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Eye movements and hazard perception in active and passive driving

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ABSTRACT
Differences in eye movement patterns are often found when comparing passive viewing paradigms to actively engaging in everyday tasks. Arguably, investigations into visuomotor control should therefore be most useful when conducted in settings that incorporate the intrinsic link between vision and action. We present a study that compares oculomotor behaviour and hazard reaction times across a simulated driving task and a comparable, but passive, video-based hazard perception task. We found that participants scanned the road less during the active driving task and fixated closer to the front of the vehicle. Participants were also slower to detect the hazards in the driving task. Our results suggest that the interactivity of simulated driving places increased demand upon the visual and attention systems than simply viewing driving movies. We offer insights into why these differences occur and explore the possible implications of such findings within the wider context of driver training and assessment.

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Driving is a complex visuomotor task, requiring not only on-line control of the vehicle being driven, but also attention to the environment itself, and changes within it; particularly given the possibility of encountering hazards. In this study we will explore interactions between the dual tasks of driving and being vigilant towards potential hazards. In particular we wish to explore how the demands of driving affect visual behaviour and hazard detection across two different driving related tasks, one active and one more passive. Before we describe our study, we first review some literature on the potential importance of investigating vision in the context of "action" and how this relates to driving and hazard perception tasks.

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Visuomotor control during natural activity

During natural activity, foveal attention must be directed towards informative areas, in both time and space, which aid task completion. It is therefore important to understand the processes involved in this guidance of vision. Current models of visual guidance in complex scenes are often derived from simple tasks using static stimuli, such as picture viewing or visual search. Although recent progress has been made in this area (e.g. Borji, Sihite, & Itti, 2011, 2014; Johnson, Sullivan, Hayhoe, & Ballard, 2014), there exist few frameworks, computational or otherwise, that can successfully predict eye movements in complex, dynamic and naturalistic environments, such as driving.

A standard method to model eye movement behaviour is by using movie based paradigms which, by definition, allows dynamic information to be presented. However, it is often difficult to generalize the findings to real world contexts. Hirose, Kennedy, and Tatler (2010) found that cuts in a movie resulted in disruptions to both memory and eye movement behaviour compared to normal scene perception. Dorr, Martinetz, Gegenfurtner, and Barth (2010) showed that the eye movement behaviour exhibited by individuals when viewing different movie types (stop motion, Hollywood movies and natural movies) was rather variable and not representative of natural viewing behaviour. These studies suggest that using movies may have limited utility when investigating eye movement behaviour during everyday tasks.

It has been argued that during natural activity incorporating visuomotor control (typically when movements of the limbs are required), the role of vision can most usefully be studied during the performance of action itself (Land & Tatler, 2009). Oculomotor behaviour and associated action during natural activity are intrinsically linked both temporally and spatially (e.g. Ballard et al., 1992; Hayhoe, Shrivastava, Mruczec, & Pelz, 2003; Land, Mennie, & Rusted, 1999). Specifically, during many tasks we see examples of “do it where I’m looking” strategies where individuals fixate directly at the objects being interacted with and “just in time strategies” where individuals’ gaze tends to precede the visuomotor action by around one second (Land et al., 1999). This suggests that simply watching movies may not capture the same visual behaviour that one would observe under more ecologically valid circumstances, i.e. tasks which incorporate visuomotor control.

Indeed, the neural substrates involved in action control and passively perceiving are thought to be at least partially separate (Milner & Goodale, 1995; Glover, 2004; Ungerleider & Pasternak, 2004). Differences have been found in oculomotor behaviour between tasks involving action versus perception. For example, Steinman (2003) reviewed a number of studies that investigated the oculomotor strategies used to complete a tapping search task, compared with a search task where observers were asked to look at, but only think about, tapping the target object. The oculomotor behaviour (e.g. gaze shift velocities, gaze shift durations, head movements) employed by individuals differed across the two tasks. Steinman (2003) argued that it was not possible to predict the differences in visual behaviour that were found on the basis of prior work done under less natural conditions where natural purposeful action was largely restricted. More recently, differences have been demonstrated in oculomotor strategies across more everyday tasks and their passive viewing analogies, e.g. visual search (Foulsham, Chapman, Nasiopoulos, & Kingstone, 2014), scene viewing (Foulsham, Walker, & Kingstone, 2011) and social attention (Risko, Laidlaw, Freeth, Foulsham, & Kingstone, 2012). Thus, there is a wide literature, drawing from a number of areas, suggesting that movie based paradigms used to investigate oculomotor and hazard perception performance in driving may not accurately represent the specific goal directed visual behaviour we would see in a more active driving environment. We discuss this possibility below.

Visuomotor control during driving, hazard perception and the current study

Hazard perception, the process by which drivers detect and respond to potentially dangerous situations, is a crucial aspect of driving. There has been considerable research into driving and driving skill, particularly of hazard perception, with many studies involving participants either viewing pictures of driving scenarios (e.g. Underwood, Humphrey, & van Loon, 2011) or using movie viewing based paradigms (e.g. Borowsky, Oron-Gilad, Meir, & Parmet, 2012; Chapman & Underwood, 1998; Savage, Potter, & Tatler, 2013; Underwood, Phelps, Wright, van Loon, & Galpin, 2005). A typical experiment involves participants watching video clips of a car driving from the perspective of the driver. The task is to press a button when the hazard is detected and eye movements will often be tracked. Results of such studies demonstrate that performance on hazard perception tasks is often a predictor for accident involvement (Horswill & McKenna, 2004; Wallis & Horswill, 2007), where faster hazard detection correlates with lower reported accident involvements. In addition, these studies have allowed us to identify possible oculomotor strategies employed by drivers of differing experience. For instance we see more exaggerated horizontal eye scanning patterns in experts than in novice drivers (e.g. Crundall, Chapman, Phelps, & Underwood, 2003; Crundall & Underwood, 1998).

From what we have previously discussed, tasks that attempt to model oculomotor behaviour without incorporating visuomotor control of a vehicle may measure something different from when participants actively control a car. The interactivity of driving (be it real or in a simulated environment) is likely to place more of a demand upon the visual system than when observers are faced with a passive movie-viewing environment. Certain locations which need to be fixated by the driver in order to control the car successfully become much more important in an active driving task. For example, drivers tend to steer in the direction of their gaze (Robertshaw & Wilkie, 2008) and fixations are clustered near the focus of expansion (FoE) when driving in a straight trajectory (Mourant & Rockwell, 1970, 1972). These fixation patterns are less important in a movie based task. As a consequence, this may limit the visual search for hazards that could otherwise be accomplished when simply viewing videos. This highlights the idea that the need to look somewhere else may hinder the ability to spot a hazard. In addition, there will be increased attentional demands in an active driving task compared to passively viewing and we know that increasing cognitive demand limits visual scanning when driving (Recarte & Nunes, 2003; Savage et al., 2013). Thus the increased attentional demands of an active driving task, compared to viewing movies, may limit the visual search for hazards.

Here we test the hypothesis that passive viewing of driving may deliver visual behaviour inconsistent with that found during active driving. This was achieved by studying and comparing eye movement fixation patterns and hazard detection when driving in a naturalistic setting that incorporates active control of a vehicle, compared with passive movie viewing. Our aim was to identify and quantify differences in oculomotor behaviour for a hazard perception task, across the two conditions, with an environment as similar as possible across conditions.

In the active driving condition, participants drove around a number of set routes using a driving simulator programme and responded (using a button press) to hazards. In the non-driving condition, participants watched a series of video clips from the same driving software and responded to the hazards using a button press. We recorded eye movements throughout, using foveal fixation location as a measure of attentional deployment. We measured how much each individual scans different locations along the road. This measure is often correlated with experience, where a more experienced driver exhibits increased scanning (Crundall & Underwood, 1998; Crundall et al., 2003; Falkmer & Gregersen, 2001; Underwood, Crundall, & Chapman, 2011). We also recorded reaction times to detect hazards with a button press (e.g. Shahar, Alberti, Clarke, & Crundall, 2010; Underwood et al., 2005). Since distinctions have been drawn between processes of perceptual guidance and perceptual identification (see Godwin, Menneer, Riggs, Cave, & Donnelly, 2015; Huestegge, Skottke, Anders, Müsseler, & Debus, 2010), we also broke this overall reaction time down into (1) latencies for individuals to fixate hazards (measured as the time of first fixation) and (2) the latencies to verify the hazards as such (measured as the time between first fixation and the button press). We expected that there would be distinct differences between the fixation locations and hazard perception performance between the driving and non-driving conditions, reflecting differences in visual or attentional processing. Specifically, the lower levels of attentional demands in the video task may (1) allow individuals to search more extensively for hazards, resulting in a wider visual search pattern, and (2) result in slower processing of hazards which would result in slower overall reaction times. This work, to our knowledge, is the first study to measure absolute behavioural comparison across video based driving tasks and simulated driving tasks. This paper updates and extends our preliminary research presented in Mackenzie and Harris (2014).

Methods

Stimuli and apparatus

Driving simulation and hazards

The driving simulator software used was Driving Simulator 2011 (Excalibur Publishing Limited, 2011). With this software, the driving environment could be controlled and the locations of the hazards determined. The hazards used here were fully developed obstructions on the roadway, involving other vehicles which, under normal circumstances, would cause an approaching car to slow down, stop or change direction. Specifically, drivers/viewers would encounter a vehicle collision that had already occurred. The term fully developed is used here to highlight that these hazards have occurred prior to encountering them (see Figure 1). The hazards were created by

Figure 1. An example of a fully developed hazard. The collision has occurred prior to the driver encountering the hazard and would require the driver to slow down, stop or change position.

re-programming the “Artificial Intelligence” of the other (virtual) road users so that they would frequently collide with another road user and create an obstruction. When encountered, individuals would need to slow down to manoeuvre around the hazard. The onset of a hazard was defined as being when it first became visible on-screen. Information about distance to the hazard at this moment was not available from the software. We calculated that, on average, the time each hazard was available to respond to did not differ across driving and non-driving conditions.

A pilot study was conducted to confirm that these hazards could be detected easily. Participants viewed four movies showing hazardous situations (six total hazards) and four movies showing non-hazardous situations. When asked to detect the hazardous events by pressing a button, participants correctly identified the hazardous situations significantly more than non-hazardous driving situations ($\chi^2(2, 36) = 41.17$, $p < .001$, using chi squared). This is unsurprising given the nature of the hazards, nevertheless this pilot study provided evidence that the types of fully developed hazards used in the main experiment are easy to detect and are suitable to measure individuals’ hazard perception performance.

The physical properties of the vehicle such as the mass of the car, its overall inertia, steering, brake torque etc. could be pre-programmed to mimic the feel of driving a car in the real world. To control the car, a Thrustmaster 5 Axes RGT Force feedback steering wheel (with left and right indicators) and pedal combination was used. The vehicle was driven in a “driving on the right” traffic environment. Participants indicated they had spotted a hazard via button press as soon as it was noticed. For both conditions, the button was located on the steering wheel where the participants’ right thumb would naturally be when holding the wheel to minimize the motor effort required in order to push. Thus, any difference in response times between the two conditions is not likely to be accounted for by latencies in motor responses. The car driven was fully automatic, controlled by gas pedal for acceleration and brake pedal for deceleration. Each pedal possessed natural pedal resistance for realism. The stimulus display monitor was a 22 inch CRT, set at a resolution of 1280 × 1024. The virtual environment was viewed at a distance of 60 cm for both driving and non-driving conditions (horizontal viewing angle of 38.50 deg).

Video and driving stimuli

Eight video clips were shown in the non-driving condition. They were pre-recorded driving scenes from the driving simulator software. The scenes were captured using FRAPS® video capturing software at a frame rate of 30 frames per second and a resolution of 1280 × 1024 (with a 5:4 monitor aspect ratio). These videos took the form of a first person perspective driver view of a vehicle driving around suburban and urban areas with varying amounts of traffic whilst adhering to the normal rules of the road i.e. by staying within the speed limit, stopping at stop signs, etc. Four of the course clips contained either one or two hazards (six in total). The other four course clips contained no hazardous events.

For the driving condition, participants drove a total of eight courses, which consisted of the same suburban and urban routes as the video condition with either no traffic, light traffic or dense traffic. Four of the courses contained either one or two hazards in the form of a collision (up to six to detect across the four courses). The other four courses contained no hazards. The courses used across the conditions were the same. Only the four courses without hazards were used in the eye movement analyses to minimize eye movement measurements associated with hazard specific events. We sought to eliminate differences in eye movements being due to differences in visual motion or duration across conditions. The number of turns and distances driven were on average equivalent across driving and non-driving conditions. Each course was driven on a single carriageway to minimize differences in the number of lane changes made across conditions. The consistency between driving and non-driving tasks limited differences in steering performance. The average time for viewing the video clips in the non-driving condition was 143.5 s (minimum, 103 s; maximum 183 s). The average time for driving the courses was 151.8 s (minimum, 61 s; maximum 240 s).

Eye movement recording

An SR Eyelink 1000 eye tracker, with tower mount apparatus (Figure 2) was used to record eye movements, sampling at 1000 Hz. Fixations and saccades were determined using a displacement threshold of 0.1 deg, a velocity threshold of 30°/s and an acceleration threshold of $8000°/s^2$ (SR Research Ltd, 2013). A 12 point calibration ensured that recordings had a mean spatial error of less than 0.8 deg. A chin rest was used in this experiment, which we acknowledge restricts naturalistic movement, however, given the relatively small visual field, head movements were not necessary in order to view the visual display.

During the driving task, each participant's drive was recorded using the FRAPS® video recording software. The temporal and spatial attributes of the eye-movement coordinates were overlain onto these video recordings using a MatLab sequence to produce an output .avi video that consisted of the video and fixation location (in the form of a red dot). The programme was coded so that this dot turned green when the participant had pressed the button indicating they had detected the hazard. Similarly, for the non-driving task, each participant's eye-movement data was overlain onto the pre-recorded videos where the eye-movements were represented as a red dot, which turned green when the hazard was detected.

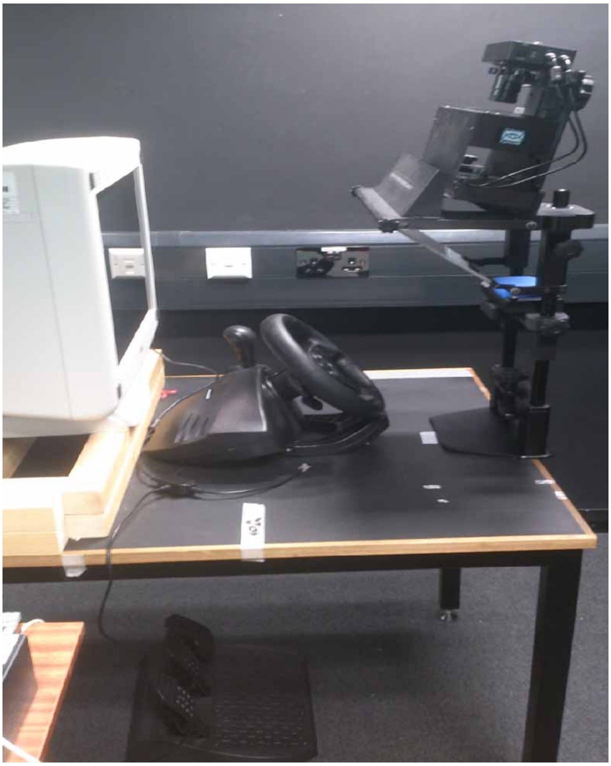

Figure 2. Apparatus set up of monitor (left), steering wheel, pedals and eye tracker.

Measures

Eye movement measures

Eye movement information (i.e. fixation coordinates) was recorded and collated via SR Research Data Viewer software.

Fixation locations/Spread of attention: The standard deviations of eye fixations across the horizontal and vertical axis (using *x*-axis and *y*-axis pixel coordinates) were measured to provide an indicator of the spread of visual attention. A larger standard deviation would suggest a larger distribution or spread of visual attention.

Average y-axis fixation location: The mean *y*-axis fixation was measured using the mean *y*-axis coordinate as an indicator of how far, on average, along the road participants fixate. Since this measure is converted from screen pixels, a smaller *y*-axis fixation value would suggest that individuals are looking higher up in the image and thus looking further ahead along the road.

Reaction times

As a measure of hazard detection performance, reaction time was measured, using a button press, which allowed us to calculate the time between when the hazard first appeared on the screen and when the participant pressed the button. This was taken as a total reaction time measure. This total reaction time measure was also split into two constituent time periods: the time it took to see the hazard and the time it took to verify the hazard as a hazard. The “Time to See” the hazard was measured from the time the hazard appeared on the screen (the first frame the hazard was visible) to when a participant fixated on the hazardous area. The “Time to Verify” was measured from the time that the initial fixation occurred to when the button press was made—where the eye movement dot would turn green on the video file. Reaction time analyses and the judgements of the initial saccades were performed manually, offline by the experimenter by viewing the video files on a frame-by-frame basis and recording the timestamps at which these events occur. All timings were calculated using Apple Quick Time^{TM} video player.

Participants

Thirty-four participants took part in the study (five males) with an age range of 19–31 years (mean age 22.3 years). All participants had normal or corrected-to-normal vision and were recruited through the University of St. Andrews SONA experiment participation scheme. They were paid £5 for participation. All participants had held a drivers’ licence for at least one year and were from countries where driving on the right side of the road is standard. Driving experience did not significantly differ across conditions (mean years since licence received, Driving task, 3.1 years [3.4 *SD*]; Non-driving task experience 2.6 years [1.5 *SD*]). The study was approved by the University of St. Andrews University Teaching and Research Ethics Committee (UTREC).

Procedures

Driving task

Participants were instructed they would be performing a hazard perception task whilst driving around a number of courses in a virtual environment. It was explained that they would be detecting hazards that were fully developed, and that such a hazard was one that would cause (the driver) to slow down or change direction in some way to avoid the hazard. The experimenter gave a full explanation accompanied by a demonstration in how to use the apparatus to control the vehicle in the virtual environment. Participants were shown how to use the gas, brake, how to steer and how to use the button press when they detected the hazard. They were also shown how to navigate through the virtual environment whilst obeying all traffic laws as they normally would if driving in the real world; such as stopping at red lights, approaching slowly at closed junctions and use of indicator signals etc. Each participant was given time for a test drive in order to use the set-up comfortably. Participants' eye movements were calibrated before each course. Participants then began to drive whilst their eye movements were recorded. The order of the eight courses driven was randomized. Throughout each course, the experimenter gave simple navigation instructions such as "turn first right" or "follow the road". These instructions were given at least five seconds in advance of any visible hazardous situation in order for the instruction to be fully processed before encountering the hazard. Participants pressed the button as soon as they saw a hazard. For the four courses containing hazards, the experimenter stopped recording the eye movements after the first or second hazardous event had occurred and the participant was asked to stop the vehicle. There were six hazards across the four courses. For the four courses that did not contain hazardous events, after a certain location (known by the experiment) was reached in the drive, the experimenter stopped recording eye movements and asked the participant to stop the vehicle. The experiment lasted one hour.

Non-driving task

Participants were instructed that they would be performing a hazard perception task where they would be watching a series of video clips of driving situations and would press the button on the steering wheel when they detected a hazardous event. The same definition of a fully developed hazard was given as that used for the active task. Eye movements were calibrated before each video. Participants were instructed to watch the video as if they were the driver. Although participants were instructed to view the clips as if they were a driver, we were unable to measure if this was what they did, since they were not instructed to commentate or report on the clips. Participants viewed the eight video clips, presented in a randomized order, whilst their eye movements were tracked. They were asked to press the button as soon as they saw a hazard. Four of the courses contained six hazards, each ending a short time after the first or second hazardous event occurred. The four non-hazardous courses were terminated at the same section of course as in the active driving condition. The experiment lasted one hour.

Design

For the eye movement and hazard perception performance analyses, the independent variable being manipulated was condition (Driving and Non-driving conditions). This is a between subjects variable where participants took part in either the Driving ($n = 17$) or Non-driving ($n = 17$) condition. Between subjects t-tests were used to determine significant differences in eye movement and reaction time measures.

Results

Here we report the eye movement measures recorded, which included the distribution of fixations and average vertical position of fixations. All eye movement data were processed and coded using SR Research Data Viewer. We also report the total hazard detection reaction times, which include both the Time to See the hazard and Time to Verify the hazards. All reaction time data was manually coded by viewing the recorded video files on a frame-by-frame basis and recording the event related timestamps. Response accuracy was also analysed. However, likely given the nature of the attention capturing hazards, this was high in both conditions (driving mean = [87.8], *SD* = [16.1]; non driving mean = [94.1], *SD* = [11.6]) and did not differ between the two conditions ($t(32) = 1.3$, $p = .2$). Therefore we focused on eye movement and reaction time measures as planned.

Eye movement analyses

In our eye-movement analyses we considered eye movements from only the four courses that did not contain hazards, to avoid hazard specific artefacts. Data were averaged and collapsed across the four courses. The specific area of interest is that of the roadway (see Figure 3) which excludes vehicle specific areas such as rear-view mirrors, wing mirrors and speedometer. We compared each measure across driving and non-driving conditions.

Figure 3. Illustration of the visual area of interest (roadway) highlighted in yellow. Screen dimensions: 1280 × 1024 pixels (41.9 × 33.4 cm; 38.5 × 31.1 deg). Interest area dimensions: 1280 × 266 pixels (41.9 × 8.7 cm; 38.5 × 8.3 deg).

Allocation of visual attention

First, to investigate road scanning behaviour we measured the standard deviations of the x-axis and y-axis fixation locations within the roadway field of interest illustrated by Figure 3. A larger standard deviation of the distribution of fixation locations would equate to a larger spread in visual attention; suggesting increased scanning of the road. Second, to investigate how far, on average, along the road participants fixated, we measured the mean y-axis fixation. This was measured as an angle (degrees), from the top of the screen (0 deg) to the bottom (31.1deg). A larger value then equates to individuals looking lower down in the display and thus closer to the front of the vehicle. We initially represent the distribution of fixation locations for both driving and non-driving conditions in the form of density heatmaps (Figures 4(a) and 4(b), respectively).

The distribution of fixations was larger for both the horizontal and vertical directions for the non-driving condition (Figures 5(a) and 5(b), respectively) and fixations tended to be located higher (smaller angle) in the non-driving condition (Figure 5(c)). Between-subjects t-tests (for mean horizontal and vertical standard deviations and for mean y-axis position) were conducted to identify any significant differences across driving and non-driving conditions. There was a significant effect of driving condition for the standard deviations of fixations in the horizontal direction ($t(32) = 4.29$, $p < .001$) and vertical direction ($t(32) = 3.19$, $p = .001$) and for the mean y-axis position ($t(32) = 7.48$, $p < .001$) after Bonferonni correction.

Although absolute effect sizes may be modest, it is important to note that several metres of the simulated roadway will correspond to a relatively small visual angle. It was not possible to accurately calculate the absolute distances along the road because we did not have "ground truth" information concerning the simulated depth distances and dimensions of the road.

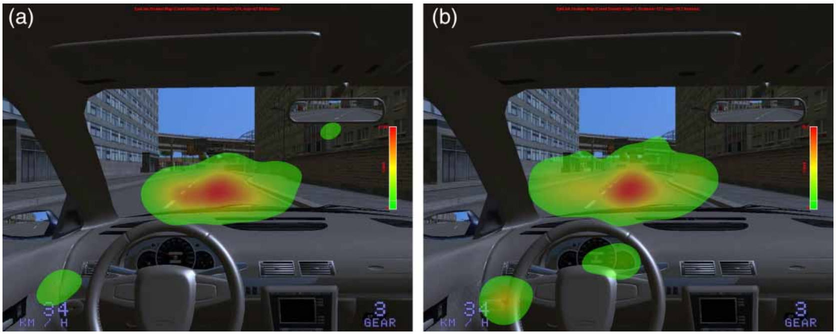

Figure 4. Prototypical examples of individual participant density heat maps showing the distribution of fixations for the (a) driving and (b) non-driving conditions.

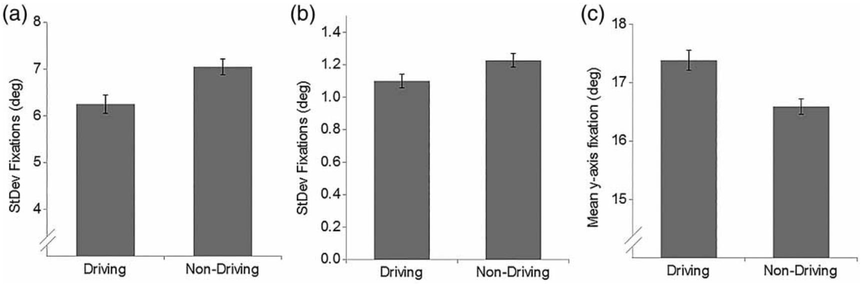

Figure 5. Mean standard deviations of (a) horizontal fixations, (b) vertical fixations, and (c) mean *y*-axis fixation location across driving and non-driving conditions. Error bars show standard error of the mean.

Reaction time data

Overall reaction times

We measured the reaction times to detect the hazards using the button press. This reaction time was taken as the latency from the first frame of the video when the hazard appeared to when individuals pressed the button. Overall, mean reaction time for the driving condition was 5.6 s (0.7 SEM) and was 4.0 s (0.4 SEM) for the non-driving condition. Between-subjects *t*-tests were conducted to identify any significant difference between the driving and non-driving groups. There was a significant difference in overall reaction time ($t(32) = 2.0$, $p = .042$) demonstrating those in the driving task responded slower than those in the non-driving task.

Breaking down the effect of the driving condition on reaction times

We propose two possible hypotheses for this increased latency for participants to respond to hazards in the driving condition. The first is the idea that there is a longer latency in seeing the hazard. That is, participants do not fixate as quickly when driving. Alternatively, the latency may be the result of a processing, or verification issue, in that participants successfully fixate the hazard but it takes longer to acknowledge the hazard. Indeed, it may be possible that both of these factors result in the longer latencies we observe.

As described in the Methods section, we can measure the average time it takes to see (Time to See) the hazards by calculating the time between when the hazard first appears to when participants first fixate on or near the hazard. And we can infer processing time (Time to Verify) from measuring the time from the initial fixation to when participants responded using the button press. Figure 6 shows these measures plotted for the two conditions. If either the Time to See or Time to Verify accounts for the reaction time latency across the tasks, we should expect to see a statistical interaction between these two timing measures and the two driving conditions.

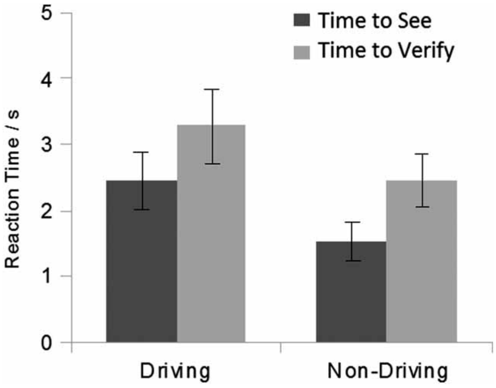

Figure 6. The interaction of the average time taken to see and verify the hazard. Error bars show standard error of the means.

Using driving condition (driving and non-driving) and timing measure (Time to See and Time to Verify) as independent variables, a mixed measures ANOVA showed that there was no significant interaction between these variables ($F < 1$) (see Figure 6). We can infer that both the Time to See the hazard and the Time to Verify the hazard contribute to the increased latency to respond to the hazard in the driving task.

Discussion

Current models of visual guidance in complex scenes are often derived from relatively simple tasks using stimuli that do not represent a naturalistic setting. Our primary aim was to measure, under controlled conditions, whether there were any differences in eye movement behaviour and hazard detection times between active driving and non-driving conditions. Underwood, Crundall, et al. (2011) presented research comparing visual behaviours between different driving experience groups across video-based, simulated and real-life driving. They suggested that differences in visual behaviour between experience groups are similar across these methods of analyses (video, simulated and real driving). For example, inexperienced drivers may scan the roadway less than experienced drivers across both video and active driving tasks (see Underwood, Chapman, Bowden, & Crundall, 2002). These similarities provide relative validity across tasks; where *similar patterns* of behaviour can be observed across different testing conditions (see Godley, Triggs, & Fildes, 2002). Relative validity is important, particularly if we are able to differentiate between safe and non-safe drivers using these methods. However, absolute measures, for example, exactly how much less inexperienced drivers scan than experienced drivers, may differ across video and active tasks. Such absolute comparisons of behaviour can only be made across driving methods if stimuli and environments are as similar as possible. In this current experiment, we used video recordings of the driving simulator environment for the non-driving condition, making the stimuli the same across conditions. We therefore provide, to our knowledge, the first study that measures absolute behavioural comparison across video based non-driving and driving conditions. In line with our predictions, we found some differences in the tasks measured, each of which we discuss below. We discuss the main eye movement and reaction time findings separately and offer possible explanations for the results before describing how these results contribute to our current understanding of driving and more generally, to models of eye movement behaviour during everyday tasks.

Eye movement behaviour

We found a number of visual behaviour differences across driving and non-driving tasks. Overall, individuals searched less of the road with their eyes (both side to side and up and down) when performing the driving task than the non-driving task; as indicated by the smaller distribution of fixations across both the horizontal and vertical planes (see Figure 5). We suggest that this may be due to the increased demand placed upon on the vision and attention systems by the interactive nature of the driving task. Certain areas of the environment are likely more informative to an active driver than a passive viewer in order to successfully navigate the environment, and thus drivers may dedicate fewer resources to generally scanning the roadway in an active task. Specific locations within the scene may be important when driving. The focus of expansion (FoE) is the apparent point from which motion vectors flow, and normally corresponds to the direction of heading (Gibson, 1979; Warren, Kay, Zosh, Duchon, & Sahuc, 2001). Some research suggests that the area on or near the FoE is typically favoured by drivers (Mourant & Rockwell, 1972; Underwood, Chapman, Brockelhurtst, Underwood, & Crundall, 2003), because it provides information to the driver about vehicle direction. More recently though, gaze has been found to be directed towards points in space you wish to pass (Robertshaw & Wilkie, 2008; Wilkie, Kountouriotis, Merat, & Wann, 2010; Wong & Huang, 2013) typically around several seconds before the vehicle reaches the gaze point (Land, 2006; Underwood, 2007). For locomotor steering, a number of different sources of information, as described by Kountouriotis et al. (2013), are thought to influence control. These include visual direction (Rushton, Harris, Lloyd, & Wann, 1998), the lane splay angle (Li & Chen, 2010) and the visual appearance of lane markers (Wallis, Chatziastros, & Bültgoff, 2002). What is important here is the idea that these sources of information allow successful control and guidance through the driving environment and are therefore useful only for an active driving task. If we are not actively controlling the vehicle, there is little need to fixate on or near these sources of information, because direction information is less critical when not actively controlling the vehicle through an environment. It is possible that observers can dedicate eye movements to searching the environment more exhaustively for hazards during a non-driving task. Such a hypothesis could explain the difference between conditions for the distribution of fixation locations presented here (Figure 5).

Other cognitive factors could also have influenced the pattern of results here. There is likely to be a cognitive load imbalance across the driving and non-driving tasks. Specifically, the driving task required allocation of attentional resources to drive, including steering, braking and lane positioning. We know that, for driving based tasks, increases in task demands results in a decrease in scanning behaviour (Recarte & Nunes, 2003; Savage et al., 2013). Thus it is likely that the increase in cognitive demand when performing the active driving task here could reduce the range of scanning behaviour.

There is also a possibility that the observed scanning differences in eye movements was simply due to less visual motion in one condition relative to the other. This is unlikely because of our design. For the eye movement analyses, each of the four courses driven and viewed were identical across conditions and contained the same number of turns with no differences in the number of lane changes across conditions. On average the active driving condition was indeed completed slower than the non-driving task, where analyses found a mean difference of 8.3 s (refer to Methods). One could argue that driving slower in the active condition than the driving speed in the video condition could deliver different visual motion across the conditions. However on average, the 8.3 s difference was around 5% of the total drive—a proportion which is likely not large enough to induce large differences in visual motion processing.

We also found individuals tended to fixate closer to the front of the vehicle, and thus less far ahead along the road, in the active driving condition than the non-driving condition. This could be due to different use of information (e.g. to maintain lane position in the driving condition) or it could reflect biases in the non-driving condition. For example, it is well known that static scenes framed in a display monitor typically elicit a bias to fixate the centre of the image, regardless of content (Tatler, 2007; Vincent, Baddeley, Correani, Troscianko, & Leonards, 2009). The same eye movement behaviour is also seen in movie viewing paradigms (Cristino & Baddeley, 2009). If our data for the non-driving condition reflects this bias, it could be argued that the interactivity of the visuomotor task allows the visual system to override this phenomenon and allows visual attention to be allocated towards more task relevant information.

Together, these differences in fixation patterns provide evidence to suggest that less naturalistic settings do not fully capture important subtleties about where gaze is deployed during natural tasks. This could be because non-active tasks do not elicit the same specific goal directed visual behaviour seen during more natural tasks where visuomotor control is incorporated. We propose that the different fixation patterns described here provide support for the claim that studying vision under the most naturalistic conditions delivers a different pattern of visual behaviour than for less naturalistic conditions.

Hazard perception

From the results obtained in this experiment, it is clear that individuals are faster at detecting hazardous situations when taking part in a non-driving hazard perception task than when driving. We found that people are around 1–1.5 seconds slower to respond to the hazards in the driving task than the non-driving task. One could argue that differences in reaction times between conditions are due to a delayed motor response in the active task since the button must be pushed whilst also driving. Our set-up was designed to reduce this possibility, with the response button located where the right thumb would naturally be when holding the wheel. We propose two explanations to explain the increased latency. First we have identified that individuals scan the roadway less in an active driving task and look closer to the vehicle (Figure 5). Drivers may be slower to identify the hazards because of this more impoverished search. The second idea relates to the problem of cognitive load. The multiple procedures in driving are comparable to dual tasking; that is, performing two or more activities concurrently. When dual-tasking, attentional limitations occur where cognitive demand is high and, as a result, task performance is poorer, particularly on a secondary task (e.g. Pashler, 1998; Moors & De Houwer, 2006; Sala, Baddeley, Papagno, & Spinnler, 1995). We may therefore expect to observe longer processing times in the driving task. We found that the time to first fixate the hazards and the time to verify the hazards were both longer when driving (Figure 6), thus providing evidence for both explanations.

In sum, we show here that the need to fixate at locations related to controlling the vehicle may infringe one's ability to see a hazard. In addition, we found that the increased attentional demands seem to influence processing time of the hazards; where an increase in processing demand reduces the ability to respond to the hazard as fast. These reaction time findings again provide support for the idea that video-based methods of investigating driving behaviour are of limited utility, because they do not predict the slower reaction times that we find when participants are engaged in an active driving task.

Implications of our work

We have identified not only performance differences across video and simulated tasks but also possible performance *deficiencies* in oculomotor behaviour and hazard perception while participants undertake the active driving task (i.e. less scanning, slower reaction times). This may have implications for assessment and training methods used in driving and particularly in hazard perception. If the scanning behaviour we see in a video-based non-driving task over-estimates how much an individual would scan the road when driving, then training of scanning behaviour may be more appropriate in a setting that incorporates both the visual and driving demands of the tasks. Encouragingly, such naturalistic approaches have been used to investigate eye movement control and it's relation to improved driving (e.g. Chapman, Underwood, & Roberts, 2002; Pollatsek, Narayanaan, Pradhan, & Fisher, 2006; Rusch et al., 2013).

We have shown that when actively engaged in a driving hazard perception task we are slower to detect hazards than if searching for them as a standalone task. If we assume this is partly due to the increase in cognitive load associated with driving the vehicle, then this may have implications for attention in real life driving. Investigations into the causes of road accidents suggest that inattention related accidents make up a large proportion of cases (Chan, Pradhan, Pollatsek, Knodler, & Fisher, 2010; Underwood, 2007; Underwood et al., 2003). When investigating hazard perception, studies which do not include driving are removing one of the aspects of driving which relates to accident involvement—that of divided attention. Performance on complicated cognitive tasks improves with practice where actions become more automated requiring less conscious intervention (Moors & De Houwer, 2006; Underwood & Everatt, 1996). One may therefore argue that when investigating hazard perception and how it can be trained, training that includes performing the tasks of driving and hazard perception together could be more effective.

Conclusions

Here we sought to compare driving and non-driving conditions while performing a hazard perception task to make an absolute comparison between the two kinds of task. We used videos recorded from the driving environment for the non-driving condition, making the stimuli the same across conditions. We have identified a number of visual and behavioural differences across these two typical driving experimental methods and conclude that the interactivity of simulated driving places more of a demand upon the visual and attentional systems than simply viewing first-person-view driving movies. We have shown therefore, that video based methods do not always provide a valid proxy for active driving and, thus, the generation of models of eye guidance should ideally originate from more naturalistic methods (e.g. Borji, Sihite, & Itti, 2014; Johnson et al., 2014). The differences found also potentially highlight the need to train and assess driving behaviour under more naturally ecologically valid conditions where individuals are engaged in an active driving task.

Disclosure statement

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