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Decisions about objects in real-world scenes are influenced by visual saliency before and during their inspection

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ABSTRACT

Evidence from eye-tracking experiments has provided mixed support for saliency map models of inspection, with the task set for the viewer accounting for some of the discrepancies between predictions and observations. In the present experiment viewers inspected pictures of road scenes with the task being to decide whether or not they would enter a highway from a junction. Road safety observations have concluded that highly visible road users are less likely to be involved in crashes, suggesting that saliency is important in real-world tasks. The saliency of a critical vehicle was varied in the present task, as was the type of vehicle and the preferred vehicle of the viewer. Decisions were influenced by saliency, with more risky decisions when low saliency motorcycles were present. Given that the vehicles were invariably inspected, this may relate to the high incidence of "looked-but-failed-to-see" crashes involving motorcycles and to prevalence effects in visual search. Eye-tracking measures indicated effects of saliency on the fixation preceding inspection of the critical vehicle (as well as effects on inspection of the vehicle itself), suggesting that high saliency can attract an early fixation. These results have implications for recommendations about the conspicuity of vulnerable road users.

1. Introduction

When inspecting a photograph of a natural scene we rapidly acquire the gist or general understanding of what the scene represents but how our eyes are guided around the scene is a matter of some dispute. The attraction of eye fixations by salient regions (Itti & Koch, 2000), a tendency to make short rather than long saccadic movements (Bahill, Adler, & Stark, 1975), and a tendency to fixate the centre of the image (Tatler, Baddeley, & Gilchrist, 2005), contribute to the view that eye guidance is dominated by low-level visual processes, at least early in the sequence of inspection. Other studies have demonstrated that the locations of fixations can be determined by the purpose of inspection (Yarbus, 1967) and that the attractiveness of high contrast, highly colourful regions with well-defined edges can be over-ridden by task demands (Einhäuser, Rutishauser, & Koch, 2008; Foulsham & Underwood, 2007, 2008; Henderson et al., 2007; Underwood et al., 2006). Whereas the potency of salient objects is disputed with evidence from laboratory studies of scene perception, there is a long-standing acceptance of the view that conspicuous objects are perceived more readily, with evidence coming from real-world studies of road accidents and roadway decisions (Olson, Halstead-Nussloch, & Sivak, 1981; Thomson, 1980).[2] Accident investigators have campaigned successfully for measures to increase the vehicle conspicuity, and have reported that crash rates decline when, for example, vehicles make themselves more visible by using headlights at all times (e.g. Elvik, 1993; Yuan, 2000; Zador, 1985). If high saliency only operated in three-dimensional environments in which objects are moving (the "real world"), but not when viewers inspected photographs in laboratories, then this in itself would be an important qualification of our laboratory results, but the suggestion that saliency has a limited role to play in attracting attention also has implications for the design of safe environments. Although there are numerous studies of visual attention by eye-tracking in natural environments the study of effects of saliency have yet to be determined. The present experiment explores the potency of salient objects in attracting attention using photographs of roadway scenes shown to viewers who are making decisions about how they would behave in each situation.

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[2] The terms *saliency* and *conspicuity* are used as equivalents here, but in the Itti and Koch (2000) model saliency is the aggregate of all operative conspicuity channels. So, the analysis of intensity conspicuity, colour conspicuity, motion conspicuity, etc., all contribute to the overall saliency map. Research on high visibility in applied setting such as road accident liability has tended to use the single term *conspicuity* to refer to any feature that increases the visibility of a road user, including changes to clothing and the vehicle itself, and temporary changes such as the use of daytime running-lights.

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The Itti and Koch (2000) saliency map hypothesis makes the prediction that the first saccade during inspection of a picture should result in fixation of the most salient region, where saliency is defined by changes in intensity, colour and orientation relative to surrounding regions. The hypothesis has been supported by eye fixation data from studies in which viewers freely inspected photographs of natural scenes as well as artificial images such as fractals (Einhäuser & König, 2003; Parkhurst, Law, & Niebur, 2002; Peters et al., 2005). When the task presented to the viewer is varied then the model receives mixed support. A task requiring encoding of an image, in preparation for a recognition memory test, gives support in that early fixations are made to salient regions. But when the same pictures are used with a task requiring a search for a target, fixations are not made on the most salient regions (Einhäuser, Rutishauser, & Koch, 2008; Foulsham & Underwood, 2007; Underwood & Foulsham, 2006; Underwood et al., 2006). Searching for differences between two pictures (comparative visual search or change detection) also fails to show effects of the saliency of the target object (Stirk & Underwood, 2007; Underwood et al., 2008). The failure to use the saliency map when searching for an object makes sense if we consider the role of saliency when searching for an object on a cluttered desktop. The desk might contain any number of bright and well-defined objects, but if looking for a bunch of keys, or a pencil, it would not matter how bright the coffee mug or textbook cover because those objects do not possess the critical features of the target object. Our early studies suggested that during inspection-for-encoding visual saliency was potent but that during search tasks it was not, but both of these conclusions can be challenged.

When domain experts look at pictures of scenes from within their areas of interest then the saliency of regions has little influence on their fixation patterns – engineering students looking at engineering plant do not look at the bright, colourful components, but when history students look at the same pictures they do tend to behave in accordance with the saliency map hypothesis predictions (Humphrey & Underwood, 2009; Underwood, Foulsham, & Humphrey, 2009). Conversely, the same engineering students inspecting scenes displaying historical artefacts tended to fixate the most salient regions, whereas the history students looked instead at objects of particular historical interest. The question remains of why salient regions attract attention for some individuals but not others, and one hypothesis here is that viewers look for something in the scene that will enable them to distinguish that scene from others in the later recognition test. Domain experts may rely more on the content of the meaningful scene whereas viewers who are unfamiliar with the domain may tend to rely more on low-level visual features. Search tasks tend not to show effects of saliency, but even in a simple target search task with arrays of isolated objects the saliency of distractors can influence detection of the target (Foulsham & Underwood, 2009). Depending on the task set for the viewer, fixations might be guided to salient regions early in the inspection sequence, or fixations might be determined more by top-down cognitive factors. If riders are more sensitive than drivers to motorcycles appearing in the roadway, by virtue of their increased experience with, and interest in motorcycles, then they might be less influenced than drivers by changes in saliency.

To determine whether a purposeful search of a roadway scene is influenced by the visual saliency of vehicles we presented car drivers and motorcycle riders with photographs taken from the side window of a car waiting to enter a major road at a T-junction. The task was to judge whether it would be safe to join the major road. This scenario is a major source of danger for motorcycles in particular (Clarke et al., 2007), with the cause of crashes at T-junctions attributed mainly to right-of-way-violations on the part of other vehicles. These "look-but-fail-to-see" crashes may be associated with inattentional blindness (see Owsley & McGwin, 2010, for other examples of this lapse during driving), or to target prevalence (see Wolfe, Horowitz, & Kenner, 2005), in that the direction of gaze is disconnected from attention, possibly due to the relatively low expectation of encountering motorcycles. The scenario used in the study is therefore of especial concern to investigators of motorcycle crashes as it requires a search of roadway to determine whether a vehicle is approaching. Search tasks tend to offer little or no support for models of saliency, with only small influences on the attraction of attention, and so we might expect that visual saliency would have minimal effects during a search of roadway for other vehicles. Searching for target objects can eliminate the potency of salient regions in scene inspection (Einhäuser, Rutishauser, & Koch, 2008; Underwood & Foulsham, 2006; Underwood et al., 2006), and if roadway inspection can be regarded as a search task then we can predict minimal effects of saliency. The evidence from the analysis of road crashes suggests that conspicuous vehicles are less crash-involved than other vehicles, however, with the use of daytime running-lights providing the clearest evidence of a benefit (Elvik, 1993; Yuan, 2000; Zador, 1985).

The current experiment asked whether high vehicle saliency would influence judgements in this search task, and also introduced domain interest as a factor by testing car drivers and motorcycle riders, who might be expected to have differing knowledge and possibly differing sensitivity to the presence of motorcycles. In a large-scale statistical analysis of an existing database of 742 crashes, using a classification and regression tree (CART) procedure, Magazzù, Comelli, and Marinoni (2006) reported that car drivers holding a motorcycle licence tended to be less responsible for car–motorcycle crashes than drivers not holding a motorcycle licence. One explanation of this effect is that riding experience gives road users some understanding of motorcycle manoeuvres, and a second is that direct experience provides greater sensitivity to the presence of motorcycles in the roadway. Hosking, Liu, and Bayly (2010) have reported that riding experience is associated with more successful detection of hazards and greater scanning in simulated situations, again suggesting that motorcycle experience provides the basis for perceptual change. On the basis of our studies with domain experts we predict that riders would be less influenced than drivers when the vehicle in the scene has high visual saliency – that riders would be more sensitive to the appearance of a motorcycle regardless of its visual saliency. To separate any effects of visual saliency in attracting attention from effects in maintaining attention, we recorded the viewers' eye fixations while they made their judgements. If salient vehicles can attract eye movements they would be associated with an effect on the preceding fixation, whereas if effects of saliency become apparent only after attention has been allocated then there would be only an increase in the time spent looking directly at the vehicle.

2. Method

2.1. Participants

The volunteers were 50 car drivers and 27 motorcycle riders, each with a minimum of 2 years experience since obtaining their licence (means of 13.3 years and 14.3 years, respectively). None of the car drivers had a motorcycle licence whereas 22 of the riders also had a car licence. Cars were driven for an average of 6.65 h/week by the drivers, and motorcycles ridden for an average of 7.75 h/week by the riders. All participants had normal or corrected-to-normal vision, and were paid an inconvenience allowance.

2.2. Materials and apparatus

A set of 120 high-resolution digital photographs were prepared as stimuli, taken using a 9MP digital camera and edited using

Adobe Photoshop. The photographs were taken from a driver's perspective through a side window in a car that had pulled up to a T-junction. These photographs were used in a task in which a judgement was required about whether it would be safe to move into the main roadway, joining either to the left or to the right. All roads were dual carriageways ("urban motorways"), so both lanes of traffic were always travelling in the same direction. To prevent the participants from anticipating the location of the traffic and then moving their eyes before each picture appeared, the traffic would sometimes be coming from the left, and sometimes from the right (see Figs. 1a and 1b).

Of these T-junction pictures, 10 had motorcycles approaching at mid-distance and 10 had cars approaching at mid-distance. A further 50 pictures had relatively little traffic and were designed to elicit positive "safe-to-pull-out" responses, and 50 more had near or heavy traffic that was expected to encourage cautious responding. Only the pictures showing vehicles in the mid distance were of interest to the analysis, as these were expected to result in the most difficult decision making, with some road users declaring the roadway safe-to-enter and others regarding these distances as unsafe. When a car or motorcycle was present in the nearest lane, it was either at a near, middle or far distance. The near distance was so near that it was clearly unsafe to pull out from the T-junction, and the far distance was safe to pull out – the pictures with far and near vehicles were also fillers. The middle distance was the distance where people were expected to be most hesitant about pulling out – approximately 65 m away from the T-junction – and so decisions about these scenes were of most interest.

The vehicles in the critical T-junction photographs were either of a high or low saliency (see Figs. 2a and 2b). The saliency was measured by running the picture through a Matlab algorithm based on the Itti and Koch (2000) analysis of saliency. High saliency vehicles were in the 70th percentile, meaning that 70% of the regions in that picture were of a lower saliency than the pixels in the area of interest containing the vehicle. Low saliency vehicles were in the 30th percentile, meaning that only 30% or less of the regions in the picture were of a lower saliency than those in the area of the vehicle.

An SR EyeLink II eye tracker was used to record eye movements during the experiment, sampling at 500 Hz. Pictures were displayed on a 48 cm computer monitor placed 60 cm from the participants, and they subtended visual angles of 34° horizontally and 27° vertically. Fixations and saccades were determined using a displacement threshold of 0.1°, a velocity threshold of 30°/s, and an acceleration threshold of 8000°/s^2. A nine-point calibration procedure ensured that recordings had a mean spatial error of less than 0.5°.

Fig. 1a. T-Junction picture from the passenger's side window with traffic approaching from the left. The task required the participants to judge whether it would be safe to pull out from a side road into the nearest lane, which is occupied in this photograph by a motorcycle followed by two cars.

Fig. 1b. T-Junction picture from the driver's side window with traffic approaching from the right.

Fig. 2a. T-junction photograph with a high saliency vehicle in the nearside lane.

Fig. 2b. T-junction photograph with a low saliency vehicle in the nearside lane.

2.3. Procedure

Participants were shown on-screen instructions and were also talked through the procedure and given some practice photographs to familiarise them with the displays and with the button press response. Participants were shown the T-junction pictures one at a time. They had to decide whether they thought it was safe or unsafe to pull into the nearest lane. Traffic could be approaching from the left or the right, but either way the task was always to pull into the nearest lane, in the direction the traffic was flowing. Participants were told that all roads had 40 mph speed restrictions and that all the traffic was travelling at the same speed. Each picture appeared for as long as the participants needed to make a button press response. They pressed 'safe' if they thought they would pull into the road out and 'unsafe' if they thought they would not pull out. Participants were told that there were no correct or incorrect responses, and that it was their opinion that should guide their response. After each picture, a 'drift-correct' fixation spot appeared in order to the eye tracker to recalibrate, in case the participant's head moved during the trial.

3. Results

3.1. Behavioural measures – deciding about safety

Participants decided whether or not it would be safe to join the main roadway, in pictures showing a T-junction, and their decisions and response times were recorded. In all of the following analyses we consider only responses to pictures in which a vehicle was shown – the filler trials were discarded. The behavioural measures are shown in Figs. 3a and 3b. The vehicle in these pictures was shown in the mid-distance and elicited an overall mean of 50.5% "safe-to-pull-out" responses, in contrast with 1.7% for near-distance vehicles and 86.9% for far-distance vehicles.

3.1.1. Differences in safe/unsafe responses

The decisions made by participants were inspected with a single ANOVA (see Fig. 3a), and the three factors were road user (driver/rider), approaching vehicle (car/motorcycle), and visual saliency of the approaching vehicle (high/low saliency). Of the three main effects in the analysis, only vehicle type was reliable, with more "safe-to-pull-out" decisions when the nearest vehicle was a motorcycle than a car ($F(1, 75) = 11.39$, $p < .01$). A motorcycle in the roadway was seen as "safe" on 57.5% of occasions, whereas cars were seen as "safe" on 47.0% of the time. A two-way interaction between road users and vehicle type ($F(1, 75) = 5.00$, $p < .05$), inspected with an analysis of simple main effects, indicated that drivers responded "safe" more when a motorcycle (mean of 63.8% "safe" responses) was shown than when a car (49.2%) was shown ($F(1, 150) = 22.45$, $p < .001$), and that riders responded similarly to both types of vehicle (means of 45.9% and 43.0% for motorcycles and cars respectively). A second two-way interaction, between vehicle and saliency ($F(1, 75) = 25.90$, $p < .001$), indicated that decisions about high saliency vehicles were similar, but that low saliency motorcycles elicited more "safe" decisions than did low saliency cars ($F(1, 150) = 41.11$, $p < .001$). High saliency cars elicited 50.6% "safe" responses and motorcycles 51.2%, whereas for low saliency vehicles the means were 43.4% and 63.9% respectively. The motorcycles in the pictures subtended smaller angles than the cars, and while this may account for main effect in responding "safe-to-pull-out", what is more interesting here is the interaction with road users, with car drivers being more prepared to pull out when a motorcycle was present.

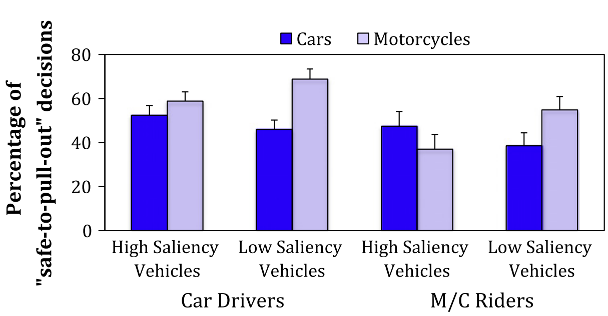

Fig. 3a. Decisions about whether it would be safe to enter the junction occupied by a car or a motorcycle.

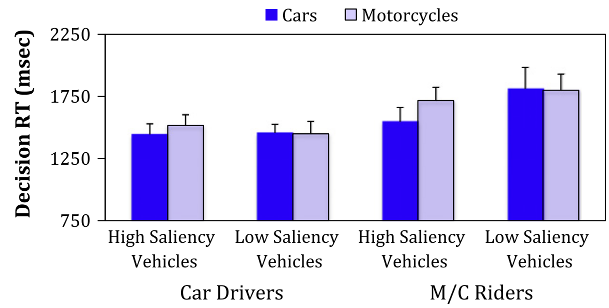

Fig. 3b. Time taken to decide whether it would be safe to enter the junction occupied by a car or a motorcycle.

3.1.2. Decision times

The times to make the decisions about the scenes were also analyzed with a three-factor ANOVA (see Fig. 3b). Only the two-way interaction involving road users and visual saliency was reliable ($F(1, 75) = 6.91$, $p < .01$). Simple main effects indicated that whereas motorcycle riders responded faster to high saliency than to low saliency vehicles ($F(1, 75) = 7.98$, $p < .01$), there was no difference in the response times of car drivers. Riders responded with a mean of 1.63 s to high saliency vehicles and 1.81 s to low saliency vehicles, whereas drivers responded with means of 1.48 s and 1.45 s respectively. Although not statistically reliable, there are two marginal effects that are perhaps worth noting. First, drivers made faster responses than riders ($F(1, 75) = 3.63$, $p = .061$), and second, low saliency vehicles elicited slower responses than high saliency vehicles ($F(1, 75) = 3.71$, $p = .058$).

3.2. Eye movement measures of picture inspection

Eye movement data were analyzed to establish the attention given to the critical vehicle itself, looking at the number of fixations on the vehicle, and the mean duration of those fixations on the vehicle. Secondly, to examine the hypothesis that highly salient objects can attract attention it is necessary to demonstrate an effect of saliency prior to inspection of the salient object, and so we also analyzed the duration of the fixation immediately prior to inspection of the vehicle. This is the $N-1$ fixation and effects of the saliency of an as-yet-uninspected vehicle upon this fixation duration would be taken as evidence of parafoveal-on-foveal processing (Kennedy, 2000). The $N-1$ fixation is used as a measure of any effects of processing prior to fixation, rather than all previous fixations, because there were a variable number of fixations prior to the vehicle, and because there were very few prior fixations. There was one prior fixation however, and this is the fixation that would be expected to show the greatest effect of any early processing of information in parafoveal vision.

To ensure comparability between analyses of different sized vehicles the area of interest for determination of fixation location was held constant for all scenes and was a rectangle 5° wide by 4.7° high centred upon the vehicle shown. The analyses examined the attention given to different vehicles by the two groups of road users. Data from one motorcyclist were lost from these analyses, due to poor eye-tracking calibration. The eye-tracking measures are shown in Figs. 4a–4d.

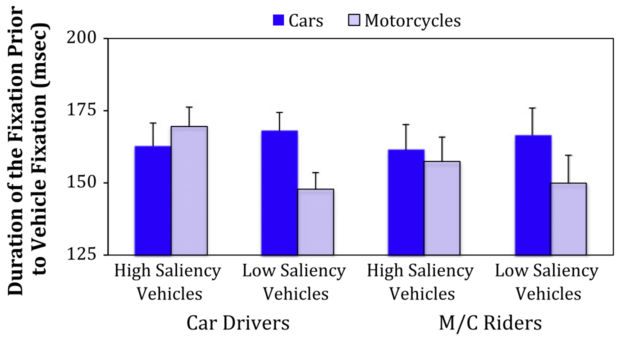

Fig. 4a. The duration of the last fixation prior to fixation of the vehicle.

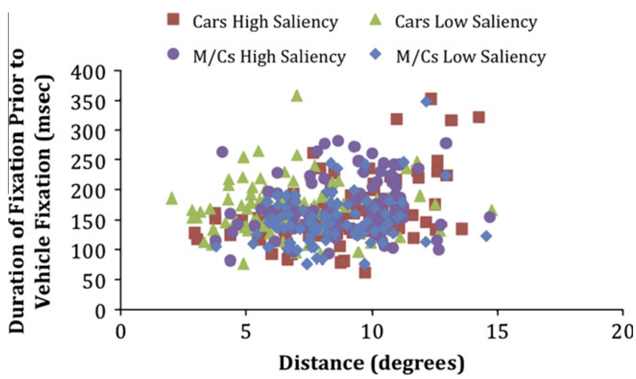

Fig. 4b. A scatterplot showing the duration of the last fixation prior to fixation of the vehicle against the distance of that fixation from high and low saliency cars and motorcycles.

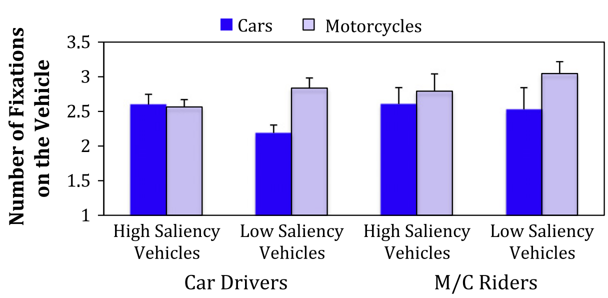

Fig. 4c. Number of fixations on the vehicle prior to indicating the "safe/unsafe" decision.

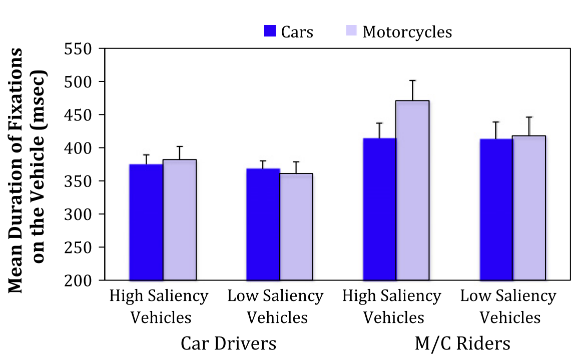

Fig. 4d. Mean fixation duration on the vehicle.

3.2.1. The duration of the $N-1$ fixation

The duration of the fixation immediately prior to the initial inspection of the vehicle (see Fig. 4a), or the $N-1$ fixation duration, provides a measure of the sensitivity to regions of the scene that are to be fixated next. If there are any parafoveal-on-foveal effects of vehicle features prior to inspection of the vehicle, then they will be seen in variations in the durations of the preceding fixations. The $N-1$ fixation durations were inspected with an ANOVA that showed no main effect of either road user, vehicle type or saliency. However, vehicle saliency interacted with vehicle-type ($F(1, 74) = 4.11$, $p < .05$), with an analysis of simple main effects indicating shorter prior fixations when the vehicle was a motorcycle than a car (means of 149 ms and 167 ms respectively), but only in the low saliency conditions ($F(1, 148) = 8.71$, $p < .01$). The means for the high saliency conditions were 165 ms (motorcycles) and 162 ms (cars).

It is possible that this effect of short $N-1$ fixations prior to inspection of a low saliency motorcycle is confounded by the distance of the fixation from the vehicle. Perhaps the effect would be present only if the fixation is proximal to the vehicle, but distant enough to be regarded as a separate fixation, and that fixations at greater distance show no effects of the characteristics of the un-fixated vehicle. To inspect this possibility we first conducted a correlation analysis to determine whether there was a relationship between fixation duration and distance between the fixation and the vehicle. The duration of the prior fixation was indeed found to be related to the distance of the preceding fixation from the vehicle ($r = .22$, $p < .001$), and this relationship is shown in Fig. 4b, with longer durations of fixations located further from the vehicle. The factorial analysis was then repeated in a mixed model ANCOVA with the covariate being distance of the fixation from the vehicle. This analysis confirmed the effect of the distance of the $N-1$ fixation from the vehicle ($F(1, 350) = 12.63$, p < .001), and also showed a reliable effect of vehicle ($F(1, 268) = 3.92$, p < .05) with shorter fixations prior to inspection of a motorcycle, as well as the interaction of vehicle saliency and vehicle-type found in the ANOVA ($F(1, 267) = 14.38$, $p < .001$) with shorter fixations prior to inspection of a motorcycle in the low saliency condition only. The effect of vehicle saliency is therefore robust when the distance of the fixation is taken into account.

3.2.2. The numbers of fixations on the vehicle

Viewers characteristically made several fixations on the critical vehicle (see Fig. 4c), and the numbers of fixations made were inspected with an ANOVA that indicated a main effect of the vehicle ($F(1, 74) = 12.59$, $p < .001$), with more fixations on motorcycles (mean of 2.78 fixations) than cars (mean of 2.46 fixations). Vehicle saliency interacted with vehicle-type ($F(1, 74) = 11.22$, $p < .01$), with simple main effects indicating more fixations on motorcycles only in the low saliency conditions ($F(1, 148) = 28.20$, $p < .001$). For the high saliency vehicles, cars received 2.60 fixations and motorcycles 2.64 fixations, and in the low saliency conditions cars and motorcycles received 2.31 and 2.91 fixations respectively.

3.2.3. The durations of fixations on the vehicle

The mean duration of fixations on the vehicle (see Fig. 4d) were inspected with a three-factor ANOVA that indicated main effects of road user ($F(1, 74) = 5.88$, $p < .05$) – riders had longer fixations than drivers – riders' fixations had a mean of 429 ms and drivers' fixations were 371 ms. There was also a main effect of saliency ($F(1, 74) = 4.13$, $p < .05$) with shorter fixations on low saliency (mean of 382 ms) rather than high saliency vehicles (mean of 400 ms). There were no interactions.

4. Discussion

The experiment was designed to determine whether visual saliency can influence a decision about whether it would be safe to enter a roadway at a junction when a vehicle was present. Conspicuous vehicles – especially motorcycles and other vulnerable vehicles – have been found to have reduced crash liability, but data from laboratory investigations of scene inspections provides mixed support for the notion that high saliency can attract attention. When drivers and riders made decisions about the safety of roadway scenes the measures indicated effects with both behavioural and eye fixation analyses, and these will be first summarised here, starting with the effects of visual saliency as this was the main interest of the experiment.

Saliency had several effects: all road users were more likely to regard the scene as "safe" when the vehicle had low saliency, and riders were slower at making decisions about low saliency vehicles. Saliency had an effect on decisions made about scenes showing a motorcycle. A "safe-to-pull-out" decision was made equally often for high saliency cars and motorcycles, but the presence of a low saliency motorcycle was associated with more "safe-to-pull-out" decisions than was the case with a low saliency car. Whereas the larger size of a car enables its detection, perhaps, a motorcycle can only be detected easily when it is highly salient by virtue of its colour or brightness relative to its background. Inspection of the vehicle also showed an effect of visual saliency, with more fixations on low saliency motorcycles, and shorter fixation durations prior to and during fixation of low saliency vehicles. Once a low saliency vehicle has been detected it tends to attract more fixations that themselves are of short duration – a pattern of rapid and detailed inspection. The effect of vehicle saliency on the fixation prior to this inspection is of particular interest and we will return to this after consideration of the other main effects.

There were few differences between drivers and riders, and the most striking of these was the tendency of drivers (but not riders) to declare as "safe" those roadways in which a motorcycle was visible. Riders also gave faster decisions about high rather than low saliency vehicles, whereas drivers (who tended to respond slightly faster than riders) did not distinguish between high and low saliency vehicles. More caution by riders compared to drivers in terms of "safe" responses and response time has been reported before by Crundall et al. (in press). Riders also showed longer fixation durations on the vehicle than drivers, perhaps suggesting greater depth of processing. Longer gaze durations for riders than for drivers have been reported in other recent studies on eye movement behaviour in manoeuvering decisions (Crundall et al., in press; Shahar et al., in press), and may suggest that drivers are more susceptible to "look-but-fail-to-see" errors (LBFTS), where an oncoming vehicle is fixated but not processed as a hazard (e.g. Brown, 2002). The phenomenon may be a form of inattentional blindness (see Owsley & McGwin, 2010) in that the direction of gaze does not command the direction of the viewer's attention. This may be because some vehicles are less expected than others. The high incidence of LBFTS errors may be comparable to the failure to detect targets in other applied domains, such as airport security and medical screening, in that the incidence of positive targets is again low relative to the numbers of non-targets and, of course, in the serious consequences of a missed target whether it is a weapon, a tumour, or a vulnerable road user. The relatively low frequency of motorcycles on roadways may result in reduced expectancy and in different detection criterion, in a way related to the difficulty that an airport security agent will have with the infrequent appearance of a weapon concealed in luggage. This has been described as the target prevalence effect by Wolfe et al. (2005). Training can overcome the problem to some extent, and in applying signal detection theory to the problem Wolfe et al. (2007) attribute the prevalence error to a criterion shift rather than a change in sensitivity, and brief retraining with high prevalence sequences of targets and non-targets can enable observers to adjust their criterion settings adaptively. The present results suggest that sensitivity also plays a role in the roadway version of the prevalence effect, in that highly conspicuous motorcycle targets are more likely to be detected than their low saliency equivalents, if we can take the number and speed of "safe-to-pull-out" decisions as an index of detectability.

Previous research on expertise has shown that the degree of domain knowledge a viewer possesses affects the way they process a visual scene, and so the experiment compared car drivers to other road users with a domain-interest in motorcycles. Humphrey and Underwood (2009) found that when inspecting a domain-relevant scene (e.g. engineers viewing an engineering scene), specialists looked at semantically interesting specialist (domain specific) features, rather than higher saliency non-specialist features. More importantly to the interpretation of the current findings, expertise also affected participants' memories for the scenes, with an increased accuracy in recognition of domain-specific scenes, suggesting that domain knowledge affected processing of the scene. It is possible that the expertise and familiarity riders had with motorcycles affected the way they processed the scene. When riders fixated a motorcycle (especially a high saliency one), it was semantically meaningful to them, and thus they processed it as a hazard, decreasing the likelihood of a "safe-to-pull-out" response. However, when drivers fixated a motorcycle, they failed to process it as a hazard, due to their lack of expertise, and thus were more likely to declare a "safe" response, when it was not necessarily safe to pull out (an LBFTS error). Riders tended to be more cautious in responding to cars and to motorcycles, confirming the suggestion that their broader experience has resulted in a change to their roadway understanding. Saliency does seem to play a role in these LBFTS errors, albeit an interactive one. When a vehicle was clearly visible (high saliency), riders were quicker to respond (giving a more cautious "unsafe" decision), whereas with low saliency vehicles, riders took longer to make a decision. It could be that the knowledge that riders have concerning the dangers of motorcycle riding makes them generally more cautious road users and thus they required longer to process the ambiguous (low saliency) hazards. Car drivers, on the other hand, have less extensive roadway experience by virtue of being car-only users, and may be less aware of possible road hazards (see also Hosking, Liu, & Bayly, 2010). This difference in roadway understanding may have prompted more decisions to pull out, regardless of vehicle saliency.

Decisions declaring the situation as being "safe to pull out" were more frequent when a motorcycle was the vehicle in the roadway, although this trend was moderated when it was a high saliency motorcycle. There was no difference in judgements when high saliency vehicles were shown, but low saliency motorcycles enabled more decisions to enter the junction. There were also more eye fixations on motorcycles than on cars, immediately prior to a decision. These results confirm the efforts of accident investigators and safety campaigners in advocating the use of daytime running-lights and high-visibility clothing for motorcycle riders, in that decisions about whether it is safe to enter a roadway are more likely to be cautious when a motorcycle that is present is visually salient (e.g. Elvik, 1993; Olson, Halstead-Nussloch, & Sivak, 1981; Thomson, 1980; Yuan, 2000; Zador, 1985).

The study set out to determine the effects of visual saliency on decisions about roadway manoeuvres. Does it make a difference to the decision about pulling out of a junction, if a vehicle in the roadway is more conspicuous? Whereas it might seem obvious that a high saliency vehicle is more likely to be seen, a dispute in the scene perception literature casts doubt on the efficacy of saliency to attract attention. Data from visual search tasks generally fail to demonstrate effects of salient objects (e.g. Einhäuser, Rutishauser, & Koch, 2008; Foulsham & Underwood, 2007, 2008; Underwood & Foulsham, 2006; Underwood et al., 2006), whereas tasks encouraging free inspection, or inspection in preparation for a recognition memory task do reveal a tendency to fixate salient regions (e.g. Einhäuser & König, 2003; Foulsham & Underwood, 2007, 2008; Parkhurst, Law, & Niebur, 2002; Peters et al., 2005; Underwood & Foulsham, 2006; Underwood et al., 2006). Given that the inspection task in the present experiment shows effects of salient objects in attracting attention, the division between search and other tasks perhaps informs us about the processes involved when motorists make decisions about the safety of a roadway scene. If we can use the appearance or non-appearance of effects of saliency as an indicator of what cognitive processes the viewer is employing, then looking at the roadway for other road users is not a simple search task. The decision involved is more than one of whether or not a pre-specified object is present, and the evaluation of the situation is aided by the conspicuity of the objects present.

Secondary questions involved differences between car drivers and motorcycle riders making the decisions, and differences between decisions when a car or a motorcycle was present. The results with simple measures of judgements were clear: when a vehicle in the scene was more conspicuous, by virtue of being more colourful or brighter than its background, it elicited more cautious decisions (more "unsafe" responses indicating that the driver/rider would not pull out into that roadway scene) that were also made more quickly than when the vehicle had low saliency.

Eye movement analyses also indicated effects of visual saliency, and as well as having implications for vehicle conspicuity, these also inform the debate about when the influence of saliency operates. When saliency effects are observed prior to fixation of the vehicle, then we can conclude that an analysis of features that contribute to the vehicle's saliency is started (if not completed) prior to inspection. We addressed this question by analyzing the duration of the fixation immediately prior to the initial inspection of the vehicle – the $N-1$ fixation. This analysis examined differences in the ability of different vehicles in attracting attention. Differences here are attributable to the recognition of vehicle features before the vehicle itself had been fixated. Variations in fixation duration prior to fixation of the vehicle, but associated with some aspect of that vehicle, must be attributed to pre-fixation processing – to what elsewhere has been termed a parafoveal-on-foveal effect that suggests a role for the parallel allocation of attention in eye guidance during scene inspection. A related account has been presented by Kennedy (2000) for the role of parafoveal-on-foveal effects in word recognition, in an argument against the sequential allocation of attention to successive words in reading.

A relationship between saccadic amplitude and fixation duration has been known for some time, but some reports suggest that it is positive (e.g. Viviani & Swensson, 1982; in visual search), whereas others have found it to be a negative (e.g. Pelz & Canosa, 2001; in a hand-washing task) or a more complex non-linear relationship (Unema et al., 2005; in picture viewing). The present study seems to support the existence of a positive relationship, as fixations tended to be elongated the further away they were located from the next fixation. Prior to a longer saccade, in other words, there was a longer fixation, and short saccades were associated with short fixations. The difference in patterns of results may stem from differences in tasks. Furthermore, in the present study the relationship was only analysed for the $N-1$ fixation. Parafoveal processing of the vehicle seems to play a role here – a fixation relatively close to a high saliency vehicle can be curtailed and a saccade made earlier than when the $N-1$ fixation is made at greater distance from the target object.

The results of the early identification of the features of non-fixated objects may be responsible for attention being attracted to salient vehicles in the pictures. This would be consistent with the Itti and Koch (2000) model of scene inspection in which regions of high saliency attract attention earlier than regions of low saliency, and with Guided Search Theory as described by Wolfe and his colleagues (e.g. Wolfe, 1994; Wolfe, Cave, & Franzel, 1989). Preattentive processes guide the movement of attention, according to this theory, by identifying locations in the scene that are likely to contain the target, and with feature analysis and top-down evaluation processes contributing to the detection of task-relevant locations. The present study confirms the potency of a visually salient object in contributing to this "activation map" of likely target locations.

Inspection of the vehicle itself also showed effects of visual saliency, helping to account for the faster decision times for high saliency vehicles. There were similar numbers of fixations on high saliency cars and motorcycles, but more fixations on low saliency motorcycles than cars. This is likely to be a product of participants giving the scene closer inspection when motorcycles were shown, because their images occupied less space in the photographs and their identity would have been more difficult to determine. The cars could be seen more readily (see Fig. 2b), especially when vehicles were shown in their low saliency forms, and this is confirmed by the tendency for participants to declare that they would be prepared to pull out into the roadway more often when low saliency motorcycles were in the scenes. This is, of course, a result of some concern in the context of road safety measures, and in conjunction with analyses of crash databases (e.g. Thomson, 1980) and on-road observations of manoeuvres (e.g. Olson, Halstead-Nussloch, & Sivak, 1981) provides support for the notion that highly conspicuous motorcycle riders are more likely to avoid being victims of "look-but-fail-to-see" crashes. Although supportive of conclusions from analyses of on-road studies, the present data come from laboratory observations of the inspection of pictures, and as such have limitations. To establish greater generality of the effects of high saliency an initial development might involve the use of movies showing road junctions, or interactive driving/riding simulators. In both situations decisions about manoeuvres in the proximity of highly visible motorcycles could be compared with decisions when less conspicuous vehicles were approaching. The present study gives a strong indication, however, that road users are less likely to be cautious when a low saliency motorcycle is in the roadway.

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