Why do car drivers fail to give way to motorcycles at t-junctions?

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ABSTRACT

Studies of accident statistics suggest that motorcyclists are particularly vulnerable to collisions with other vehicles which pull out of side roads onto a main carriageway, failing to give way to the approaching motorcycle. Why might this happen? The typical response of the car driver is that they looked in the appropriate direction but simply failed to see the motorcycle. To assess the visual skills of drivers in such scenarios we compared the behaviour of novice and experienced drivers to a group of dual drivers (with both car and motorcycle experience). Participants watched a series of video clips, displayed across three screens, depicting the approach to various t-junctions. On reaching the junction, participants had to decide when it was safe to pull out. Responses and eye movements were measured. The results confirmed that dual drivers had the safest responses at junctions, especially in the presence of conflicting motorcycles. On a range of visual measures both novice and experienced drivers appeared inferior to dual drivers, though for potentially different reasons. There were however no differences in the time it took all drivers to first fixate approaching motorcycles. Instead the differences appeared to be due to the amount of time spent looking at the approaching motorcycle. The experienced drivers had shorter gazes on motorcycles than cars, suggesting that they either process less salient motorcycles faster than cars, or that they terminated the gaze prematurely perhaps because they did not realise they were fixating a motorcycle. We argue that this is potential evidence for an oculomotor basis for Look But Fail To See errors.

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1. Introduction

Of all road users in the UK motorcyclists are the most over-represented sub-group to appear in the crash statistics. Despite making up only 1% of annual vehicle miles in the UK (DfT, 2010a, b), they account for nearly 21% of fatalities (DfT, 2010c). A recent study of motorcycle collisions (Clarke et al., 2007) identified three primary causes. The most common cause was that of another vehicle pulling into the path of a motorcycle when exiting from a side road onto the main carriageway. In such instances as the motorcycle is travelling on the main carriageway, the other vehicle should give way. Although there is no legal right-of-way in the UK, such collisions are often termed right-of-way violations (ROWVs). Such right-of-way violations have also been reported as a major cause of collisions with motorcyclists in the US (Hurt et al., 1981) and Australia (Haworth et al., 2005). Brown (2002) noted that such accidents are often referred to as Look But Fail To See errors (LBFTS). Typically car drivers report acting with due care and attention and performing all necessary visual checks, yet still failing to see anther road user. While LBFTS errors can occur with any other road users

including bicyclists (Summala et al., 1996) and even liveried police cars (Langham et al., 2002), they are most often discussed in regard to collisions with motorcycles. The high prevalence of such LBFTS collisions (as, for instance, reported in Brown's (2002) re-analysis of Sabey and Staughton's data, 1975) may however be inflated by self-report biases. One could imagine alternative causes: a failure to look in the appropriate direction; or having looked and perceived the approaching motorcycle the car driver might fail to judge the level of risk that the conflicting motorcycle presents. Both of these alternatives are, effectively, admissions of guilt on behalf of the car driver. However, claiming that the collision was due to a LBFTS error might be considered to mitigate the blame, as the resultant collision occurred despite the best efforts of the car driver, rather than due to their negligence. Crundall et al. (2008c) provided a framework for interpreting car-motorcycle collisions at t-junctions which focussed upon these three potential causes. We argued that future research should aim to identify where the chain of behaviour breaks down, based upon three questions: Did the driver look at the approaching motorcycle? Did the driver perceive the approaching motorcycle? Did the driver correctly appraise the approaching motorcycle? The framework is represented in Fig. 1.

There are several possible reasons why any of these three behaviours may fail, resulting in a collision with a motorcycle. Bottom-up factors such as the higher spatial frequency of motor-

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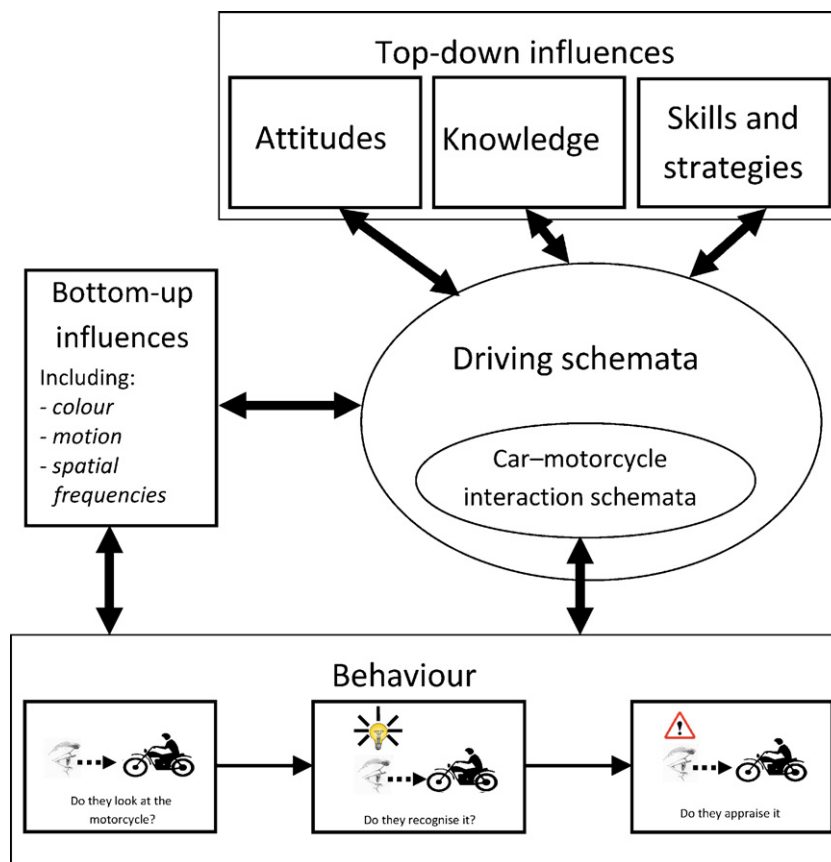 *E-mail address:* david.crundall@nottingham.ac.uk (D. Crundall).

Fig. 1. A framework for interpreting car–motorcycle collisions; a chain of behaviours influenced by top-down and bottom-up factors (adapted from Crundall et al., 2008a,b,c).

cycles (e.g. Oliva and Torralba, 2006), a smaller change in retinal size with head-on movement (motion camouflage is more effective with smaller objects; e.g. Edwards, 2005), luminance contrast (Hole et al., 1996), and even obscuration from A-frame pillars (e.g. Beach, 2004), interact with top-down factors such as experience and expectations of what vehicle could be approaching.

An initial study was conducted by Crundall et al. (2008b) to assess car drivers' abilities to spot and appraise the risk of conflicting motorcycles at t-junctions using still images of junctions containing a conflicting car, a conflicting motorcycle, or no conflicting vehicle. When presentation times were very brief, the percentage of distant motorcycles was degraded significantly more than that for distant cars. However, given sufficient time to judge the risk of the conflicting vehicles, drivers did not adopt a different criterion for conflicting cars and motorcycles when making a decision to pull out from the junction. This suggested that the problem might be more associated with the *look* and *perceive* stages of the behaviour rather than the *appraisal* of risk, however we acknowledged the limitations of using static images in this study which may have underestimated the impact of some factors upon appraisal such as the size-arrival effect (Horswill et al., 2005).

A more naturalistic study was undertaken by Labbett and Langham (2006) using video clips from a static camera at a junction. Participants viewed 6 clips of t-junctions with no vehicles, a conflicting motorcycle, or a motorcycle travelling away from the junction. While it is difficult to make firm conclusions with so few stimuli, there was a suggestion from eye tracking data that experienced drivers tended to fixate the focus of expansion of the main carriageway more so than novice drivers, yet in some instances novices were first to fixate the conflicting motorcycle. While there

are still problems with the nature of the task (use of a static perspective, no other driving demands placed on the participants) there is an interesting suggestion that experienced drivers might be more susceptible to t-junction crashes than novices, perhaps due to expectations and over-learned visual strategies that are better suited for detecting conflicting cars (e.g. Van Elsande and Faucher-Alberton, 1997).

For the current study we aimed to expand the methodologies of Crundall et al. (2008b) and Labbett and Langham (2006), to assess car drivers' visual skills in spotting and appraising conflicting motorcycles at t-junctions. We developed a multi-screen video test that provides participants with such a wide view that participants can turn their heads to the left and right to look for conflicting traffic at t-junctions. We tested both novice and experienced drivers, based on the suggestion (cf. Labbett and Langham, 2006) that the latter might fare the worst. We also tested a group of dual drivers (with considerable experience of both cars and motorcycles). These drivers are often considered the 'gold standard' compared to car drivers with without motorcycle experience, as studies have reported them to have more favourable attitudes and improved visual skills during car–motorcycle interactions (Brooks and Guppy, 1990; Magazzù et al., 2006; Crundall et al., 2008a). Specifically we were interested in when drivers first fixate the conflicting vehicles approaching the t-junction (when they *look*), how long they looked for (a measure of whether they *perceive*) and when they press a button to pull out from the junction (which, given that the necessary – but not sufficient – preconditions of *looking* and *perceiving* are met, can be considered a measure of *appraisal*). Any deviations of the novice and experienced drivers from the dual drivers will provide insight into the occurrence of Look But Fail To See errors at t-junctions.

2. Method

2.1. Participants

Data were collected from 74 participants. There were 25 novice car drivers (mean age = 20.6, SD = 2.2; Range = 18–27; mean license seniority = 1.6, SD = 0.6), 25 experienced car drivers (mean age = 33.4, SD = 8.5; Range = 24–58; mean license seniority = 14.8, SD = 7.9), and 24 dual drivers (mean age = 44.9, SD = 9.6; Range = 27–62; mean car license seniority = 25.7, SD = 11.3; mean motorcycle license seniority = 20.0, SD = 11.0). All participants received £10 inconvenience allowance.

2.2. Design

A 2×3 mixed design formed the core of the study, with three groups of drivers (novices, experienced drivers, and dual drivers who were experienced in both car and motorcycle use), and two types of conflicting scenario; 10 scenarios with conflicting motorcycles and 10 with conflicting cars (which appeared from the right and left with equal frequency). A further 10 clips contained no conflicting vehicle at the junction. These were primarily included to ensure that participants did not always expect a conflicting vehicle to be present, though they were also subjected to analysis across the participant groups where the results were considered potentially informative. These clips presented the approach to a t-junction (which could take up to 30 s of driving) before the film car stopped at the junction. In one sub-set of analyses, a third factor was included. This factor broke the clips down into a number of temporal bins to allow eye movement measures to be charted across the time course of the scenario.

In addition to these 30 clips, a further 42 clips (not analysed in the current paper) were randomly interspersed which required a different response; either a lane-change decision (see Shahar et al., submitted) or a hazard perception response. Participants could not predict when a hazard might appear, and thus had to remain vigilant to hazards even during the t-junction scenarios.

Response times reflecting when the participants thought it was safe to pull out were recorded, along with the participants' eye movements.

2.3. Stimuli and apparatus

All of the t-junction scenarios presented to participants were high definition videos displayed across three 40 in. Toshiba 40XF355D plasma televisions. The scenarios were filmed around Nottingham in August 2008 using three bonnet-mounted high definition video cameras facing to the front, and the left and right. Three bullet cameras were also mounted on the external mirrors and on the roof to record the view behind the car. T-junction scenarios used stooge vehicles (both motorcycles and cars) to provide the conflicting traffic, coordinated via short-wave radio. A police escort was also present at all times during filming.

The resulting footage was edited into clips displaying the approach to a t-junction with the film vehicle stopping to give way. The clip ended at the point when the film vehicle began to pull out. Mirror information was edited into the forward-facing video footage, providing a left-side mirror in the bottom-right of the left screen, a right-side mirror in the bottom-left of the right screen, and a rear view mirror at the top of the central screen. The three televisions were angled from each other at 120° providing an immersive video, wherein participants could look to the left and right, as if looking through the side windows of their car, to check for conflicting vehicles on the main carriageway. Although the horizontal visual angle across the three screens was approximately 112° (at a distance of 115 cm from the central screen), the actual

view from the three forward cameras on the film car was closer to 180°. The pilot study did not reveal any problems with this artificial representation of visual angle, and the overall appearance was reported as realistic. A hand-held button recorded their decision to pull out, and a foot pedal was provided for hazard responses. A four-camera Smarteye system recorded eye movements. A more detailed description of the procedure for generating the stimuli and the apparatus can be found in Shahar et al. (2010).

2.4. Procedure

Participants were informed that they would see a series of short video clips taken from a driver's point of view, and were given a series of practice clips prior to the main study. The primary task was to sanction a particular manoeuvre as quickly as possible once they had deemed it safe by pressing a button. The particular manoeuvre was announced via an audio file attached to each scenario, immediately prior to the start of each clip. For all t-junction clips the audio file contained the instruction "at the t-junction ahead, press the button to turn right". The instruction was always to turn right. This was chosen to ensure that for every clip the film car could approach the junction perpendicularly, allowing equal viewing distances to both the left and right. They were also told to press the foot pedal whenever they saw a hazard. While no hazards actually occurred in the clips analysed here, participants did not know this and therefore had to remain vigilant for hazards throughout the experiment.

Each clip played until the participant pressed the button to sanction the manoeuvre, or the film car began to make the manoeuvre itself. A pilot study confirmed that there was sufficient time to safely respond before each clip ended.

3. Results

3.1. Behavioural measures

Prior to analysis, 4 driving experts unconnected with the study rated the clips, identifying 5 scenarios (three car and two motorcycle clips) where participants might pull out from the junction without collision with a conflicting vehicle. While these clips were left in the experiment to provide sufficient variation in the approach times of conflicting vehicles they were removed from analyses, ensuring that all the responses made before the *safe point* (the point at which the rear of the conflicting vehicle reaches the centre of the display, indicating that it has passed the junction) are considered risky. Furthermore, any response times that were 3 standard deviations away from the mean for each clip were removed, further ensuring against early responses which participants considered safe.

The first analysis compared the percentage of conflicting motorcycle and car trials on which participants made safe responses (after the vehicle had reached the safe point) across the three driver groups with a 2×3 Analysis of Variance (ANOVA). One dual driver was excluded from the analysis due to missing data.

Motorcycle clips received a higher percentage of safe responses than car clips (89% vs. 84%; $F(1,70) = 7.2$, MSe = 106, $p < 0.01$). *A priori* contrasts also revealed dual drivers to make more safe responses than novices ($p < 0.05$). Both effects can be seen in Fig. 2 (top panel). The experienced drivers do not appear to show much sensitivity to the different conflicting vehicles, though the effect was not sufficient enough to produce an interaction.[1]

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[1] If age is partialled out with an Analysis of Covariance (ANCOVA) an interaction shows only dual drivers respond more safely to motorcycles than cars ($F(2,69) = 4.1$, MSe = 96, $p < 0.05$). Unfortunately heterogeneity of the regression slopes (primarily due to the truncated age range in the novice group) breaches the statistical condi-
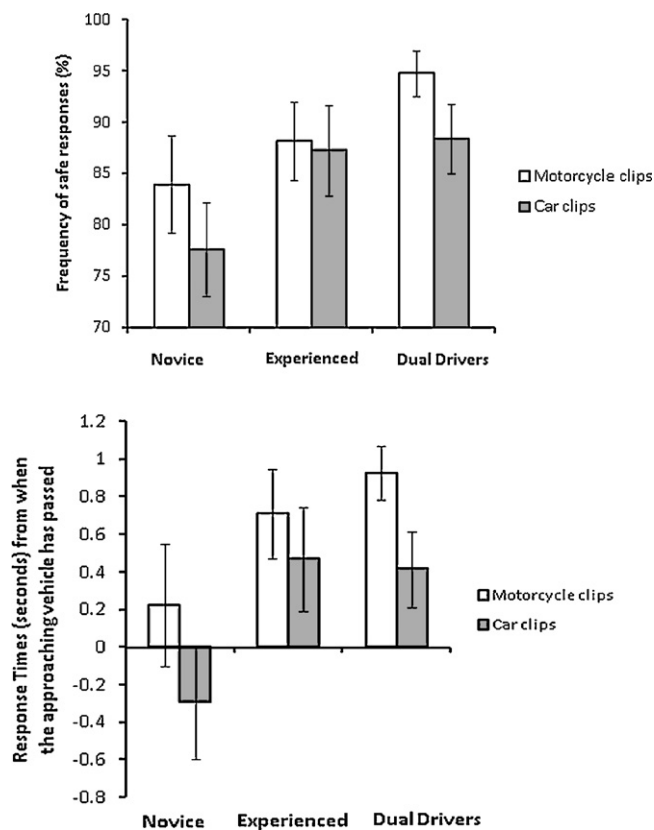
Fig. 2. The mean percentage of safe responses (top panel) and the mean response times (bottom panel) made by novice, experienced and dual drivers (with standard error bars added).

Response times (RTs) were also subjected to a 2×3 ANOVA. Motorcycle clips received more cautious responses than car clips (621 ms vs. 197 ms $F(1,70) = 15.5$, MSe = 0.42, $p < 0.001$), with positive RTs reflecting a response made after the conflicting vehicle had reached the safe point. This suggests all drivers give the motorcycles a greater safety margin than cars. *A priori* contrasts again suggested dual drivers to give the most cautious responses, with longer RTs than novices ($p < 0.05$). These effects can be viewed in Fig. 2 (bottom panel), where the quicker RTs from novices reflect a greater number of risky responses made prior to the safe point. The greatest absolute safety margin is produced by dual drivers facing conflicting motorcycles, providing further evidence that dual drivers respond more safely to motorcyclists on the road than other drivers.

No-vehicle trials were not included in the above analysis as they have no comparable safe point from which to calculate RTs. Instead RTs for the no-vehicle trials were calculated from the time when the film car stops at the junction and analysed separately, with negative RTs reflecting responses made before the film car reached the junction. There was a main effect of driver group ($F(2,70) = 3.2$, MSe = 0.6, $p < 0.05$) with simple *a priori* contrasts showing dual drivers to respond more cautiously than novice drivers (790 ms vs. 235 ms). Experienced drivers fell in-between (513 ms). Experience both in cars and on motorcycles appears to lead to more cautious decisions to pull out from t-junctions, regardless of the presence of conflicting traffic. While it is possible that age-related

slowing may have had an impact on these response times, the magnitude of the difference (over half a second between novice and dual driver) argues that they are using different criteria in making the response.

In addition to the behavioural responses, we also recorded eye movements. We analysed eye movements in two different ways. The first is concerned with calculation of two measures that we believed might discriminate between the driver groups. These were how far down the junction did drivers look (*mean eccentricity*) and how widely did they scan (*mean spread of search*), both of which were calculated from the gaze coordinates generated by the eye tracker. The second approach to eye movements was to code a video overlay file that showed exactly where a participant was looking at any particular moment during each scenario. This allows us to assess when and for how long participants looked at conflicting cars and motorcycles (see Fig. 3 for an example of eye gaze overlaid on a video clip). We shall discuss these two approaches in order.

3.2. Measures of visual search

First, to calculate mean eccentricity we took the average gaze location in the horizontal axis for every participant relative to the centre of the three-screen display in pixels. This measure is based on the fact that the furthest points down the junction that could be viewed were invariably those points of the road that were furthest to the left and to the right of the horizontal display. The mean gaze location was calculated across either 4 temporal bins of 1-s duration (for no-vehicle trials) or 6 temporal bins (for all comparisons of car and motorcycle trials). For the no-vehicle trials these temporal bins comprised the 4 s prior to the driver's car stopping at the junction, while the car and motorcycle comparisons included an additional 2 s following the car having stopped at the give-way line (these conflicting-vehicle trials typically ran for longer before the participant made a response than the no-vehicle trials, allowing more temporal bins to be included). Any clip that did not provide data for all 6 bins was not included in the means for that participant. Within each bin the x-coordinates of the eye locations were averaged to provide a mean gaze distance away from centre. The factor created by using temporal bins was given the name *time-to-junction*. Larger numbers within a bin reflect a mean eye position that is further to either the right or left of the centre, reflecting a visual search that probes further down the junction.

To reflect the spread of the driver's visual search we took the standard deviation of the absolute horizontal coordinates for eye location samples (in pixels), calculated for each of the four temporal bins on the approach to the junction and the two bins following the car having stopped at the junction. This measure provides an indication of how widely the eyes were scanning across the scene. Initially both measures were compared across four temporal bins for just the no-vehicle trials. This was undertaken in order to assess whether the driver groups had any strategic differences in how to view a junction when no conflicting vehicles were present.

A 3×4 (group × bin) ANOVA assessed mean eccentricity from no-vehicle trials (with 4 participants removed due to missing data) found no differences between the groups in how far down the junction they looked. There was an effect of time-to-junction however ($F(3,201) = 471$, MSe = 12120, $p < 0.001$), with eccentricity of search increasing from bin 1 to bin 3 ($Fs(1,67) > 200$, $ps < 0.001$), at which point it plateaus.

The mean spread of search on no-vehicle trials was also compared across driver groups for the 4-s approach to the junctions. Again there were no group differences or interaction, but there was a main effect of time-to-junction ($F(3,201) = 392$, MSe = 12367, $p < 0.001$). In contrast to the mean eccentricity measure, spread of

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tions under which an ANCOVA should be conducted. While this interaction supports our prediction that dual drivers behave more safely towards motorcyclists, this could be confounded by an inflation of the type 1 error rate through the misapplication of the same covariance adjustment across all conditions. To avoid all doubt, we have rejected the use of ANCOVA in the remaining analyses, and will only use ANOVA.

Fig. 3. A composite image of all three screens presented together depicting a t-junction scenario with a conflicting motorcycle appearing from the right. The centre screen presented the image in a widescreen format, while the side screens presented the image in a 4:3 format. When the screens were angled appropriately, the image provided a realistic view. The small circle on the motorcycle reflects where one of the participants was looking at this point during the clip.

search increased significantly across each of the four temporal bins without reaching a plateau.

To summarise the analyses of the no-vehicle trials, the driver groups did not differ in regard to how far down the junction they looked or how widely they spread their visual search. The lack of group differences argues against the hypothesis that drivers of varying experience might adopt different search strategies at junctions.

Following the analysis of no-vehicle trials, trials with conflicting vehicles were analysed. Both mean eccentricity and mean spread were subjected to $2 \times 3 \times 6$ ANOVAs comparing cars to motorcycles across the three driver groups and across the 6 temporal bins of the time-to-junction factor (4 s approaching the junction and 2 s

after stopping at the junction). One dual driver was removed due to missing data.

In regard to mean eccentricity there was marginal evidence for an overall group effect ($F(2,70) = 2.9$, MSe = 12875, $p = 0.059$) with dual drivers tending to look the furthest down the road. The main effect of vehicle type was not significant ($F(1,70) = 3.1$, MSe = 11385, $p = 0.08$) though it did interact with the time-to-junction ($F(5,350) = 5.5$, MSe = 7526, $p < 0.001$). Specifically, repeated contrasts suggested that mean eccentricity in car and motorcycle clips diverged significantly in the final temporal bin (1–2 s after the film car stopped at the junction; $F(1,70) = 7,1$, MSe = 39142, $p = 0.01$). From Fig. 4 (top left panel) it can be seen that eccentricity on motorcycle clips decreases more in the final
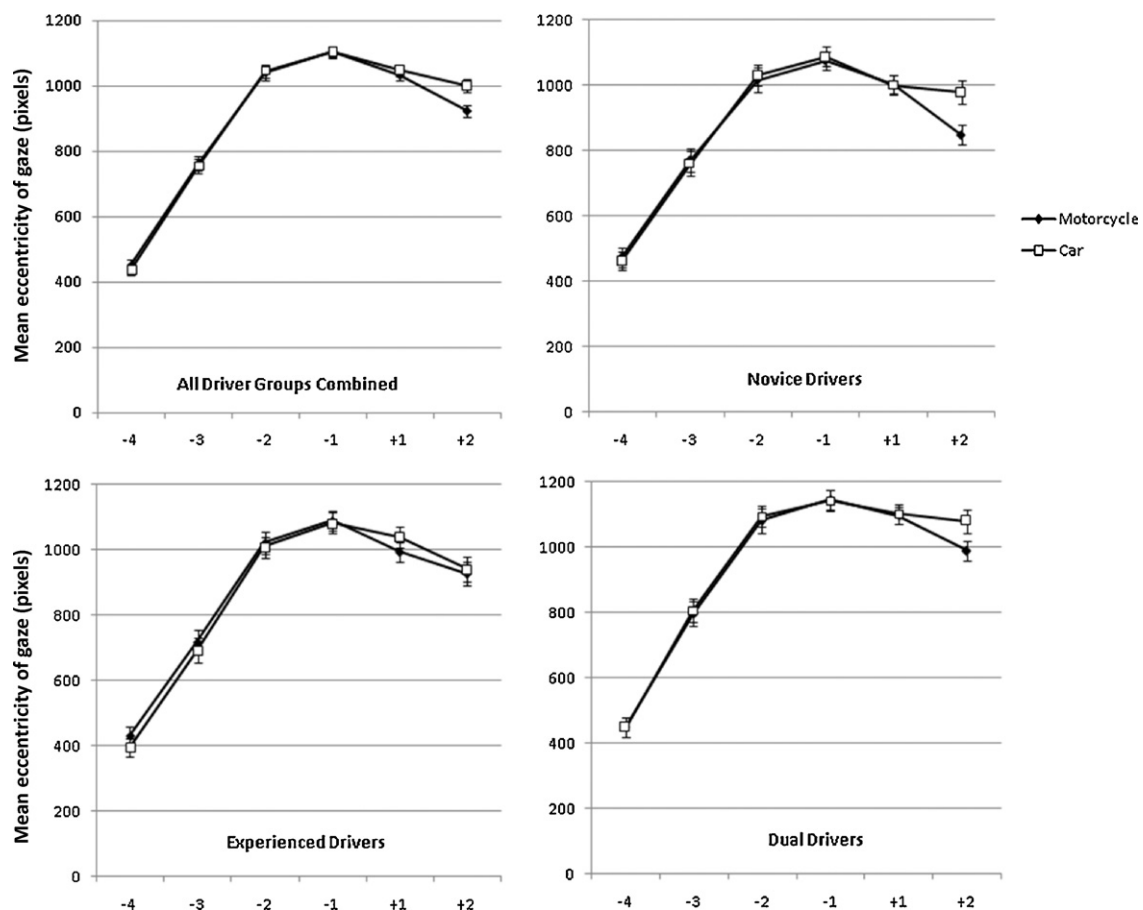

Fig. 4. The mean eccentricity of gaze along the horizontal viewing axis (in pixels), reflecting the distance that participants look down the road on approach to (bins 1–4), and having stopped at (bins 5–6), the junction. The graphs represent means for all groups combined, and for novices, dual drivers and experienced drivers separately (clockwise from top left), with standard error bars.

bin than on car clips. While there is no omnibus significance for the three-way interaction between vehicle, time-to-junction and driver group, the *a priori* contrasts suggest that the vehicle × time-to-junction interaction is moderated by driver group when specifically looking at the 2 s following the car stopping at the give-way line ($F(2,70) = 4.5$, MSe = 39141, $p < 0.05$). Interestingly it appears that while the novice and dual drivers follow the general pattern noted in the two-way interaction, the experienced drivers fail to reduce their gaze eccentricity on motorcycle trials in the final temporal bin (Fig. 4).

Taken together these results suggest that (a) there is marginal evidence that dual drivers look furthest down the junction in the presence of conflicting vehicles; (b) participant's tend to reduce the eccentricity of their search 1–2 s after stopping at the junction more so with conflicting motorcycles than cars; (c) assuming that dual drivers produce the safest behaviour, this reduction in eccentricity is commensurate with safe behaviour towards the motorcycles (perhaps indicating that they follow the motorcycle more closely as it approaches the junction); (d) novice drivers behave similarly to dual drivers; it is the experienced drivers who do not use this strategy, suggesting that perhaps an over-learned strategy encourages them to search beyond a motorcycle once it has been spotted, or perhaps reduces the chances of spotting the motorcycle at all.

The measure of spread of search was then subjected to a 2 × 3 × 6 ANOVA comparing conflicting cars and motorcycles across driver groups and the 6 temporal bins of the time-to-junction factor. An interaction between vehicle and time-to-junction was noted ($F(5,350) = 16.5$, MSe = 13462, $p < 0.001$). While spread of search peaks for the car clips in the final second of approach (bin 4), perhaps resulting from attentional capture by the early fixation of a conflicting car, spread of search in the motorcycle clips increases across all bins, suggesting that the motorcycle has not had the same narrowing effect on oculomotor behaviour.

3.3. Gazes on conflicting vehicles

In order to ascertain a more direct measure of whether drivers spot approaching motorcycles a frame-by-frame analysis of eye-tracking videos of each scenario was conducted. These videos contain a cursor representing where each participant was looking. Those clips which were not considered risky by our raters were removed from these analyses (cf. RT analysis), along with 4 participants due to missing data.

In coding the t-junction clips we were primarily concerned with recording exactly when and for how long participants looked at the conflicting vehicles. The first analysis compared the percentage of trials on which drivers failed to look at either the approaching cars or motorcycles (a 2 × 3 ANOVA across vehicle type and driver group). Though novice drivers had the largest rate of failures to fixate approaching vehicles (9.3%) compared to experienced and dual drivers (5.6% and 4.9%, respectively) this did not reach statistical significance [$F(2,67) = 1.3$]. None of the other effects were significant. The results suggest that all drivers fixated the approaching vehicles equally and regardless of whether it was a motorcycle or a car.

The next analysis compared the time it took for drivers to first look at the approaching car or motorcycle. This measure was calculated from the safe point for each vehicle (cf. RT analysis). The 2 × 3 ANOVA (vehicle × driver group) revealed nothing more than a main effect of vehicle type ($F(1,67) = 888$, MSe = 0.09, $p < 0.001$) which suggested that all drivers fixated cars sooner than motorcycles (4.35 vs. 2.86 s before the conflicting vehicle reached the safe point). Several measures of gaze duration were recorded and analysed. Gaze duration is usually interpreted as the amount of time devoted to processing a stimulus. Longer gazes reflect dif-
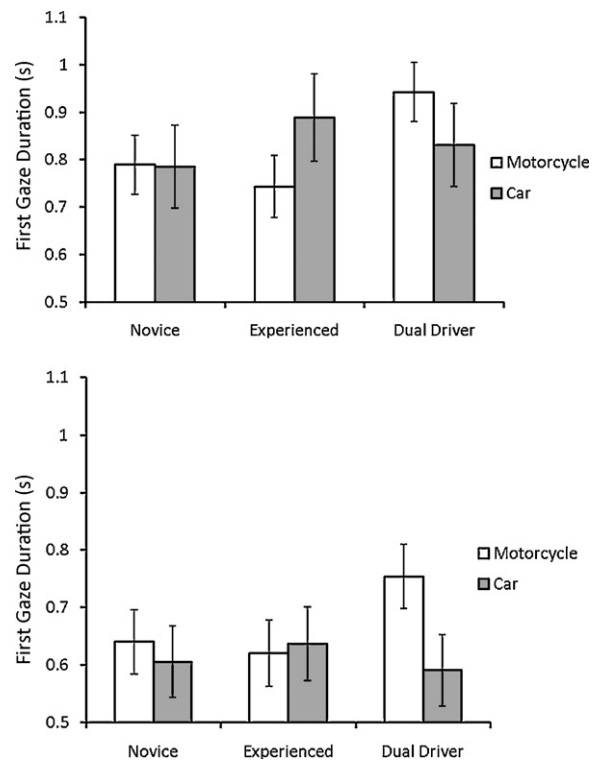

Fig. 5. First gaze duration and mean gaze duration (in s) upon the conflicting vehicle on those trials with an approaching car or an approaching motorcycle (with standard error bars added).

ficulty in processing, whereas short gazes reflect relatively easy processing. However, in situations where we know that a particular stimulus should incur reasonably lengthy gazes, short gazes on these stimuli are more likely to reflect a failure to process them. We believe that motorcycles are harder to process than cars as they are less salient, more visually complex, and potentially more unpredictable due to their greater manoeuvrability and acceleration. Relatively short gaze durations on motorcycles (compared across driver groups) therefore provide the best opportunity for identifying Look But Fail To See errors. The gaze measures that we recorded included First Gaze Duration (FGD; a measure of initial processing difficulty) and the Mean Gaze Duration (total gaze duration/number of gazes; an indication of overall processing difficulty).

The first gaze duration produced an interaction between vehicle and experience ($F(2,67) = 3.1$, MSe = 0.06, $p = 0.05$). As can be seen in Fig. 5 (top panel), experienced drivers made longer first gazes on conflicting cars than motorcycles, while dual drivers have the reversed pattern with their longest first gaze on the approaching motorcycle.

Analysis of the mean gaze duration on the conflicting vehicles produced marginal evidence of an interaction ($F(1,67) = 3.6$, MSe = 0.04, $p = 0.067$), with dual drivers having greater mean gaze durations on conflicting motorcycles than all other groups (Fig. 5; bottom panel). These gaze analyses suggest that dual drivers devote more attention to motorcycles than cars (presumably reflecting the increased risk they pose and the inherent difficulty of processing a smaller, less salient object). The experienced drivers however appear to have relatively shorter initial gazes on the motorcycle, suggesting that they might not even realise they have been looking at a motorcycle, or at least that they have decided for whatever reason not to process it any further.

4. Discussion

The most immediate finding from the analyses was the greater caution given to conflicting motorcycles than to conflicting cars. Both the percentage of safe responses and the RTs reflect a greater safety margin in responding to motorcycles. While one might argue that this is driven by the fact that the participants are taking part in a laboratory experiment in which they presumably want to appear as competent drivers (and thus make more cautious responses to more vulnerable road users), it would be unfair to the vast majority of drivers to suggest that such safe behaviour toward motorcyclists does not reflect decisions made during actual driving. Despite the over-representation of motorcyclists in crash statistics, by far the majority of motorcycle journeys do not result in a crash. Car drivers do not want to have a crash, and it is reasonable to assume – especially in light of recent high-impact UK television campaigns – that in the majority of cases drivers will respond appropriately to motorcycles. It is the occasional situation that we are concerned with, where attention might lapse, or judgment is made too hastily, which may result in a crash. While we do not doubt that participants will try to project a safe driving image for the experimenter, we have two approaches to circumvent this problem. First we can compare responses across groups, in the current case using the dual drivers as our gold standard. Even when participants try to project a safe image, unavoidable group differences may still be apparent. Secondly, we must measure more subtle indicators of behaviour, such as eye movements, which are less vulnerable to the demand characteristics of the experiment.

In regard to group differences, dual drivers were more cautious than the novice drivers, with the experienced group falling in-between. This pattern held regardless of whether or not there was conflicting traffic. While the overall means improved with experience, the differentiation between motorcycle clips and car clips seemed greatest for the dual drivers followed by the novice drivers. Attempting to partial out age only increased the suggestion that dual drivers were the most sensitive to the presence of a conflicting motorcycle, while experienced drivers appeared the least sensitive. This suggests that different processes might distinguish the novices and experienced drivers when compared to the dual driver group.

This rationalisation receives further support from the eye tracking analyses. In regards to the mean eccentricity measure (how far down the junction participants searched) it was clear that while novices drivers did not search as far down the road as the dual drivers, they responded in the same manner to an approaching motorcycle. Both novices and dual drivers tended to bring their eyes further towards the centre of the display in the presence of a motorcycle, as if they were following its course of travel foveally, while the trajectory of conflicting cars might have been monitored with peripheral vision. Thus novices appear to use the same visual strategies as dual drivers, but at a lower level of competence. Equally of interest however was the fact that the driver groups did not differ in their visual search on approach to the junctions (either across the four temporal bins of the no-vehicle junctions or the first 4 bins of the clips with conflicting vehicles). Once they reached the junction however the dual drivers delayed the decision to pull out in order to search the junction, and if a motorcycle was detected their search strategy adapted to deal with it.

The failure of experienced drivers to reduce the eccentricity of their search in the presence of conflicting motorcycles suggests they either have better peripheral vision and can monitor the motorcycle extra-foveally, or they do not choose to monitor (or perhaps are not aware that they are not monitoring) the motorcycle's approach.

Perhaps the most interesting results came from the frame-by-frame coding of the eye location. The first gaze duration (FGD) is an immediate measure of initial processing difficulty and is the eye measure that is most unlikely to be influenced by the demand characteristics of the experiment. The FGDs of the dual drivers fit with our hypothesis that motorcycles should warrant longer gaze durations as they are less salient and will take longer to process. The FGDs of the experienced drivers upon conflicting cars are consistent with those of the dual drivers, but their first gazes on approaching motorcycles are shorter. This suggests that when experienced drivers are presented with a conflicting motorcycle, they either view this as easier to process or perhaps less risky than a conflicting car, or instead they do not realise what they are looking at. If the first gaze does not identify the object as a motorcycle as quickly as it would identify a car, then the fixation may be terminated prematurely with gaze moving to a new location in the junction. The novice drivers show neither sensitivity to the demands of motorcycles (as dual drivers do), or evidence of a failure to realise that it is a motorcycle (as experienced drivers do). Their initial gazes are equally low on both cars and motorcycles, again suggesting that they differ from the dual drivers in a different manner to that shown by the experienced drivers.

The mean gaze durations (MGDs) also identify the dual drivers as the group who devote most time to the approaching motorcycles, reinforcing the suggestion that they are more sensitive to the level of processing motorcycles require. We are presuming that this is due to the specific motorcycle experience of the dual driver group, though it should be noted that they also have the most car driving experience. If it were the case that the additional car driving experience of the dual drivers was the primary factor in their superior behaviour we might expect improvement across the three groups, however the experienced car driver group displayed inappropriate visual behaviour that was not indicative of a linear improvement with car driving experience. Instead we propose that greater car driving experience on its own is likely to lead to decreased expectancies for motorcycles, which may account for the inappropriate visual search patterns.

While we are proposing that the superior dual driver performance is a direct benefit of increased sensitivity to motorcycles, it is also possible that the increased processing of motorcycles is a positive but inadvertent side-effect of a having a greater interest in motorcycles than in cars. We cannot refute this, though the extra caution that dual drivers also show in the absence of conflicting motorcycles argues against this as the predominant factor in the increased safety of this group.

In comparison to the scant previous literature on this topic, the results concur with Crundall et al. (2008b) in the suggestion that any potential problems in t-junction collisions between cars and motorcycles are most likely to be perceptual. In the current study, most drivers showed an appreciation for the risk presented by motorcycles evident in the RT analysis (and to a lesser extent in the percentage of safe responses). Despite this, the more sensitive eye movement measures identified key differences in eye movements between the groups. Assuming the dual drivers reflect the most appropriate behaviour, it suggests that the other driver groups have deficiencies in their visual search and processing time devoted to the conflicting motorcycles. In regard to the work of Labbett and Langham (2006), we too have found a suggestion that novice drivers might be more responsive to conflicting motorcycles than more experienced drivers, especially as their mean eccentricity follows the pattern of dual drivers, and they do not dwell on cars more than motorcycles. This is likely to be due to a mixture of causes including the employment of explicit visual rules gained during relatively recent driving tuition, and the lack of deeply engrained expectations about what we might face on the roads that might accrue with years of experience. However, there are some crucial differences between our results and those of Labbett and Langham. First, we did not find any difference in the time taken to first fixate the motorcycles across the group. The differences arise in the pro-

cessing time devoted to the motorcycles and the subsequent search strategy once they have been detected. Secondly, novice drivers still produce the poorest absolute measures of visual search and depth of processing (reflected in gaze durations). We cannot therefore claim novice drivers to be safer than experienced drivers at t-junctions. We can however suggest that the causes of any potential collision might be different. Whereas experienced drivers may pull out in front of an approaching motorcycle due to over-learned visual search strategies (which might be well suited to spotting cars but not motorcycles), or due to expectations of typical hazards built up over years (which will favour cars as the source of a hazard rather than motorcycles), novices may suffer from capacity-limited problems due to the higher demands of driving.

There remains however the possibility that the current study underestimates the potential for Look But Fail To See collisions to occur. While we have acknowledged the possibility of experimental demand characteristics influencing the level of vigilance participants devote to the task, it is also possible that the design negates the impact of motorcyclist speed. In all of the clips the conflicting cars and motorcycles adhered to the posted speed limit of 30 mph when passing junctions. Some researchers argue however that there is evidence that motorcyclists are more likely to exceed the speed limit than car drivers (Brenac et al., 2006; Kim and Boski, 2001) and that this may increase the probability that drivers fail to look at or perceive a conflicting motorcyclist (Pai, 2009). In fact Peek-Asa and Kraus (1996) even suggested that controlling a motorcyclist's approach speed when passing a side road might reduce these type of collisions. Effectively this is what we have done, ensuring that all conflicting vehicles approach at the same legal speed. Despite this potential underestimation of LBFTS errors we have still identified important differences, and it will be a priority for future research with this methodology to further identify those factors that are crucial for successful car–motorcycle interaction. With appropriately filmed stimuli, a wide range of factors can be investigated in the three-screen hazard perception rig including conspicuity issues regarding clothing or daytime running lights, the angle or speed of approach of the conflicting vehicle, and the top-down expectancies or visual search strategies of the participant. Through a more comprehensive understanding of the various factors that contribute to this type of collision, researchers can offer insights into methods for reducing their frequency, whether that is through engineering solutions (e.g. road design), enforcement, warnings, or training.

To summarise, this study provides an initial attempt to understand why t-junction collisions occur between cars and motorcycles. We simplified the problem into three questions relating to links in a behavioural chain of events. The first question was 'Do they look?' When compared to dual drivers, all other drivers do indeed *look* appropriately. Visual search is similar across all our groups until after a conflicting vehicle is spotted, while time taken to first fixate a motorcycle does not appear to differ either. The second question, 'Do they perceive?', is more of a problem. The reduced gaze durations of the experienced drivers upon motorcycles suggests that even though they might fixate the approaching motorcycle, they may not fully realise what they are looking at, and may therefore terminate their gaze before fully processing it. The final question, 'Do they appraise?', is dependent on the success of the previous stages, though this research has demonstrated that perceptual deviations from the gold standard of dual drivers can be found even when most drivers respond more cautiously to motorcycles. Certainly in the current study most drivers adequately appraised the approaching motorcycles on the majority of trials, but as noted earlier, this explicit response is more open to the demand characteristics of the study than are the associated eye movements.

In conclusion this study has provided the first evidence for an oculomotor basis to Look But Fail To See errors in a dynamic driving-related situation. The most noted difference between driver groups was in their gazes upon the conflicting vehicles, and we therefore tentatively suggest that such errors may indeed be true errors of fixation without perception, rather than a failure to fixate or a failure to appraise.

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