James, W. (1890). *Principles of psychology*. New York: Holt.
Kerr, J. S. (1991). Driving without attention mode (DWAM): A formalisation of inattentive states while driving. In A. G. Gale et al. (Eds.), *Vision in vehicles III* (pp. 473–479). Amsterdam: Elsevier.
Lee, J. D., Regan, M. A., & Young, K. L. (2008). What drives distraction? Distraction as a breakdown of multilevel control. In M. A. Regan, J. D. Lee, & K. L. Young (Eds.), *Driver distraction: Theory, effects and mitigation* (pp. 41–56). Boca Raton, FL: CRC Press.
Lewis Evans, B., & Charlton, S. G. (2006). Explicit and implicit processes in behavioural adaptation to road width. *Accident Analysis & Prevention, 38*, 610–617.
Lewis Evans, B., & Rothengatter, T. (2009). Task difficulty, risk, effort and comfort in a simulated driving task—Implications for risk allostasis theory. *Accident Analysis & Prevention, 41*, 1053–1063.
Logan, G. D. (1988). Automaticity, resources, and memory: Theoretical controversies and practical implications. *Human Factors, 30*, 583–598.
MacKay, D. G. (1982). The problems of flexibility, fluency, and speed-accuracy trade-off in skilled behaviour. *Psychological Review, 89*, 483–506.
Manser, M. P., & Hancock, P. A. (2007). The influence of perceptual speed regulation on speed perception, choice, and control: Tunnel wall characteristics and influences. *Accident Analysis & Prevention, 39*, 69–78.
Martens, M. H., & Fox, M. R. J. (2007). Do familiarity and expectations change perception? Drivers glances and response to changes. *Transportation Research Part F, 10*, 476–492.
Michon, J. A. (1989). Explanatory pitfalls and rule-based driver behaviour. *Accident Analysis & Prevention, 21*, 341–353.
Moors, A., & De Houwer, J. (2006). Automaticity: A theoretical and conceptual analysis. *Psychological Bulletin, 132*, 297–326.
Morgan, J. F., Duley, A. R., & Hancock, P. A. (2010). Driver responses to differing urban work zone configurations. *Accident Analysis & Prevention, 42*, 978–985.
Most, S. B., Scholl, B. J., Clifford, E. R., & Simons, D. J. (2005). What you see is what you set: Sustained inattentional blindness and the capture of awareness. *Psychological Review, 112*, 217–242.
Norman, D. A. (1981). Categorization of action slips. *Psychological Review, 88*, 1–15.
Ranney, T. A. (1994). Models of driving behaviour: A review of their evolution. *Accident Analysis & Prevention, 26*, 733–750.
Reed, G. (1979). Anomalies of attention. In D. Goleman & R. J. Davidson (Eds.), *Consciousness, the brain, states of awareness, and mysticism*. New York: Harper and Row.
Retting, R. A., McGee, H. W., & Farmer, C. M. (2000). Influence of experimental pavement markings on urban freeway exit-ramp speeds. *Transportation Research Record, 1705*, 116–121.
Shiffrin, R. M., & Schneider, W. (1977). Controlled and automatic human information processing. II. Perceptual learning, automatic attending and a general theory. *Psychological Review, 84*, 127–190.
Shinar, D., Meir, M., & Ben-Shoham, I. (1998). How automatic is manual gear shifting? *Human Factors, 40*, 647–654.
Stanton, N. A., & Salmon, P. M. (2009). Human error taxonomies applied to driving: A generic driver error taxonomy and its implications for intelligent transport systems. *Safety Science, 47:2*, 227–237.
Stutts, J., Feaganes, J., Reinfure, D., Rodgman, E., Hamlett, C., Gish, K., et al (2005). Drivers exposure to distractions in their natural driving environment. *Accident Analysis & Prevention, 37*, 1093–1101.
Summala, H. (1988). Risk control is not risk adjustment: The zero-risk theory of driver behaviour and its implications. *Ergonomics, 31*, 491–506.
Summala, H. (2000). Automatization, automation and modelling of driver's behavior. *Recherche Transports Sécurité, 66*, 35–45.
Törnros, J. (1998). Driving behaviour in a real and a simulated road tunnel – A validation study. *Accident Analysis & Prevention, 30*, 497–503.
Trick, L. M., Enns, J. T., Mills, J., & Vavrik, J. (2004). Paying attention behind the wheel: A framework for studying the role of selective attention in driving. *Theoretical Issues in Ergonomic Science, 5*, 385–424.
Wegner, D. M. (1994). Ironic processes of mental control. *Psychological Review, 101*, 34–52.
Wickens, C. D., & Horrey, W. J. (2008). Models of Attention, distraction, and highway hazard avoidance. In M. A. Regan, J. D. Lee, & K. L. Young (Eds.), *Driver distraction: Theory, effects and mitigation* (pp. 57–69). Boca Raton, FL: CRC Press.
Wilde, G. J. S. (1982). The theory of risk homeostasis: Implications for safety and health. *Risk Analysis, 2*, 209–226.
Wilde, G. J. S. (1988). Risk homeostasis theory and traffic accidents: Propositions, deductions and discussion of dissension in recent reactions. *Ergonomics, 31*, 441–468.