Running head: Route familiarity and visual attention

Familiarity breeds contempt for the road ahead: The real-world effects of route repetition on visual attention in an expert driver

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Abstract

The majority of journeys by car take place on familiar roads, with many routes being driven time and time again. This familiarity has been linked to mind wandering and reduced attention to specific elements of the visual scene (e.g. speed signs). The current study presents on-road eye tracking data from a driving instructor who drove the same route 28 times, incorporating two types of suburban roads, dual and multi-lane carriageways, and a country road. Data reveal a significant positive correlation between the number of times the same route is navigated and off-road dwell time across all five road sections. In addition, route familiarity was associated with decreasing dwell time on safety-relevant aspects of the road ahead in four out of the five sections. These data suggest that route familiarity can lead to undesirable changes in visual attention on real roads, even for expert drivers under observation.

1. Introduction

While most tests of driving skill or hazard perception involve drivers encountering a novel environment in videos, simulation or the real-world, the majority of the drives we complete are on routes with which we are familiar. In the UK, 15.3 million people report that they usually drive to work (ONS, 2013), many of whom presumably drive the same route twice a day, five days a week, potentially for many years. Repetition of a task leads to the automatization of its subroutines, with a reduction in conscious attention to the task (Schneider and Shiffrin, 1977). In many cases, this automatization is helpful. Novice drivers will eventually benefit from the freeing up of cognitive resources, as activities such as changing gear become automated and these resources can be allocated to other aspects of the driving task (e.g. Shinar et al., 1998). However, researchers have argued that the development of such open-loop behaviour can render drivers insensitive to changes in the driving environment (e.g. Charlton and Starkey, 2013; Harms and Brookhuis, 2016), potentially leaving them vulnerable to hazards.

A deciding factor in whether automation of certain driving sub-routines is beneficial may lie in what the driver chooses to devote their spare attention to. In demanding conditions, as capacity is freed from operational, and perhaps even tactical demands, a driver can pay more attention to strategic problems ahead (e.g. mitigating potential hazards in the road ahead; Pradhan and Crundall, 2017). However, in undemanding conditions, this spare capacity may be redirected to less relevant aspects of the external world in an effort to maintain arousal (e.g. Wilde, 1982), or may even be directed inwards to task-unrelated images and thoughts (TUITS; Chapman, Ismail and Underwood, 1999), often called mind-wandering (Burdett, Charlton & Starkey, 2016), day dreaming (e.g. Berthié et al., 2015) or driving without awareness mode (DWAM; Kerr, 1991). Crucially for the current study, instances of driving without awareness are reported more often in relation to highly familiar roads, as well as under conditions of fatigue (Burdett et al., 2016), as if navigation of whole routes become automated. While this extreme argument for automation is unlikely (Groeger, 2000), the evidence that route familiarity reduces awareness is compelling. Given the importance of driving on familiar routes, experimental investigations of repeated-route driving are relatively limited, due to the resources required to familiarise participants with a route. However, simulator studies, in which participants drive parts of the same route on a number of occasions, have begun to indicate that there are measurable changes in driving performance as a route becomes well-practiced. Speed and lane variability have been seen to decrease across a number of free-drives (Charlton and Starkey, 2011). These changes might be indicative of better prediction of the physical road layout, meaning that fewer corrections are required, but this could also suggest that the drivers are less sensitive to the vagaries of on-road hazard levels., perhaps suggesting that drivers are less sensitive to the vagaries of on-road hazard levels. In a follow-up simulator study Charlton and Starkey (2013) had drivers undertake 20 sessions on the same simulated route and assessed their ability to detect changes across the number of sessions (and compared to a control group). They found that drivers' attention for changes in the driving scene (the removal and additional of buildings, the changing of road signs, etc.) diminished with increased route familiarity, suggesting that they were driving without awareness. Certain changes were still detected with high accuracy however, such as the removal of lane markings. Road markings are typically viewed peripherally in order to maintain lane position, and are thus used perhaps more implicitly. The removal of these cues may have thus degraded the otherwise automated task of steering, drawing attention to the absence of lane markings.

The decrease of attention to road-signs with increased route familiarity has been noted by other researchers (e.g. Harms and Brookhuis, 2016), but is this a problem? It is understandable that drivers should pay less attention to a sign that explains a dip in the road ahead, if they are already expecting the dip and therefore have no need to be warned (Charlton and Starkey, 2013). Problems arise however when changes to road layout result in the addition or modification of road signs that may be missed.

Even more concerning however is the possibility that route familiarity may influence the way we behave on the road. In a car following task, Yanko and Spalek (2013) found that on the fifth occasion of driving the same route participants followed the lead car more closely, braked more slowly in response to the lead cars' brake lights, and were slower to respond to pedestrians crossing the road, compared to a control group who had driven five different routes.

The above studies discuss results that have been obtained through simulated driving. This poses one clear possible confound: Drivers may be more willing to allow their minds to wander in a situation where the threat to their safety is only virtual. While it appears easy to accept that reduced attention to road signs should transfer from simulators to the real world (see Martens and Fox, 2007), are drivers really likely to pay less attention to safety-critical aspects of highly familiar roads when they risk injury or even death?

While such on-road studies of familiarity are extremely rare, there is some evidence that speed increases with route-repetition (Colonna, Intini, Berloco and Ranieri, 2016). Without a direct measure of how dangerously the participants were driving however, one could argue that this is a result of the driver better calibrating the demands of the road to their self-perceived skill level (though their participants' choice of speed often exceeded the posted limit). A harder finding to argue against is that of Rosenbloom et al., (2007) who observed drivers on both familiar and unfamiliar routes, noting that dangerous behaviours and driving violations increased on the most familiar of roads. It is unclear however what mechanism lies behind such increases in risk-taking with familiarity.

The current study attempts to bridge the gap between simulator studies of inattention in familiar route driving and studies that suggest on-road behavioural changes. If drivers do become more inattentive on familiar routes on real roads, as suggested by the simulator studies, then this may provide one cause of increased danger on familiar routes. The experiment reported here looks at the effect of increasing route familiarity on an expert driver (an experienced ADI) on a real-world driving route. Specifically, we expand on recent findings by looking, not just at whether the driver does or does not attend to specific signs or markings, but at how they allocate their visual attention across the driving scene and how this changes with exposure. This is examined across five different driving environments, to establish whether different driving demands may affect how attention changes with familiarity.

2. Method

2.1. Expert driver

The same driver was used in all of the drives. To examine the effect of route repetition for a very experienced driver, we recruited a fully-qualified UK Approved Driving Instructor. The instructor was female, aged 45 and had been a practicing ADI for 8 years. The instructor was paid £20 for each drive.

2.2. Apparatus

SMI Eye Tracking Glasses (ETG2), sampling binocularly at 60Hz and used a forward facing camera recording at 60 frames per second. Fixations were automatically overlaid onto the recorded video from the forward-facing camera by the eye tracking hardware. Eye movements were calibrated using the standard SMI ETG one-point calibration at the start of each drive. The driver could turn her head naturally, while eye tracking continued.

The driver drove in her own vehicle, so that route practice was not confounded with practice with the vehicle, as she was already familiar with it.

2.3. Driving route

A loop was driven that took around 25 minutes to complete and was a total of 11.6 miles in length. On each drive the loop was driven in the same direction, from the same starting point. Although eye tracking data was recorded throughout, the targeted sections for analysis were five different sections of the route. These are described in Table 1.

Table 1. The Five Road Sections Analysed

No.	Name	Length (metres)	Speed Limit (mph)	Description
1	Multi-lane Carriageway	1450	50	Varying between two and four lanes of traffic in the direction of travel. Includes 3 off-ramps and 3 slip-roads.
2	Dual Carriageway	1040	50	Two lanes in the direction of travel, with a central reservation separating oncoming traffic from the instructor's vehicle.
3	Country Road	1250	60	Two way traffic. Hedges and fields to the side of the road.
4	Open Suburban	850	30	Two way traffic. Houses set well back from the pavement, allowing good visibility. No parked vehicles on the road.
5	Closed Suburban	640	20	Two way traffic. Houses set close to pavement. Parked vehicles on the road mean the driver must frequently decide whether to proceed or give-way to oncoming traffic.

2.4. Procedure

Each experimental session began in a car park on Nottingham Trent University, Clifton campus in Nottingham, UK. As part of a separate experiment, each drive included a different passenger, who also wore eye tracking glasses while occupying the passenger seat throughout the drive. At several points during each drive a simple conversation would be undertaken between the driver and passenger, but the parts of the drive included in this paper included no conversation or interaction with the passenger or experimenter. The experimenter sat in the rear seat of the vehicle and conducted eye tracking calibrations before each drive began. The earliest drive started at 10:00 and the latest drive ended at 16:30, meaning that morning and evening rush hours were avoided and all drives took place in full daylight. The driver was asked to drive as normal.

2.5. Data Cleaning

In the first two drives the driver was given on-road directional instructions, whilst she learnt the route. These two drives were excluded from the analysis, as the verbal interaction and need to follow instructions may impact the observed eye movements. In the following drives, the instructor was able to drive the route from memory, without the need for verbal directions. Data from drive 11 had to be discarded due to poor calibration throughout the drive.

The length of time taken to drive a road section was calculated in milliseconds, as was the sum of duration of all fixations made within the section. The eye tracking glasses' algorithm does not classify saccades, so 10% of section time was deducted to account for saccades. Percent missing data was then calculated as the percentage of the section time, after 10% deduction for saccades. Any section with more than 40% missing data was removed from the analysis. This meant the removal of two drives from the multilane carriageway section and two drives for the dual carriageway section. Included number of drives (n) for each section is shown in table 3.

In order to establish where the driver was looking in a dynamic visual environment, it was necessary to manually code each fixation as belonging to a particular category. Each fixation was initially coded by the specific sub-category to which it corresponded. These were then grouped into larger categories for analysis, as shown in Table 2.

Table 2. Fixation Coding Categories and Descriptions

Category	Description & Subordinate Categories
In-Car	Any in-car fixation that was not on the rear view mirror (passenger, speedometer, any other in-car location excluding the rear view mirror)
Mirrors	All mirrors in the driver's car (left wing mirror, right wing mirror, rear view mirror)
Road ahead - near	The road in front of our driver, in the bottom two-thirds of the visible roadway ahead (near tarmac, near oncoming vehicles, near vehicles heading in the direction of travel)
Road ahead - far	The road in front of our driver, in the top one-third of the visible roadway ahead (far tarmac, far oncoming vehicles, far vehicles heading in direction of travel)
Side roads	Any fixations on a side road or vehicle in a side road, regardless of direction of travel (vehicles with and without priority in side roads moving towards or away from our driver, tarmac on any side road)
Adjacent lanes	Any lanes that could contain traffic going in the same direction of the driver (adjoining slip roads, other lanes)
Potential hazards at road side	Important locations that were either not on the road, or were on the road but were not other vehicles (parked vehicles at least partially on the road, any pedestrians)
Signage	Any signs (warning or speed sign, direction or location sign)
Off road	Any fixation that could not be attributed to any other category, but was shown in the video (off-road left, off-road centre, off-road right)
Unclassifiable	The eye tracking range of the glasses was somewhat wider than that of the video camera, meaning fixations could sometimes be recorded outside of the visible area. These fixations were recorded as unclassifiable and excluded from later analyses.

Dwell times were calculated as the sum of all fixation durations in a given category. For example, if two 200ms fixations were made on the mirrors in the country road section of a drive, then the dwell time on mirrors in the country road section would be 400ms for that drive. The total dwell time for a section was then calculated as the sum of the durations of all fixations made while the driver completed that section of the drive. Finally, dwell times in each category were then converted to a percent of the total dwell time for a road section, in order to account for variation in time taken to complete a given section across different drives.

Any fixation that fell outside of the area that could be recorded by the video camera built into the goggles could not be allocated to a location and were not included in the analyses. These fixations accounted for 0.9% of the total dwell time across all road sections.

3. Results

Table 3 shows mean dwell time in each location type as a percentage of total dwell time across the drive section, giving an indication of where the driver typically looked overall. In the open suburban road the driver generally spent most time looking off-road (34%), followed by the distant road ahead (31%) and the close road ahead (11%). A similar pattern was observed in the closed suburban road with 34% of dwell falling off-road, but with a much more even split between road near and far ahead (both accumulating 16% of dwell). The closed suburban route was also the only route to result in a substantial amount of dwell given to potential road-side hazards. In the dual and multi-lane carriageways, most time was spent looking at the road far ahead (37% and 43%, respectively), yet our driver still devoted a considerable amount of dwell off-road (28% and 26%, respectively). Finally, on the country road most dwell time was again devoted off-road (40%) though the far road location also commanded a substantial amount of dwell (39%).

Table 3. Mean (SD) percentage of dwell time in each road section spent fixating each of the possible fixation location categories.

Fixation Locations	Mean Percent Dwell Time (SD)				
	Open Suburban n = 25	Closed Suburban n = 25	Dual Carriageway n = 23	Multilane Carriageway n = 23	Country Road n = 25
Road ahead - far	31.07 (11.68)	16.02 (7.49)	36.58 (16.75)	42.61 (16.64)	38.57 (15.81)
Road ahead - near	11.47 (6.79)	16.28 (5.94)	8.42 (9.00)	3.97 (4.41)	8.76 (12.20)
Side roads	1.64 (2.48)	3.48 (1.26)	3.20 (2.23)	*0.07 (0.27)*	*0.39 (1.04)*
Adjacent lanes	*0.00 (0.00)*	*0.00 (0.00)*	4.62 (3.55)	6.71 (3.24)	*0.04 (0.21)*
Potential hazards at road side	1.62 (1.93)	15.28 (5.02)	*0.42 (0.95)*	*0.00 (0.00)*	*0.41 (1.42)*
Mirrors	11.16 (2.96)	9.53 (2.17)	12.27 (2.97)	12.89 (3.65)	7.68 (2.42)
Signage	*0.89 (1.02)*	*0.00 (0.00)*	1.38 (1.14)	1.66 (1.67)	*0.00 (0.00)*
In-Car	7.32 (3.60)	4.18 (2.43)	3.60 (2.35)	5.29 (3.40)	3.28 (1.95)
Off road	34.25 (11.21)	34.17 (9.56)	28.05 (16.65)	25.58 (13.12)	40.22 (13.43)

Note: n refers to the number of drives included in the analysis, after removal of drive sections with poor eye tracking data. Italics denote cells where mean dwell time was below 1%, these were not analysed further.

Data were analysed separately for each of the five different types of road. In each case, correlations were conducted between the drive number and the percent of the dwell time in the road section that was given to a particular scene category. Positive correlations show increasing overt visual attention to particular scene categories as familiarity with the route increases, while negative correlations show decreasing overt visual attention across drives. Any category within a drive section that received an average dwell time of less than 1% was not included in the correlations, as such a small proportion of attentional time typically meant that the location type was not present or very rarely present. For example, there were very few potential hazards at the road side (e.g. pedestrians/parked vehicles) on the dual carriageway, the multilane carriageway or the country road. Conversely, the category of 'adjacent lanes' was only relevant to dual and multi-lane carriageways. See Table 4 for all correlations between dwell percentage and drive number.

Table 4. Correlations between drive number and percent dwell time in each of the 10 different fixation locations. Separate correlations are presented for each of the 5 different road types that the driver encountered.

Fixation Locations	Open Suburban	Closed Suburban	Dual Carriageway	Multilane Carriageway	Country Road
Road ahead - far	-.279	**-.573****	**-.588****	**-.546****	**-.450***
Road ahead - near	**-.538****	-.369	-.274	-.241	-.090
Side roads	-.271	-.313	-.282	—	—
Adjacent lanes	—	—	.048	.062	—
Potential hazards at road side	-.115	.008	—	—	—
Mirrors	.219	.197	.131	-.105	.166
Signage	—	—	.127	-.078	—
In-Car	-.255	.156	**.462***	.410	.033
Off road	**.691*****	.597**	**.673****	**.686*****	**.535****

Notes: A dash denotes that this fixation location was not included in the correlations due to receiving less than 1% of average dwell time. Bold text highlights significant correlations. $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$

As shown in Table 4, significant positive correlations were observed for every road type, with percentage dwell time on non-road relevant areas increasing across drives. On the dual-carriageway section in-car fixations also increased across drives ($r(21) = .462$, $p = .026$).

Significant negative correlations between drive number and percentage dwell time on far road ahead locations were observed on closed suburban ($r(23) = -.573$, $p = .003$), dual-carriageway ($r(21) = -.588$, $p = .003$), multi-lane carriageway ($r(21) = -.561$, $p = .007$) and country road ($r(23) = -.450$, $p = .024$) sections, while a significant negative correlation between drive number and percentage dwell on near road ahead locations was observed for open-suburban locations ($r(23) = -.538$, $p = .006$).

4. Discussion

Evidence from previous research suggests that route familiarity may reduce attention for important safety-relevant stimuli (e.g. Charlton and Starkey, 2013, Burdett et al., 2016), though the majority of such research has been undertaken in simulators, or has involved self-report of remembered instances. This study demonstrates that these effects translate to real roads, even with a highly expert driver, which may partly explain why observation studies have identified an increase in dangerous behaviour on familiar roads (e.g. Rosenbloom et al., 2007).

Detailed coding of our expert driver's eye movements across five different types of road revealed a decrease in attention to the road ahead. In four out five road sections, this decrease was noted for gaze on the far roadway. Where was the spare attention reallocated? It might be plausible to expect gaze to retreat closer to the vehicle, as happens with novice drivers who are presumably under greater processing demands (e.g. Mourant and Rockwell, 1972). This did not occur however. Indeed, the non-significant tendency was for attention to the near roadway to also decrease with route familiarity.

Instead, the driver appeared to allocate spare attentional capacity to off-road, safety-irrelevant aspects of the scene. This increase in off-road attention was observed in all five road types, even on the rural route. This particular section contained very little off-road stimuli of particular salience, with occasional houses separated by hedgerow and fields. Nonetheless, our driver found elements within the roadside scenery of sufficient interest to capture overt attention. As the naturalistic nature of the study precluded probe questions to assess driver thoughts, we cannot be sure however that she was actively engaging with off-road stimuli. It is possible that this increased off-road gaze reflected internal distractions.

The lack of relationships between mirror inspections and route familiarity is notable. Often mirror-glances are reported to be one of safety checks that suffer from increased roadway demands (Yang, McDonald and Zheng, 2010). In the current study, mirror glances accrued approximately 10% of dwell across all road types. What little variation was found in mirror dwell across the road types suggests that the least demanding road accrued the fewest mirror fixations. The relative uniformity of mirror dwell across road types, along with the insensitivity to route familiarity, suggests that the mirror-checking schema is entrenched. This is understandable with our participant – a driving instructor who must instruct her students in the importance of mirror awareness. Again however we do not know whether the efficacy of these mirror checks was impacted by route familiarity, as eye tracking can only tell us what people look at, rather than what they are thinking about.

On-road studies do not allow us to manipulate hazards, so we cannot empirically test whether the change in attention with route familiarity is associated with poorer hazard response and reduced safety on the road. Certainly, no events occurred that were classed as hazardous by the experimenters, and the instructor was not involved in any collisions during the experiment. One could argue, therefore, that the decrease in fixation time on the road could be attributed to more efficient processing. However, even if processing is more efficient, because the spare capacity was allocated off-road the driver ultimately spends less time looking at the road. It seems reasonable to suggest that readiness to respond to the development of hazards relies upon the driver looking at either the road itself, vehicles, pedestrians, signage, or other safety-related features, and that an increase in time spent attending to safety-irrelevant stimuli is likely to represent increased risk, as a hazard could begin to develop while the driver is looking off-road.

It was interesting to note that dwell on signage was not particularly related to route familiarity, as would be argued by other researchers (Harms and Brookhuis, 2016, Martens and Fox, 2007). However, it appears that the removal of the first two practice drives of the route may have removed almost all overt attention to road signs. Thus, the drop of dwell on signage is so abrupt that the relationship with route familiarity does not feature in our more longitudinal measure.

4.1. Conclusions

The current results demonstrate that roadway familiarity, developed through route repetition over several weeks, appears to shift our driver’s overt attention from the road itself (particularly at far locations) to off-road areas of the scene that are irrelevant to driving safety. This may reflect a decrease in arousal due to the repetitive nature of the task, with a concomitant desire to seek out novel stimuli in order to redress the balance. Fixating discrete off-road stimuli may reflect an attempt to maintain engagement with external stimuli and prevent the mind wandering onto internal thoughts, though without probing the thoughts of the driver, either during the drive (disrupting the natural flow of task), or retrospectively (which depends on whether those fleeting thoughts were laid down in memory), we cannot be sure of this. Whether drivers attempt to influence the choice of an external or internal focus of their mind wandering, and its relationship with eye movements, offers an interesting avenue for future research.

While the current results do not link familiarity-related off-road dwell with unsafe driving behaviours, it is plausible to assume that the sudden appearance of a hazard is more problematic if the driver is not looking at the road. It is important to note that these results pertain to only one professional driving instructor, and as such, it is difficult to draw any strong generalised conclusions. Since familiarity-induced degradation of attention to the roadway may have much more dangerous implications for the average driver, there is a clear need for further investigation of the effects of familiarity on visual search of the road scene in expert, experienced and novice drivers alike.

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