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Change blindness in driving scenes

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ABSTRACT

One of the key perceptual errors that contributes to accidents on the road is 'looking but failing to see'. Though this has previously been attributed to failures of attention or time gaps, the recent change blindness literature suggests another alternative. Researchers have proposed that we have a poor memory for the visual world, and as such, participants find it very hard to notice a change between two successive pictures providing the transients that normally catch attention are masked. Such masking can occur naturally due to blinks and saccadic suppression. It is suggested that these effects may contribute to accident liability. An experiment was undertaken to test the application of the change blindness paradigm to the driving domain. It was predicted that experienced drivers may have greater visual persistence for changed targets in a road scene provided they are relevant to a driver's parsing of the road (i.e. if the targets are potential hazards such as pedestrians, rather than changes in background scenery). The experiment required drivers and non-drivers to view a complex driving-related visual scene that was constantly interrupted by a flash once per second. During the flashes one item in the scene was changed. This target was manipulated according to location and semantic relevance. Results showed an interaction between central and peripheral items with semantic relevance. Participants found it hard to detect central items that were inconsequential, relative to other classifications of targets. No effect of experience was noted. The results are discussed in relation to the general theoretical literature and their potential applications to the driving domain.

1. Introduction

Previous research in accident classification has identified perceptual errors as a major cause of accidents (e.g. Cairney & Catchpole, 1990; Nagayama, 1978), yet the reasons why these perceptual errors occur are poorly understood. 'Failing to look' and 'looking but failing to see' (cf. Staughton & Storie, 1977) have been identified as two major perceptual errors. The former can be explained in regard to improper visual search; failing to check the blind spot for example. The latter is harder to understand – how can a driver actively search a visual scene, and fixate a stimulus, yet not process it? One suggestion is that drivers may experience time gaps. These are periods of time, often termed highway hypnosis (Williams, 1963) or driving without attention mode (DWAM, Kerr, 1991), during which the driver's attention is diverted by task-unrelated images and thoughts (TUITs, Chapman, Ismail, & Underwood, 1999). There have even been suggestions that eye movements may still scan the driving scene in an apparently normal fashion, though automatised, procedural patterns may have taken over the guidance of saccades and fixations (e.g. Martens & Fox, 2007; Wertheim, 1991). If this is the case, then a driver suffering

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from a time gap may look as active and aware as a fully attentive driver. In this example a driver could check a blind spot automatically and fixate a passing vehicle, yet still fail to process this information.

Recent research in the theoretical attention literature has however identified a second potential cause of 'looking but failing to see' (cf. O'Regan et al., 2000). The phenomenon has been termed 'change blindness' and is characterised by an inability to notice a change in two pictures presented alternately providing they are separated by a brief flicker (e.g. Rensink, O'Regan & Clark, 1997), eye blinks (O'Regan et al., 2000), mudsplashes (O'Regan et al., 1996), or saccades (Grimes, 1996), or if one is simply attending to something else (inattention blindness, Mack & Rock, 1998). Researchers suggest that these effects demonstrate the paucity or complete lack of visual memory (Dennett, 1991; O'Regan, 1992). Dennett (1991) rejected the commonsense belief that an internal representation of the visual world is contained in our heads, as the brain only holds a small number of details about the visual scene before us. Without the interruptions in the change blindness experiments, such as saccades or flickers, the changes would be easy to detect. This is not however due to memory, but rather due to attention-grabbing transients. When the ability of popout, or a sudden movement, to attract attention, is suppressed via a change blindness paradigm, or redirected according to inattention blindness, participants seem unaware that anything has changed. This occurs even for large changes such as two people swapping heads during a conversation (Grimes, 1996) or an impromptu basketball match being infiltrated by a man in a gorilla suit (Simons & Chabris, 1999).

The findings in the change blindness literature are highly applicable to the driving task. Though "mudsplashes" (blocks of colour or texture that flicker on the screen during the change between two images) may not be directly comparable to the problems facing drivers (despite the constant analogy that compares mudsplashes in such experiments to those found on the windscreens of cars, e.g. O'Regan et al., 2000), the problems of changes occurring during a saccade are very pertinent. Drivers are often reminded of the need for constant visual search, and the danger of leaving the eyes fixated in one place for too long. This advice, coupled with the dynamic nature of the driving scene, tends to encourage more saccades than normally occur when viewing static scenes (Cohen, 1981). The more saccades that are made increase the possibility that a change in road conditions may occur when the driver is not attending. Once the driver returns attention to the location of the change, the suggested lack of visual memory means that the driver may not realize that something has altered in the environment, or at the very least degrade response times to any changing stimulus. In a situation such as driving, where rapid responses can save lives, the adoption of the change blindness paradigm seems particularly fitting.

A number of factors have been previously noted to ameliorate the change blindness effect, three of which are particularly relevant to driving. The first of these factors to be assessed in the current experiment is location of the change. If the change occurs further from the point of fixation, participants should be less likely to notice it (e.g. O'Regan et al., 2000). For the current study location was defined as either central or peripheral along the horizontal axis (due to drivers predisposition to search in the horizontal axis), with the central 50% of the screen and the two 25% portions to the left and right side of the screen defining the categories. This factor was predicted to interact with a second factor of domain experience. As it is known that both eye movements (e.g. Crundall & Underwood, 1998) and extra-foveal attention (e.g. Crundall, Underwood, & Chapman, 1999) are influenced by driving experience, and also that domain experience (in this particular case relating to American football) improves change detection in relevant scenes (Werner & Thies, 2000), it was predicted therefore that driving experience may interact with the location of the target change.

A third variable of interest is the semantic relevance of the target change. In one of the first change blindness experiments, Friedman (1979) presented participants with prototypical visual scenes such as kitchens and farmyards, and found that participants spent more time looking at the unexpected items that ran against the scene schema. When objects were selectively changed she also noted that the non-typical items were the most easily identifiable targets. She concluded that visual memory is stronger for differences between an event and its prototypical representation. It should be noted however that such visual memory experiments often confound measures of foveal duration with salience. Items that are mismatched with the relevant scene schema may attract attention sooner (cf. De Graef, 1998), and capture attention for longer, and this may be the underlying reason for improved visual memory.

In natural situations however, one is unlikely to find a rolling pin in an office. What happens to attention for items within a scene that all fit with the schema, yet some are more semantically relevant than others? Rensink, O'Regan, and Clark (1997) compared changed targets of differing levels of "interest" based upon frequency of occurrence in verbal reports of the scene. They found that changed targets of "high interest" were located sooner than those of lesser note. This result has been criticised by Hollingworth and Henderson (2000) as the semantic informativeness of an object may be confounded with the location of the target. They suggest that centrally located objects may have been reported more frequently because of their position rather than their semantic relation to the context. The current study avoided this criticism by manipulating both the semantic informativeness of the target and the location. To this end, use of static scenes was necessary in order to systematically manipulate location of change, since position of objects within the driver's field of view would not be held constant in dynamic clips. Whilst this creates differences between the driving situation and our lab-induced change blindness, it was critical for the investigation of target relevance to tightly control target location. It was predicted that location would interact with the semantic relevance of the target to the scene. As the semantic targets were all relevant to the parsing of the road scene, it was also predicted that driving experience would interact with semantic informativeness of the change as greater driving experience should lead to greater discrimination between relevant and irrelevant stimuli.

An effect of semantic relevance has been noted in one other driving-related change blindness study. Hoffman, Yang, Bovaird and Embretson (2006) described a change blindness test which they have called DriverScan. Essentially it is a change blindness flicker task aimed at discriminating between older drivers with attention deficits from the general older population. They argued that the effect of semantic relevance suggests that participants "were using goal-directed expectations about scene content to guide their eye movements and attention", (p 998). If this is truly the case then one might also expect semantic relevance to distinguish between drivers on the basis of experience.

To summarise, the following experiment attempts to apply the standard change blindness paradigm, using alternate images containing a change (separated by a brief flicker), to the driving task, while controlling for eccentricity and semantic relevance. Interactions between the three factors of target location, target relevance, and driving experience, were predicted to shed light on visual memory for driving scenes, and provide greater understanding of perceptual errors in driving.

2. Method

2.1. Participants

Fourteen drivers (with mean experience of 70 months) and 15 non-drivers (with a mean age of 20, 12 were female) were recruited from an undergraduate population. All participants had normal or corrected-to-normal vision and were reimbursed for their time.

2.2. Stimuli and apparatus

Forty pairs of stimuli were chosen for the experiment from a larger corpus. These were selected on the basis of pilot data that suggested certain changes were either too easy or too difficult to find on the basis of contrast or the size of the change, rather than due to a manipulation of the factors. The stimuli were pictures of rural and urban crossroads in Nottinghamshire, UK, taken with a digital camera from the vantage point of a driver approaching the junction. Each of the paired road scenes differed in one crucial detail that was either relevant to the road scene (such as the offset of a traffic sign) or irrelevant (such as the onset of windows in a previously blank wall). These features were removed or added (in equal measure) using Adobe Photoshop. Pilot data allowed unrealistic changes to be ejected from the corpus of stimuli. The stimuli were presented for one second each on a colour monitor powered by a P3 PC. The road scenes were separated by a blue screen that appeared for 100 ms. After participants had responded to say they had found the change, they were presented with the original road scene (before the change) divided into four sections either diagonally, or vertically and horizontally. Each section was given a letter A to D and participants had to record where the change had been located. The different divisions of the forced choice screen were used so that none of the changes would bisect one of the lines separating the quadrants.

2.3. Design

A mixed $2 \times 2 \times 2$ design was used. The between-groups variable was experience (drivers and non-drivers) and the two within-group variables were road relevance (was the change relevant to the safe or correct interpretation of the road ahead) and location of the change. For the latter factor the screen was divided into three sections along the horizontal axis. The central 50% of the screen was considered 'near' and the two 25% portions of the screen to the left and right were termed 'far'.

Simple response times were recorded for the participants' time to detect the change by pressing the space bar. Accuracy rates were recorded for the untimed location responses following the space bar response. This was included to check whether participants had really detected the change, or were simply pressing the space bar without detecting the location of the change. If participants had been using this latter strategy, the forced-choice location test would report accuracy rates at, or close to, chance (25%).

2.4. Procedure

Participants were seated approximately 60 cm from the screen and allowed to read through the instructions on screen. A practice block of 6 stimuli pairs was undertaken before the experiment, and then participants were allowed to ask questions before starting. Each trial was preceded by a fixation cross for 1000 ms followed by the first picture of a pair, which in turn was followed by the second picture that contained the critical change. The pictures were presented for 1000 ms each before returning to the start of the cycle (separated by a blue screen for 100 ms). A space bar response terminated this cycle and then displayed the original picture separated into quadrants. Participants would choose the relevant quadrant that they believed the target to have appeared or disappeared and would be provided with feedback (see Fig. 1). The experiment ended after 40 stimuli pairs had been presented which took approximately 15 min to complete.

3. Results

The response times to correctly detect changes were subjected to a $2 \times 2 \times 2$ ANOVA across the factors of location (near versus far), relevance of the change to driving (semantically relevant, or semantically irrelevant), and driving experience (drivers versus non-drivers).

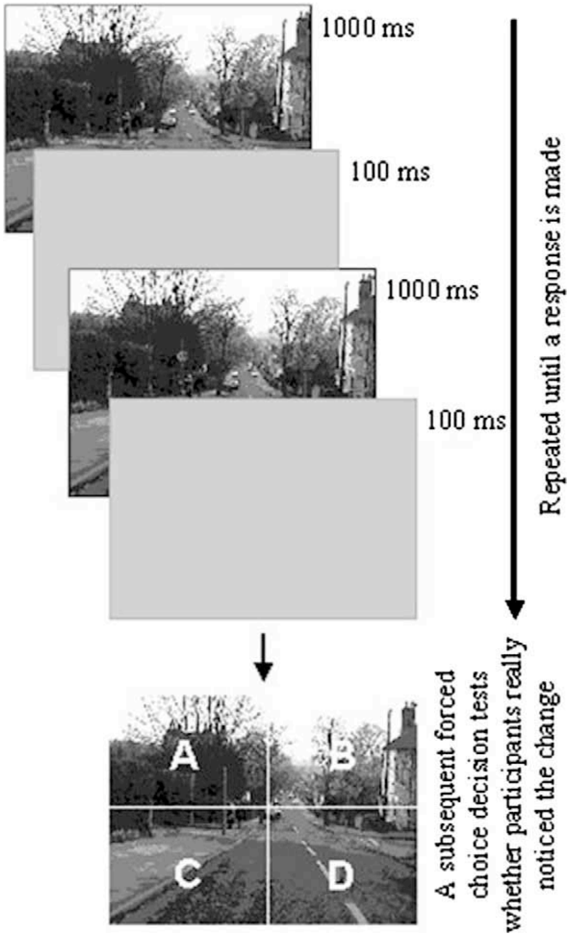

Fig. 1. Sequence of stimuli displayed in the experiment.

Main effects of location and relevance were found ($F_{\text{location}(1,27)} = 63.4$, MS$e$ = 0.4, $p < 0.001$; $F_{\text{relevance}(1,27)} = 159$, MSe = 0.03, $p < 0.001$) with far targets found faster than near targets, and relevant targets found faster than irrelevant targets. An interaction was also noted between location and relevance ($F_{(1,27)} = 37.8$, MSe = 2.3, $p < 0.001$). Though all mean comparisons (post hoc t-tests) were different to each other even allowing for bonferroni corrections ($p < 0.001$), a greater difference was noted between the near-irrelevant and near-relevant conditions, than between the far-irrelevant and far-relevant conditions. This suggests that response times to irrelevant targets were degraded if they were presented in the central 50% of the

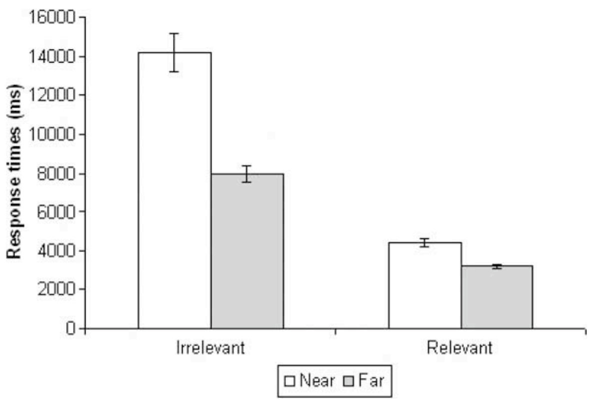

Fig. 2. Response times to change detection in milliseconds, across the factors of target relevance and target location.

screen along the horizontal axis. The interaction can be viewed in Fig. 2. Neither a main effect nor interaction was found for driving experience.

In order to eliminate the possibility of a speed-accuracy trade-off, the percentage accuracy rates were also analysed with a $2 \times 2 \times 2$ ANOVA. The pattern of degradation was identical to that of the RTs, with far changes responded to more accurately than near changes ($F_{(1,27)} = 67.3$, MSe = 0.7, $p < 0.001$), and relevant changes reported more accurately than irrelevant changes ($F_{(1,27)} = 188$, MSe = 1.4, $p < 0.001$). The interaction was also significant ($F_{(1,27)} = 54.5$, MSe = 0.8, $p < 0.001$), with little difference between the accuracy rates to near-relevant and far-relevant changes (98% and 100%, respectively). Far-irrelevant changes were responded to less accurately (87%) though near-irrelevant changes had the worst accuracy rates (59%). Post-hoc *t*-tests revealed all levels to differ from each other ($p < 0.001$) except the near-relevant and far-relevant changes. These results argue against a speed-accuracy trade-off.

4. Discussion

The results clearly demonstrate the applicability of change blindness to driving stimuli. The finding that relevant targets were detected more quickly than irrelevant targets suggests that participants in this experiment were viewing the scenes from the perspective of the driver. In other words, the images were activating a driving-related schema that was guiding attention to relevant scene details. Furthermore, the high-levels of induced change blindness point to the potential of this phenomenon to account for road traffic accidents. Changes that were relevant to the understanding of the road scene, such as the disappearance of road signs, or the appearance of hazards such as pedestrians or other vehicles, took on average over four and a half seconds to detect when presented centrally. This equates to four transitions between stimuli involving a change, whereas evidence in favour of a strong visual memory would predict the change to be noticed after one transition, or at least two transitions allowing for a lag between detection and subsequent response. Detections of far-relevant targets had average response times of 3184 ms, suggesting that the change was responded to, on average, after two transitions. These targets were detected faster than the centrally presented targets, suggesting that change detection was greater at the left and right extremes of the screen at the expense of the central portion. If we accept that attention is required to overcome change blindness (e.g. Simons, 2000) this suggests that visual search of the scene was predominantly directed towards the left and right portions of the screen, with less attention paid to the centre. While the eye movement literature does suggest that drivers have a wider horizontal search than vertical search (cf. Crundall & Underwood, 1998), it is also recognised that the focus of expansion (i.e. the furthest point visible on the current road, which in all current images was in the central region) is the most salient of locations when actually driving (e.g. Underwood, Chapman, Brocklehurst, Underwood, & Crundall, 2003). In other words, while one might expect eye movements to the far locations, we did not expect the results to favour these locations over the central portion of the screen.

There are two potential explanations for this result. First it may be the case that the participants under-sampled the central portion of the picture compared to the typical scan pattern that one might expect when actually driving (Underwood et al., 2003). There is evidence to suggest that the accrual of visual information from static and dynamic images may be fundamentally different (Pollatsek & Rayner, 2001), which might explain why the predicted bias for near changes was reversed. The static nature of the images may have allowed participants' visual search to be biased in a way that would be less likely in a dynamic display. For instance we know that long-term representations of the spatial layout of scenes can guide attention (e.g. if told to search for a toaster in a kitchen scene, one is likely to search along the work surface rather than the floor; e.g. Hollingworth, 2006). As the horizontal search bias noted in both real world and simulated driving (and even when watching videos of driving) has, in part, been put down to the greater preponderance of relevant stimuli located around the horizontal meridian (e.g. Crundall & Underwood, 1998; Konstantopoulos, Chapman, & Crundall, submitted for publication; Crundall, van Loon, and Underwood, 2006), one might predict a horizontal search bias in static images on the basis of learned probabilities for the locations of interesting stimuli. The predisposition for attending to the focus of expansion (i.e. straight ahead, at least on straight roads; Underwood et al., 2003) may however have a different rationale. For instance, it may not reflect the actual processing of stimuli directly ahead, but instead may reflect the optimal position for anticipating any obstruction ahead. This may even be facilitated by low level factors during actual driving, such as the stability that the focus of expansion provides in an otherwise changing landscape of optic flow (e.g. Land, 1998). Thus while the imperative for a horizontal search bias may persist from dynamic to static images, the underlying reasons for paying attention to the focus of expansion may not.

A second explanation for the superior performance of participants on the far targets may relate to the nature of the processing that people typically engage in at the centre of a driving scene. The increased salience that is normally attributed to the focus of expansion should reduce the ability of viewers to ignore the semantically relevant stimuli and attend to irrelevant objects. Conversely, when drivers attend to the left and right of the roadway, they often look at many things that may be irrelevant to the driving task, and engage in processing of these stimuli to eliminate them from their priority hierarchy for subsequent fixations. For instance, drivers may often fixate bus shelter advertisements when searching for hazards, but these are irrelevant fixations that are quickly discounted and have no bearing on subsequent memory (Crundall et al., 2006). If it is indeed the case that drivers have an increased likelihood of fixating irrelevant stimuli following large saccades to the extremes of the visual scene, this would explain why the difference between relevant and irrelevant changes is greatest for targets in the central portion of the screen.

It is likely that both of these explanations may play a role, though future research involving eye movement recording may help distinguish between these two post hoc theories.

The predicted interactions with experience (cf. Werner & Thies, 2000) did not occur. This may be due to an enforced homogeneity of eye movements due to the artificial task, or simply due to the lack of a large enough experience gap between drivers and non-drivers. While further research comparing drivers of varying experience on change blindness tasks, including eye movement recording, should be undertaken before this is regarded as a task that does not improve with experience, it still poses a potential problem for tests such as DriverScan that claim to reflect visual driving abilities (Hoffman et al., 2006). There is at least one study however that has demonstrated a clear experiential difference using a slightly modified change blindness methodology. Crundall (in press) has demonstrated experiential differences between drivers with varying levels of experience, though in that study the participants always knew what the change was, and where it was going to occur: the change was a decrease in headway to the car ahead, reflected in an increase in size of that vehicle. Participants however did not know when the change was going to occur. Furthermore they had to share attention between the lead car and a secondary vigilance task. While Crundall (in press) may have found a test that discriminates between drivers on the basis of experience, it appears that the ambiguity of the nature and location of the change in the current study may render any benefits of experience impotent.

It is worth at this point noting some of the potential differences between our paradigm and a real driving situation. Our use of the flicker paradigm produced high levels of change blindness and long detection latencies. This begs the question, why do we not witness more traffic accidents due to change blindness when drivers do not have the luxury of time? First, change blindness on the road will most likely be induced by a blink or saccadic suppression that occurs at the exact moment a change occurs. This is of course much less likely than our experimentally induced change blindness. Furthermore, objects continue to move across the field of view in real-life situations, giving the driver continued opportunity to notice change. We would argue that accidents occur during the relatively unusual instances when conditions for blindness continue to be met, or in a situation when time limitations only require a single instance of blindness. To assess the parameters of such change blindness on the road, further experimentation could combine gaze-dependant eye-tracking with driving simulation to induce change at the exact moment of a blink. A further useful avenue of enquiry would involve expanding the field of view with a projector to investigate change blindness at more peripheral locations[2].

In conclusion, viewers can suffer from an inability to spot sudden changes such as the appearance of a vehicle in a central position. Though this finding requires validation and comparison with more realistic, dynamic circumstances, it offers a potential mechanism for the phenomenon of 'looking without seeing'. This could relate directly to specific road accidents, such as rear end shunts. This methodology may also provide important insights into the nature of processing of stimuli according to semantic relevance and eccentricity from the focus of expansion.

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