Road Safety Research Report No. 121

Car Drivers' Attitudes and Visual Skills in Relation to Motorcyclists

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GLOSSARY

Analysis of variance (ANOVA) – this is the primary statistical technique used in this report. It compares two or more groups or conditions to see whether there is a difference between the scores they produce. Any difference could be due to the experimental manipulation or due to random error. ANOVA estimates the variance in the population attributed to both of these causes. If significantly more variance can be accounted for by the experimental manipulation than by random error, then the experimental manipulation has worked and has identified different underlying groups.

Analysis of covariance (ANCOVA) – this is similar to an ANOVA, except it can statistically remove the influence of a covariate (e.g. age) that might otherwise distort the results of a normal ANOVA.

Bottom-up – the generation of a behaviour or outcome on the basis of factors that are external to the human system. For instance, the brightness of a motorcycle may attract attention to it. Such stimulus-driven behaviour is often contrasted against **top-down** influences, though often any behaviour is the result of a mixture of bottom-up and top-down factors.

Conflicting vehicle – any vehicle that is travelling on a path that will potentially intersect with the participant. The participant's vehicle in this study is expected to give way to the conflicting vehicle. In T-junction scenarios the conflicting vehicles approached from either the left or right side of the junction. In change-lane scenarios conflicting vehicles approached from behind to overtake the participant's car on the right.

Dual drivers – drivers who had at least seven years of car driving and motorcycle riding experience since passing the respective tests.

Experienced drivers – drivers who had at least seven years of car driving experience and no motorcycle riding experience.

Eye–mind assumption – the assumption that the eye looks at an object as long as the mind is processing it. Nowadays this is considered to be a flawed assumption.

First gaze duration (FGD) – the duration (in milliseconds) of the first **gaze** on a particular object or area of interest.

Fixation – an instance in which the eyes are stationary, allowing visual information to be input from a particular area of the visual scene.

Focus of expansion – the point in the visual field from which optic flow emanates. In driving this is often used to describe the farthest distance down a road that one can see: the point at which the edges of the road meet in perspective.

Gaze – one or more subsequent **fixations** in a predefined area of interest. If the eye leaves the area of interest for a single fixation elsewhere, the gaze is considered to have ended. If the eye returns to this area later, a new gaze begins. Length of gaze is usually interpreted as the amount of time devoted to processing a stimulus.

Helmert contrasts – a statistical test that compares the mean of each level of a factor to the mean of subsequent levels. In Studies 2 and 3 we used this test to compare the scores of no-vehicle clips with vehicle clips, and to directly compare measures from motorcycle clips with car clips.

Look But Fail To See (LBFTS) errors – instances in which drivers look in the appropriate direction, but do not register the **conflicting vehicle**, typically cited as contributing to **right-of-way** violation crashes.

Mean eccentricity – a measure used to reflect how far down the junction (either to the left or right) the drivers look. It is calculated as the absolute distance of gaze from the centre of the visual display (in pixels).

Mean gaze duration (MGD) – the total gaze duration (in milliseconds) divided by the number of gazes. This can be calculated across a whole clip or just for specific areas of interest.

Mean spread of search – a measure used to reflect the activity and spread of drivers' visual search. The current project is only concerned with the spread of search in the horizontal axis. The spread is calculated from the standard deviation of the x co-ordinates of the eye position.

Novice drivers – drivers who have no more than three years of car driving experience and no motorcycle riding experience.

Percentage total gaze duration – a measure for the relative time spent looking at an area of interest, calculated as a proportion of the time spent looking at an area of interest from the total gaze duration (of all areas of the visual scene) and then transformed into percentages.

Right-of-way – the term 'right-of-way' is often used to refer to one vehicle having priority over another vehicle. Right-of-Way Violations (RoWVs) refer to one vehicle entering the road space of another vehicle, when the latter vehicle has priority. While the use of right-of-way as a term has become a convention, it is not a legal definition of such situations.

Safe point – the point at which it could be considered safe to make a manoeuvre (i.e. change lanes or pull out of a T-junction) without pulling out in front of conflicting traffic and risking a collision. For T-junction scenarios, we used the point at which the rear of the conflicting vehicle had reached the centre of the visual display. For change-lanes scenarios, we used the point at which the rear of the conflicting traffic (centre of the licence plate for cars) was lined up with the right vertical axis of the inset right mirror.

Simple contrasts – a statistical test that compares each group average to one control condition. In Study 3 we used this test to compare the scores of each of the three groups who had received training to the scores of the control group.

Top-down – the generation of a behaviour or outcome on the basis of factors that are internal to the human system. For instance, driving experience may lead you to pay attention to parked vehicles, as you have learned through experience that they can obscure pedestrians. These top-down factors are often contrasted against **bottom-up** influences, though often any behaviour is the result of a mixture of both.

EXECUTIVE SUMMARY

Motorcyclists are grossly over-represented in the crash statistics. They represent 1% of traffic but 21% of all fatalities. The analysis of collision data suggests that some of the most common motorcyclist collisions involve errors on behalf of other road users, for example car drivers who fail to give way to an approaching motorcycle at a T-junction. Following such accidents, car drivers often claim that they **looked**, but did not **see** the approaching motorcycle. Research needs to assess whether such 'Look But Fail To See' accidents occur and what factors might contribute to their prevalence.

This project involved three studies to explore these issues further. These were:

- a study to increase car drivers' empathy for motorcyclists;

- a study to investigate how drivers search for motorcycles at T-junctions and when changing lanes; and

- a study to assess whether training interventions can address poor visual skills at T-junctions and when changing lanes.

Study 1: Increasing car drivers' empathy for motorcyclists

Previous research has identified car drivers' negative attitudes and lack of empathy towards motorcyclists as a possible factor in car–motorcycle collisions. Study 1 aimed to improve negative attitudes in car drivers and to increase their empathy for the demands that motorcyclists face by exposing them to the motorcyclist's perspective through the use of hazard perception clips filmed from a motorcycle, and through the use of simulated hazards in a motorcycle simulator. A car simulator and car hazard clips were used as control conditions.

The analysis of responses on a post-intervention questionnaire, relative to participants' answers on a pre-intervention questionnaire, revealed that attitudes did improve specifically towards motorcyclists rather than producing an improvement for all road users. However, there was a suggestion that even hazard interventions from a car driver's perspective can improve attitudes to these more vulnerable road users.

When asked directly about their attitudes towards motorcyclists, participants who had seen the motorcycle-based hazard perception clips reported the greatest level of improvement. This suggests that film clips from a motorcyclist's point of view could be a useful tool in future safety interventions.

However, it was also noted that positively influencing attitudes towards one minority sub-group of road users could have a potentially negative effect on attitudes to other

road-user sub-groups. While it is not clear what underlying reason may lead to this, several suggestions have been put forward. Further research is required to replicate this effect and assess the competing theories.

Finally, while the results of Study 1 lend themselves to the design of future safety interventions, it should be noted that there was an apparent cost for mixing multiple perspectives in closer temporal proximity. Thus, showing both the motorcyclist's and car driver's perspective in a road safety advertisement might incur costs due to the perspective shift, which might offset any attitudinal and behavioural improvements otherwise gained.

Study 2: Investigating how drivers search for motorcycles at T-junctions and when changing lanes

Study 2 was designed to assess the visual skills of drivers in both T-junction scenarios and change-lane scenarios. A series of multiple-screen video clips were filmed from a car moving through a series of T-junctions and change-lane manoeuvres. The video streams were edited to provide a wide field of view of the road ahead (including inset mirror information) and were presented to participants across three 40 inch LCD monitors in the laboratory. The participants watched these clips with a view to pressing a button when they thought a pre-specified behaviour was safe to execute (pulling out from a T-junction or changing lanes). We termed this the Sanctioning Manoeuvres task. Some clips contained approaching cars or motorcycles on the main carriageway, while other clips had no approaching vehicles.

Three groups of drivers were tested on these scenarios while their response times to make a manoeuvre and their eye movements were monitored. The groups were novice drivers, experienced drivers and dual drivers (the latter being experienced car drivers who also have a lot of experience of riding motorcycles). Dual drivers were considered the benchmark against which to compare the other two groups in this study because research has shown that drivers who also ride motorcycles are less likely to cause motorcycle crashes while driving a car (Magazzù *et al.*, 2006).

With regard to the T-junctions, the response of the dual drivers to approaching vehicles was the safest of all the participants and they were the most sensitive to approaching motorcycles. Novices gave the least cautious responses, sometimes pressing the button to pull out from the T-junction in front of approaching cars. Overall, motorcycles were treated with more caution, though the dual drivers were the most cautious of all.

Analysis of eye movements at empty T-junctions showed that all driver groups behaved the same, steadily widening their visual search on approach to the junction.

Visual search was at its widest, however, up to 2 seconds before the participant's car stopped at the give-way line.

Eye movements on T-junction trials where approaching vehicles were present suggested that dual drivers pay more attention to approaching motorcycles than to cars, possibly reflecting the fact that they are difficult to see (low salience) and difficult to appraise (compared to cars, their greater acceleration and manoeuvrability make their actions less predictable). Novice drivers' gazes are relatively short on both vehicles (that is, attention to cars and motorcycles is equally poor compared with the dual drivers), while the experienced drivers tend to have shorter gazes on motorcycles than cars. This suggests that the experienced drivers are either not realising that they are looking at a motorcycle, or quickly decide that it does not require as much attention as a car.

In the change-lane scenarios, motorcycles approached the participant's car from behind to overtake (and were therefore only visible initially in the mirrors). These motorcycles again received the safer responses compared with cars, but dual drivers responded to them with no more caution than the other driver groups.

All drivers tended to look in the rear-view mirror before the right-side mirror. However, the first gaze on the rear-view mirror was delayed if an approaching vehicle was visible in the mirrors. As the drivers had not directly fixated on the approaching vehicles, the delayed gaze to the mirror must have been based on peripheral vision. We suggest that peripheral vision might detect enhanced clutter in the rear or side mirrors when approaching vehicles are visible, which then encourages the driver to spend longer focusing on the forward view before moving to inspect the mirror. The rationale for this is that, in anticipation of longer than average gazes on the mirror (which do indeed occur), the drivers first give more attention to assessing their headway to the vehicle in front. Once a more thorough check of headway has been completed, the drivers then look at the rear-view mirror.

Dual drivers delay their first gaze on the rear-view mirror for even longer than the experienced drivers, but then have longer gazes upon the rear-view mirror if a motorcycle approaching from behind is visible. We suggest that the increased delay to look at the mirror prepares them for longer gazes upon the mirror once they look at it (by providing more in-depth analysis of the forward headway prior to looking at the mirror).

Despite looking at the rear-view mirror sooner than dual drivers, experienced drivers look to the right-side mirror later than dual drivers. This suggests that they are returning to the forward view more frequently to continuously monitor headway.

Experienced drivers also had shorter gazes on the right-side mirror than dual drivers. Novices were very similar in gaze length to the dual drivers on the right-side mirror.

Overall the results of Study 2 argue for differences in processing time between groups on approaching motorcycles. In both the T-junction scenarios and the change-lane scenarios, dual drivers devote longer gazes to the motorcycles. This suggests that they are aware that they are looking at a motorcycle and that it is worthy of more in-depth processing. The shorter gazes of the other groups to motorcycles suggest that they may be more susceptible to failures of perception. We believe that this has provided the first experimental evidence that true 'Look But Fail To See' errors can occur in car–motorcycle collisions.

Study 3: Assessing whether training interventions can address poor visual skills at T-junctions and when changing lanes

Study 3 was an attempt to change the behaviour of car drivers with regard to their eye movements and response times through the application of three training interventions based on the look, perceive and appraise chain of behaviours. These training interventions were given prior to participants undertaking the same tasks as reported in Study 2. Drivers in the **look training** group received explicit instruction on where to look during the video scenarios. Drivers in the **perceive training** group undertook training designed to reduce the processing threshold for subsequent motorcycles in the video scenarios. Finally, drivers in the **appraisal training** group viewed hazardous video clips from a motorcyclist's perspective (used in Study 1), with the possibility that awareness of the vulnerability of motorcycles might reduce risky appraisals. The performance of these drivers on the sanctioning manoeuvres task (pressing a button when it is safe to pull out of the junction or change lanes) was compared with an untrained control group:

1. The training interventions had no appreciable positive impact on decision times or eye movements to approaching vehicles on T-junction scenarios.

2. Changes in eye movements were noticeable in the change-lane scenarios, though any benefits occurred early in the clips (increasing early use of the rear-view mirror), and had potentially negative side effects (decreasing use of the right-side mirror).

3. While some of the eye movement measures in our scenarios are open to modification (especially though the use of **look training**), it is too early in our understanding of how instruction affects eye movements to make definitive suggestions that will guarantee desired results.

4. In conclusion:
   - we have shown that attitudes towards motorcyclists can be improved with hazard-based training;
   - car drivers report more favourable responses to motorcyclists following the presentation of hazard perception video clips taken from the motorcyclist's perspective;

- we have developed an innovative testing rig that presents drivers with a wide field of view and mirror information;
- this apparatus has been successful in identifying important differences between different groups of drivers with regard to how they process appraoching motorcycles;
- the key difference between dual drivers and other drivers is in the length of their gazes upon approaching motorcycles;
- we believe this provides the first experimental evidence for visual processing being the basis for 'Look But Fail To See' errors; and
- while training interventions hold promise for the future, the current attempts failed to produce the desired results.

1 INTRODUCTION

1.1 The problem

Motorcyclists in the UK are over-represented in the crash statistics. While they make up only 1% of annual vehicle miles in the UK (Department for Transport, 2010a, b), they account for 21% of fatalities (Department for Transport, 2010c). Studies that have investigated the causes of motorcycle accidents acknowledge that many crashes resulting in death or serious injury are due to the behaviour of the motorcyclist, most typically reflecting the loss of control of the motorcycle in a bend (Clarke *et al.*, 2007), though inappropriate speed and manoeuvres also feature (Carroll and Waller, 1980; Lynham *et al.*, 2001; Mannering and Grodsky, 1995).

There are, however, a number of categories of motorcycle collisions that are often attributed to the behaviour of another road user. For instance, Clarke *et al.* (2004; 2007) reported that the violation of a motorcycle's right-of-way, by an emerging vehicle from a side road onto the main carriageway, actually occurs more frequently than crashes attributed solely to the motorcyclist's behaviour (38% of crashes were attributed to other vehicles pulling out from side roads, 80% of which were solely attributed to the driver of the other vehicle). A second category of collisions, also deemed primarily to be the fault of the other road user, appears linked to the level of manoeuvrability of the motorcyclist which might not be expected by the driver. For instance, motorcyclists who overtake or filter between lanes of stationary or slow-moving traffic may find cars making a u-turn or changing lanes without apparently detecting their approach (21.5% of all crashes).

Much research is focused upon the role of the motorcyclist in an attempt to reduce their crash liability. Topics of research include attitudes toward risk (though this is primarily dominated by studies of non-compliance with helmet laws, which is a greater problem on continental Europe, Asia and Africa, e.g. Germeni *et al.*, 2009), impairment through alcohol, drugs and fatigue (e.g. Creaser *et al.*, 2009), and motorcyclists' safety-related skills such as hazard perception (Hosking *et al.*, 2010; Lui *et al.*, 2009). However, it is important that research also be devoted to the other road users that contribute to motorcycle crashes. In a precursor to the research discussed in this report, the current authors undertook a review of all potential causes that could lead a car driver to have a collision with a motorcycle. See Crundall *et al.* (2008) for an in-depth discussion of all potential causes, and the limited research that has already been undertaken to address them from the car drivers' perspective.

Figure 1.1: A framework for understanding 'Look But Fail To See' errors (Crundall *et al.*, 2008)

Top-down influences

Attitude

Knowledge

Skills and strategies

Bottom-up influences

Driving schemata

Car–motorcycle interaction schemata

Behaviour

Do they look at the motorcycle?

Do they recognise it?

Do they appraise it appropriately?
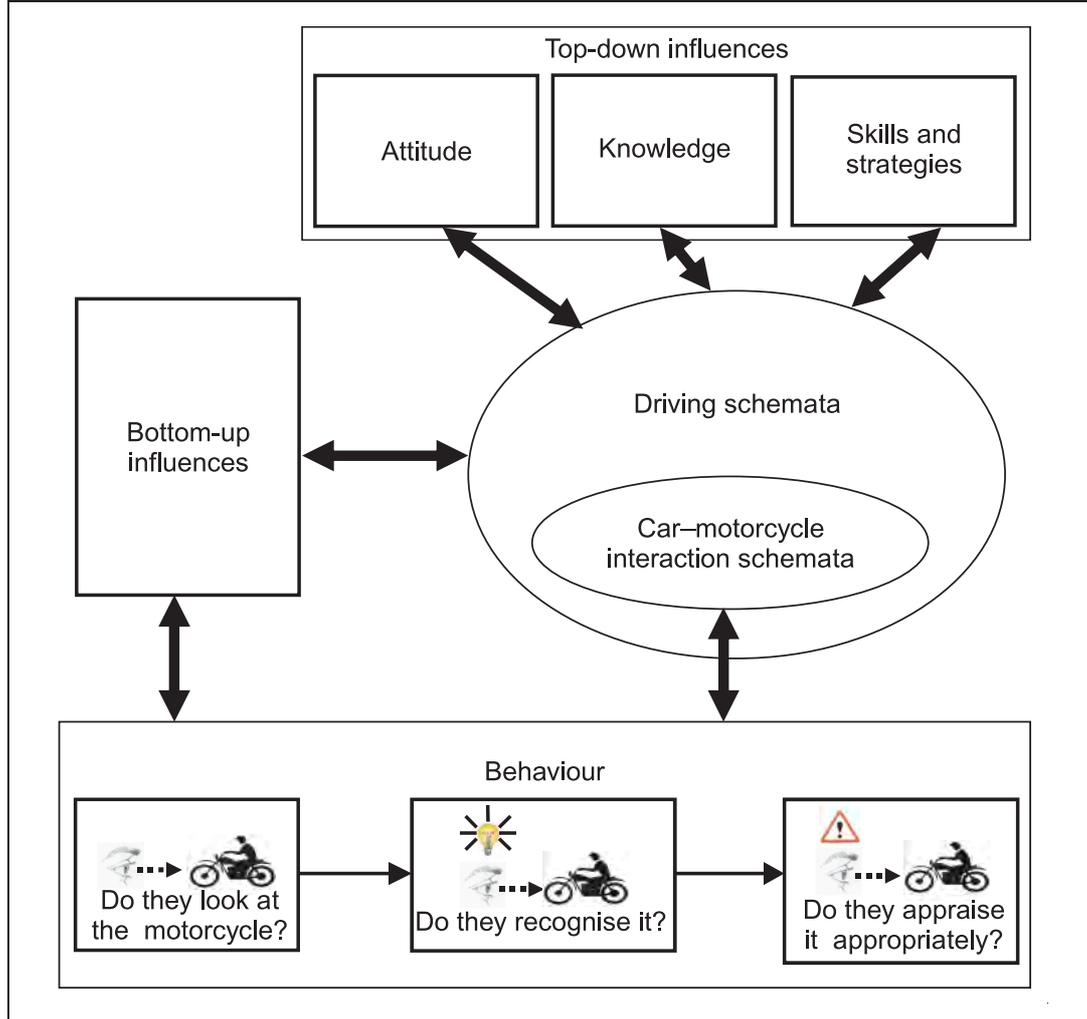
1.2 The solution?

As part of the previous review (Crundall *et al.*, 2008) we suggested a behavioural framework with which one can approach the problem of car–motorcycle collisions, where the fault lies primarily with the car driver (Figure 1.1). These accidents are typically referred to as 'Look But Fail To See' (LBFTS) errors, where the driver claims to have performed all necessary visual checks yet still failed to notice the approaching motorcycle. Brown (2002), however, pointed out that drivers may often report that they 'looked but did not see' the conflicting motorcycle as this may mitigate blame by appealing to an unspecified cause that was outside their control. We have identified at least two further potential causes of these particular right-of-way violations in addition to the LBFTS explanation. First, the driver may fail to **look** appropriately. At a T-junction this could be as basic as completely failing to look down the junction, though more subtle arguments can be made about **where** one looks down the junction. For instance, a single fixation to the focus of expansion

may be optimum for spotting cars in the distance with focal vision, while still being sensitive to nearer conflicting cars through peripheral vision. The narrow image of a nearby motorcycle may be less detectable in peripheral vision, however. The second possibility is that the driver looks in the appropriate places, perhaps with the eye even landing upon a conflicting motorcycle, but yet still fails to **perceive** the motorcycle. It is perhaps common-sense to assume that the brain immediately processes whatever the eye lands upon (the **eye–mind** assumption; Just and Carpenter, 1976), though even in the highly-restricted task of reading, this assumption does not hold in every instance (Underwood and Everatt, 1992). It is possible that a short fixation on a conflicting vehicle is enough to identify an approaching car (especially as this is what one expects to see), yet the same length of fixation may not be sufficient to identify a less salient motorcycle. In such cases it is theoretically possible to have a driver's eyes land on a motorcycle, and then move on to somewhere else, without the driver realising that he/she was looking at a conflicting motorcycle. This is the truest description of an LBFTS error. Finally, one can imagine a situation where the driver looks at the motorcycle, and even perceives it to be a motorcycle, yet fails to adequately appraise the risk that it poses (e.g. misjudging the time-to-contact), resulting in the driver making a risky manoeuvre, possibly leading to a collision.

Despite the theoretical basis for LBFTS errors, and the anecdotal evidence, there has been no experimental evidence for such errors occurring in a complex and dynamic driving situation. Furthermore, we need to investigate the causes for a breakdown in this chain of behaviour. For this we posit that the three links in the behavioural chain (look, perceive and appraise) can be influenced by driving schemata. Schemata are rules and guidelines that allow us to interact in various situations from dining in a restaurant (e.g. if there is a number on your table, you might infer that you order food at the bar) to making a manoeuvre at a T-junction (e.g. if there are give-way lines ahead, you might infer that you should slow for priority traffic). Motorcycle-specific schemata are influenced by a range of top-down factors, including the drivers' attitudes (are motorcyclists all thrill-seekers and risk-takers?), their knowledge (how fast can motorcycles accelerate?), and their visual skills and strategies (where should you look at T-junctions, and how long for?). Future research into car–motorcycle collisions needs to consider these top-down factors (which work in concert with bottom-up factors), along with collecting evidence to identify the break-point in the behavioural chain that results in such collisions.

1.3 Overview of the current studies

This report describes three studies that focus on the role of car drivers in car–motorcycle interactions. Study 1 targets some of the top-down influences that feed into the driving schemata. The study builds on our previous research which found car drivers to have poor empathy and considerable negative attitudes towards motorcycles, and linked them to reported accident rates (Crundall *et al.*, 2007;

2008). In an attempt to improve car drivers' attitudes towards motorcyclists we exposed drivers to a motorcyclist's perspective through the use of hazard perception clips filmed from a moving motorcycle, and had them ride a motorcycle simulator through a series of virtual hazards. By exposing car drivers to some of the dangers that motorcyclists face we hoped to encourage empathy and to reduce negative attitudes towards motorcyclists. Attitude change was measured via pre- and post-intervention questionnaires, based on the questionnaire used in a previous study (Crundall *et al.*, 2008).

Study 2 was concerned with assessing why drivers pull out in front of approaching motorcycles at T-junctions and why some drivers change lanes on multiple-carriageway roads without ostensibly being aware of an overtaking motorcycle. Both of these situations are right-of-way violations on the part of the car driver, and equate well to the two most common forms of car–motorcycle accident as noted by Clarke *et al.* (2007). Often drivers resort to a LBFTS excuse, yet it remains to be seen whether the drivers have problems looking at, perceiving or appraising the conflicting motorcycle. In order to gain insight into this, we developed a multiple screen hazard perception test, allowing drivers to watch videos that included T-junction and change-lane scenarios. The additional screens allowed participants to look down the road at junctions, while inset mirror information allowed drivers to search for overtaking vehicles in change-lane scenarios. Eye movement recordings allowed us to assess whether any problems with motorcycles were due to failures to look (the visual search strategy), failures to perceive (as noted in gaze durations upon conflicting vehicles) or failures to appraise the level of risk (button responses).

Finally, Study 3 attempted to improve where drivers look, whether they perceive, and whether they correctly appraise, the risk of an approaching motorcycle. Three separate training interventions were developed. The performance and eye movements of the three trained groups on the multiple-screen hazard perception rig were compared with a control group.

2 STUDY 1: INCREASING EMPATHY FOR MOTORCYCLISTS

Results from a previous report to the Department for Transport by the authors suggested that car drivers have negative attitudes towards motorcyclists and a lack of empathy for the demands that riders face on the roads from other road users (Crundall *et al.*, 2008). This is especially the case for drivers with 2–10 years of car driving experience, as seen when compared with more experienced drivers and dual drivers (these are participants who have considerable experience both driving a car and riding a motorcycle). It was suggested (Crundall *et al.*, 2007) that negative attitudes and a lack of empathy towards motorcyclists can influence not only the **appraisal** stage of the behavioural chain (Figure 1.1), but potentially also the **perceive** stage (by increasing expectations of seeing motorcycles, and priming drivers to process them faster) and even the **look** stage (by encouraging preparatory searches that might increase the chances of spotting a conflicting motorcycle). Evidence already exists to suggest that individuals who have a close friend or family member who rides a motorcycle, and may have ridden pillion with them, will themselves have better observation of motorcycles, implying that their personal concern over the risks faced by the other person potentially improves their sensitivity to motorcycles (Brooks and Guppy, 1990).

One appealing method for improving attitudes and empathy towards riders is to expose car drivers to the perspectives of motorcyclists. This can be of benefit in two ways. First, it is recognised that in-group members (people who group themselves together on the basis of some commonality) have more positive attitudes towards other in-group members than to out-group members. This suggests that negative attitudes towards motorcyclists may be partly due to the fact that drivers see themselves as the majority group, distinct from the motorcycling minority (e.g. Griffiths and Nesdale, 2006; Brewer, 1979). Exposure to out-group perspectives may lead to greater inclusivity in the car drivers' in-group definition, hopefully with a concomitant reduction in negative attitudes.

Secondly, a motorcyclist's perspective can convey some of the danger and demand that riders face on the road, and provide a vicarious experience of what it feels like to be placed in such vulnerable situations. While testing a multi-dimensional measure of empathy, Davis (1983) found that the ability to take on the perspective of another person was most highly related to cognitive elements of empathy, rather than emotional elements. Inducing emotive empathy in car drivers would be much harder to achieve than an appeal to the cognitive aspect of empathy. If perspective-taking ability merely reflects the extent to which a participant can imagine a situation through the eyes of another actor, then a direct presentation of the other person's perspective should encourage empathy even in those individuals who find it difficult to visualise a situation from an alternative perspective. It has been recently

demonstrated that imagining a situation from another person's perspective can result in greater activation of an area of the brain related to self-referential thought (the ventromedial prefrontal cortex; Ames *et al.*, 2008); thus providing direct access to another person's perspective may have a similar or even greater link to self-referential thought. If the ability to take on someone else's perspective is predictive of empathy (Davis, 1983), then directly presenting car drivers with situations that motorcyclists might face may result in improved empathy in addition to reductions in negative attitudes.

On this basis we predicted that exposing car drivers to the motorcyclists' point of view may improve their empathy and attitudes towards motorcyclists. It was the aim of Study 1 to induce such change through one of two methods. The first method employed hazard perception clips taken from a motorcyclist's perspective to show car drivers just how fast and unexpected hazards can appear to a rider, and how little time they might have to react. These clips provided a high-definition visual representation of the dangers faced by motorcyclists, requiring participants to press a button when they saw the particular hazards. We used hazard perception clips from a car driver's perspective to act as a control condition.

A second method to induce empathy was obtained through the use of a motorcycle simulator, which provides a relatively realistic experience of some of the aspects of riding a motorcycle. While the visual representation of the motorcyclist's perspective is not as realistic as that of the high-definition hazard perception clips, we thought that the interaction provided by a simulator may provide an additional level of immersion that could be important in encouraging empathy. We used a car driving simulator for the control group.

The experiment had four groups of participants, with each participant viewing either the motorcycle hazard clips or the car hazard clips, and undertaking a journey through a hazardous route on either the motorcycle simulator or the car simulator. Nearly two weeks before the laboratory intervention, participants filled in a variant of the Crundall *et al.* (2008) questionnaire to assess negative attitudes towards motorcyclists and empathy. A third factor reflecting the car drivers' level of introspection into the difficulties faced with spotting conflicting motorcyclists, and a fourth factor based on spatial understanding of motorcycles (e.g. how much space does a motorcycle need to safely filter through stationary lines of traffic?) were also included (cf. Crundall *et al.*, 2008). Participants were then randomly assigned to a set of hazard clips and a simulator (car or motorcycle), and undertook both in a counterbalanced order. It was predicted that the motorcycle hazard clips and the motorcycle simulator would improve scores on a post-intervention version of the questionnaire (filled in immediately after the intervention), especially for the negative attitude and empathic factors.

2.1 Method

2.1.1 Participants

One hundred and thirty six participants took part in the experiment (76 females, overall mean age = 22.9; SD = 3.52; range = 20 to 42). The participants were recruited through advertisements and were mainly native UK car drivers (with very few exceptions of non-native drivers who still had considerable experience of driving in the UK), with between 3 to 10 years of driving experience (mean experience since passing test = 4.8 years; SD = 2.49). None of the participants reported ever having driven an LGV (large goods vehicles), a bus, a motorcycle (of any size), or a taxi. While we were only concerned to minimise the influence of motorcycle experience, the other measures of driving experience (along with a number of items on the pre-intervention questionnaire) were included to deflect initial awareness that the study was primarily oriented towards motorcycles.

The participants were randomly distributed to the four groups. There was a group who were presented with car hazard perception clips and drove the car simulator (CcCs (car clips – car simulator); $n = 32$, of which 19 were females), a group who saw the motorcycle clips and drove the car simulator (McCs (motorcycle clips – car simulator); $n = 33$, 20 females), a group who saw car clips and rode the motorcycle simulator (CcMs (car clips – motorcycle simulator); $n = 36$, 18 females), and a final group who saw motorcycle hazard perception clips and rode the motorcycle simulator (McMs (motorcycle clips – motorcycle simulator); $n = 35$, 19 females). There were no significant age or licence seniority group differences ($ps > 0.10$). Participants were offered an inconvenience allowance of £15 for their time. All of them had normal or corrected-to-normal vision.

2.1.2 Apparatus and stimuli

2.1.2.1 Attitude questionnaire

The questionnaire presented 30 statements, 15 of which were relevant to motorcycles and were taken from Crundall *et al.* (2007; 2008). Of these 15, 13 were statements that respondents could agree or disagree with on a seven-point Likert-type scale, varying from 'disagree strongly' to 'agree strongly', while two had other seven-point scales, relevant to the specific statements. The 15 motorcycle items mapped onto the four factors identified by Crundall *et al.* (2008; negative attitudes to motorcyclists, empathic attitudes towards motorcyclists, awareness of perceptual problems, and spatial understanding regarding motorcycles). The remaining 15 statements were related to other road users such as car drivers, LGV drivers, bus drivers, taxi drivers and pedestrians (for the full list of questions see Appendix 1). The non-motorcycle items served as control questions for the motorcycle items, as well as to conceal the fact that the study was solely concerned with motorcycles. The questionnaire was presented online. Each item appeared on a separate display,

and once answers were given, there was no option to go back to view previous questions or to change previous answers.

2.1.2.2 Recollection of questions and answers, and self-perceived attitude change

The post-intervention questionnaire included a number of additional questions asking participants about their recollection of the pre-intervention questionnaire and whether they had any specific intentions to answer questions in a certain way when filling in the post-intervention questionnaire. Items used a seven-point Likert-type scale, varying from either 'no recollection' to 'perfect recollection' (memory questions) or from 'never' to 'always' (intention questions). The questions asked whether the respondents remembered the items from the previous questionnaire; whether they could remember their previous answers; whether they approached the questions with the intention to respond identically to their previous answers; and whether they approached the questions with the intention to respond differently to their previous answers. Two final questions asked participants to rate their general attitudes towards motorcyclists both before and after the intervention (again on a seven-point scale, with higher scores reflecting more positive attitudes).

2.1.2.3 Hazard perception clips

Fifteen short clips were filmed from a moving motorcycle in a wide-screen high-definition format, and then edited such that each contained one major hazard reflecting typical hazards seen by motorcyclists on the roads (e.g. right-of-way violation by a car from a side street, a car making a u-turn to avoid congestion in front of a filtering motorcycle, a car entering a roundabout in front of the motorcycle, etc.). These motorcycle clips reflected what a motorcyclist would see, including judder due to a change in road surfaces, and the tilting of the scene when navigating bends. An equal number of clips from the car driver's viewpoint were used for a control condition. These were similar in structure to the motorcycle clips and had been validated in previous research (Jackson *et al.*, 2009). The clips were a mixture of genuinely occurring hazards and staged clips. Figure 2.1 contains screen shots from a motorcycle clip and a car clip.

2.1.2.4 Simulators

For the motorcycle condition, the Honda Motorcycle Rider Trainer was used. This simulator has been used in previous research studies (e.g. Liu *et al.*, 2009) for testing motorcycle experience, though it is more typically used by Honda as a training and marketing tool. It consists of a motorcycle handlebar and controls mounted at desk height (ignition, signalling and horn), and pedal controls for clutch operation and braking (it does not, however, allow the bike to lean to the sides). The simulator was used in its manual mode, and the virtual model was based on a medium-sized motorcycle. The simulated scene was played through a Sony

VPL-EX4 projector (1024 × 768 pixel resolution) on to a white wall creating an image of approximately 2.2 metres by 1.7 metres (see Figure 2.1). Three virtual routes were chosen: two for practice rides and one for assessment. One practice route was a straight road with no traffic. Another one was a predetermined route in a city environment without traffic. Together, the two practice rides lasted approximately five minutes. The hazardous route was in a city environment with traffic and with 10 hazards (e.g. a parked car reverses from a driveway into the road in front of the rider). This ride lasted approximately eight minutes.

For the car condition a Faros GB3 car simulator was used. As with the motorcycle simulator, this also has been used in previous research, in this case to demonstrate the beneficial effects of commentary training on hazard perception (Crundall *et al.*, 2010). This simulator presents the visual world across three 19-inch LCD monitors (380 mm × 300 mm). Door mirror and rear-view mirror information is available in the three-screen scene, while speed information was available via a real speedometer embedded in a dashboard (see Figure 2.1). All car controls (steering wheel, handbrake, lights, indicators, and windscreen wiper switches, gear box and gear stick) were modelled on a right-hand drive Vauxhall Corsa. Following a practice drive, the hazardous drive lasted approximately nine minutes, contained nine predetermined hazards and included other traffic in a city environment.

Figure 2.1: Screen shots taken from: (a) the motorcycle hazard clips; (b) the car hazard clips; (c) the motorcycle simulator; and (d) the car simulator

(a)   (b)

(c)   (d)
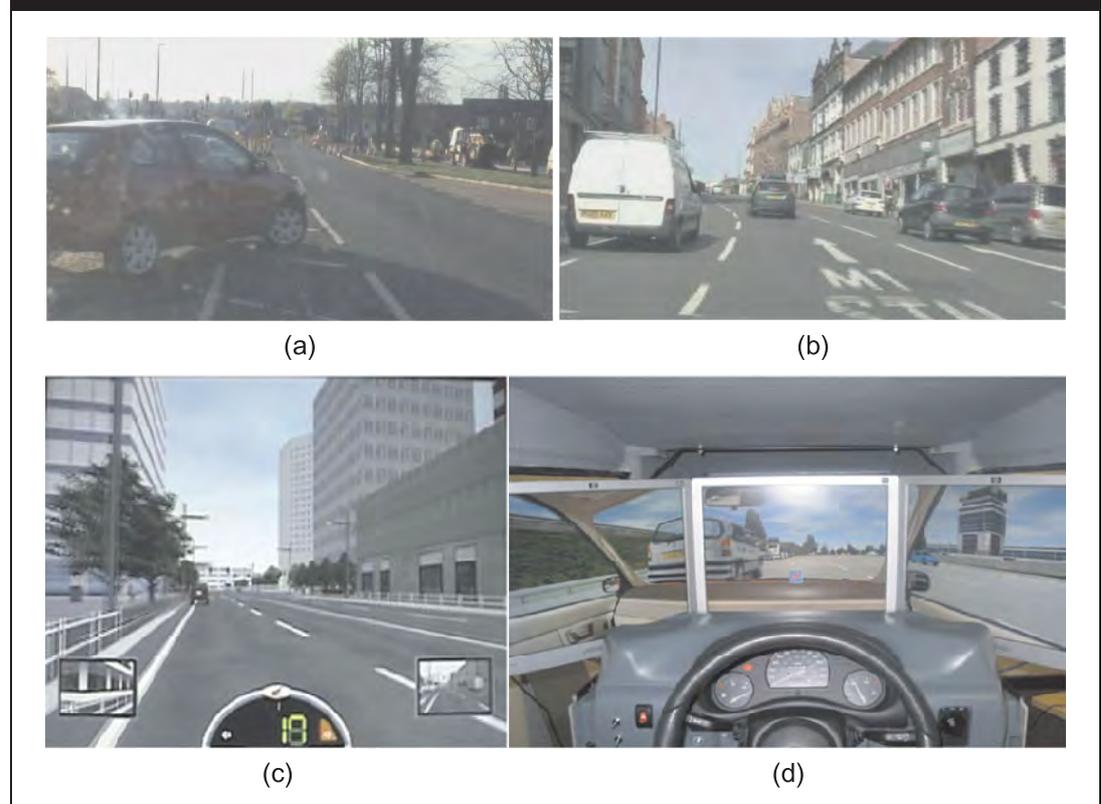
2.1.3 Design

The study assessed change in responses to items between a pre- and a post-intervention questionnaire for four groups of drivers: those who saw motorcycle hazard clips and drove in the car simulator (McCs), those who saw motorcycle clips and rode on the motorcycle simulator (McMs), those who saw car hazard clips and drove in a car simulator (CcCs), and those who saw car clips and rode on a motorcycle simulator (CcMs). With this design we intended to isolate whether it was the high-definition video or the interactive simulator that had the greatest effect upon attitudes.

The primary analysis was concerned with how the attitude ratings changed following the assessment, across the four intervention groups. Comparisons were made between the overall motorcycle items and the filler items (regarding taxis, buses, etc.) to assess whether any improvement had been motorcycle-specific. Additional analyses broke down the motorcycle items according to their underlying factors (comparing changes in negative attitudes, empathic attitudes, awareness of perceptual problems and spatial understanding) to identify whether the intervention had specifically targeted negative attitudes and empathy.

The behaviour of participants in the various conditions (performance on the hazard perception tests and on the two simulators) is not of relevance to the current study, which is concerned with the mere impact of undertaking a test upon subsequent attitudes towards motorcyclists. Indeed, no specific factors were manipulated in the study to provide any *a priori* rationale for behavioural analyses. For instance, hazard perception clips would be typically validated by demonstrating a difference in hazard response times between drivers with a high or low crash risk (often using driving experience as a surrogate). In the current study no effort was made to recruit participants according to specific sub-groups (safe or unsafe, experienced or inexperienced). Furthermore, it is not even necessary that the hazard perception clips are 'validated' (while the car clips have been validated on groups of differing driving experience by Jackson *et al.* (2009), the current motorcycle clips have not been validated in this way). The validation of hazard perception clips ensures that the scenarios discriminate between safe and unsafe drivers, usually in regard to a response time measure. A lack of validation in this sense usually means that the hazard was either easy to see in advance (creating a floor-effect in response times across driver groups) or very difficult to spot until the last moment (creating a ceiling-effect). In both cases the hazard is still seen, but fails to discriminate between safe and unsafe drivers. Fortunately, this study does not aim to discriminate between driver groups, nor does it need to. The rationale for providing hazards (whether in the simulators or in video clips) is to give the participants an insight into the type of dangers that motorcyclists might face.

2.1.4 Procedure

Approximately two weeks after completing the online pre-intervention questionnaire, the participants arrived at the laboratory. The participants in each of the four groups completed two tasks (e.g. the car simulator followed by motorcycle hazard perception clips), followed by the post-intervention attitude questionnaire. Finally, they completed an additional set of questions about their recollection and intentions when completing the post-intervention questionnaire, and about their general attitudes towards motorcyclists before and after the experiment.

2.1.4.1 Hazard perception clips

The participants were seated in front of a computer screen. They were told that they were about to watch video clips taken from, depending on the condition, a car driver's or a motorcyclist's viewpoint, and that in each clip they needed to spot one major hazardous event – a situation where the rider or driver had to brake or steer to avoid some danger. The participants were instructed to press the spacebar as soon as they saw the hazard, and were told that following their button press the clip would stop and the screen would go black. At this point the experimenter asked the participant to verbally report what the hazard was. After the participants verbally told the experimenter what the hazard was, the rest of the clip was shown. Following this the next clip began until all 15 clips were shown. The clips were presented in a random order.

2.1.4.2 Simulators

The participants engaged in the motorcycle simulation were seated in front of the simulator, approximately 3.5 metres from a white wall on which the image was projected (with images subtending a visual angle of approximately 35×27 degrees). They were provided with a brief explanation of how the motorcycle (simulator) is operated (i.e. braking, throttle, clutch and gear operation, electric ignition and signalling), after which the participants completed two practice rides. In the first practice ride (on a straight road), they were required to shift gears and increase speed until they had reached sixth (top) gear, following which they reduced speed and gears until obtaining a full stop. In the second practice ride, they practised riding in a city environment without traffic, allowing them to experience turning and signalling. After these rides, they completed the hazardous route.

Each car simulation session was conducted in a similar fashion, though only one practice drive was given as all the participants were familiar with the use of a manual transmission car.

2.2 Results and discussion

2.2.1 Analysis of attitude change

The ratings given to the pre-intervention items were subtracted from the ratings to the identical post-intervention items to produce a single score of **attitude change** for each question. Five analyses of variance (ANOVA – a statistical technique to test whether the groups differ following their attitudinal training intervention) were conducted on this measure of attitude change. The main ANOVA compared the mean change in the ratings for all 15 motorcycle items with the mean change in the non-motorcycle items across the two types of simulator and the two types of hazard clip. Four subsidiary ANOVAs combined motorcycle items into the four factors (Crundall *et al.*, 2008) of negative attitudes, empathic understanding, awareness of perceptual problems and spatial understanding.

In the overall ANOVA, a significant main effect of question type ($F(1,132) = 41.69$; $p < 0.001$) indicated greater improvement in ratings for motorcycle-related items as compared with non-motorcycle items. Motorcycle items improved by 0.24 points on the seven-point scale, while non-motorcycle items saw a decrease of -0.03 points across the pre- and post-intervention questionnaire (effectively no change). The three-way interaction between question type, hazard-clip type and simulator type was also significant ($F(1,132) = 4.83$; $p < 0.05$). Greater improvement was indicated in overall attitudes towards motorcyclists for those participants who saw the motorcycle clips and rode on the motorcycle simulator (McMs), compared with the mixed groups (McCs and CcMs). However, the group who saw the car-based hazard clips and who drove the car simulator (CcCs) also showed considerable improvement compared with the two groups with mixed conditions. There was, however, some marginal evidence of a slight trade-off, with the two groups with most improved motorcycle attitudes also showing a slight decrease in attitudes towards the other road users (taxi drivers, bus drivers, etc.) as reflected in the attitude change scores on the non-motorcycle questions (see Table 2.1).

Significant main effects of question type (motorcycle versus non-motorcycle items) were also found in the four additional ANOVAs, which compared motorcycle items for each factor (e.g. negative attitudes, empathy, etc.) with the non-motorcycle items (Fs(1,132) = 22.1, 66.3, ps < 0.001, respectively for the empathic and perceptual factors, and Fs(1,132) = 4.0, 6.0, ps <0.05, respectively for the negative and spatial factors). All of these main effects indicated greater improvement in the motorcycle factors compared with the non-motorcycle items.

The spatial understanding factor was the only factor to produce a significant three-way interaction between question type (spatial factor versus non-motorcycle items), clip type and simulator type ($F(1,132) = 6.1$; $p < 0.05$). Similarly to the main ANOVA, greater improvement on the spatial items was found with car hazard clips compared with motorcycle hazard clips when presented in conjunction with the car

simulator. Table 2.1 gives improvement scores for the four groups, for the non-motorcycle and motorcycle items, and for the four motorcycle factors.

Table 2.1: The mean attitude change (with standard deviations) for participants exposed to the four different conditions					
Motorcycle items	**CcCs**	**CcMs**	**McCs**	**McMs**	**Total**
Negative	0.15 (0.68)	0.1 (0.76)	—0.01 (0.53)	0.13 (0.83)	0.09 (0.71)
Empathic	0.26 (0.53)	0.17 (0.52)	0.32 (0.64)	0.29 (0.50)	0.26 (0.55)
Perceptual	0.73 (0.93)	0.49 (0.74)	0.82 (1.04)	0.76 (1.00)	0.70 (0.93)
Spatial	0.44 (0.80)	0.11 (0.79)	—0.06 (0.88)	0.11 (0.68)	0.15 (0.80)
Motorcycle items	0.34 (0.36)	0.20 (0.34)	0.26 (0.44)	0.31 (0.47)	0.28 (0.41)
Non-motorcycle items	—0.08 (0.32)	0.03 (0.41)	0.02 (0.50)	—0.10 (0.48)	—0.03 (0.44)

Note, CcCs = 'car clips – car simulator'; CcMs = 'car clips – motorcycle simulator'; McCs = 'motorcycle clips – car simulator; McMs = 'motorcycle clips – motorcycle simulator'. These means are further broken down across the four questionnaire factors, and for all motorcycle and non-motorcycle items.

Thus, following their participation in the experiment, the participants had slightly, but significantly, improved attitudes towards motorcyclists, but not towards other road users. This improvement was seen overall with the motorcycle-related items as well as within the particular factors identified by Crundall *et al.* (2008). Specifically, there was an increase in reported empathy and a reduction in the negative attitudes of car drivers, as well as improved spatial understanding and awareness of the perceptual demands involved in spotting motorcycles. The greatest improvements were noted in the empathy ratings (as predicted) and in the increased awareness of perceptual problems (not predicted).

Although the experiment appears to have achieved its primary goal of improving attitudes specifically towards motorcyclists rather than other road users, there are two caveats to these findings. The first caveat is that there was no clear advantage for the motorcycle simulator and hazard clips, as compared with the car-based conditions which were used as controls. Instead, attitude improvement on motorcycle items appears to be more dependent on the consistency of the perspectives used. Thus, maintaining either a car's or motorcyclist's perspective throughout the intervention was more beneficial than those conditions which combined car clips with the motorcycle simulator, or combined the motorcycle clips with the car simulator.

Why should the condition containing the car clips and the car simulator be as effective as the motorcycle clips/simulator condition with regard to the improvement of attitudes towards motorcyclists, but not to other road users? It suggests that motorcycle attitudes can be improved with any hazard-based intervention (regardless of perspective). As the non-motorcycle items were predominantly concerned with other road users who are less vulnerable than motorcyclists, it

follows that any successful hazard-based training might improve car drivers' attitudes to road users who are more vulnerable than themselves. Furthermore, it suggests that the mixed conditions (e.g. car clips and motorcycle simulator) incurred a cost presumably due to the need to switch between perspectives.
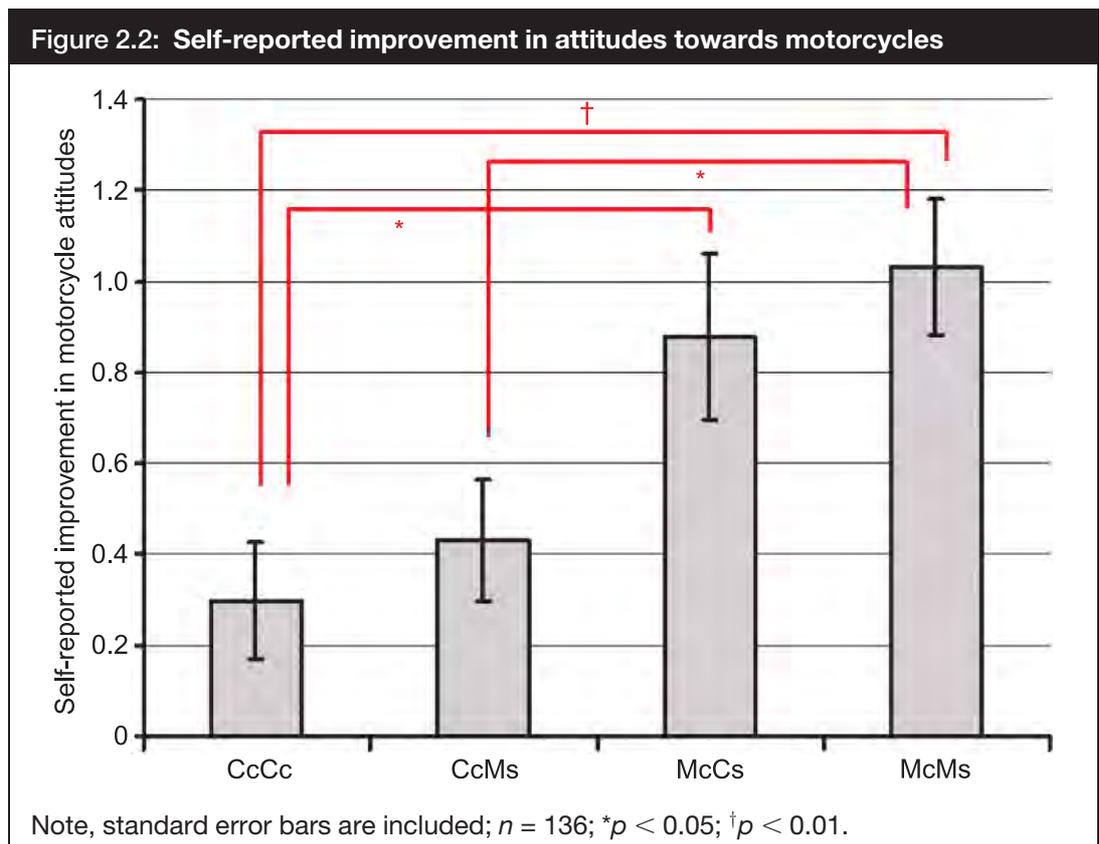
The second caveat is that the level of improvement was relatively minor. While the rather minor improvement in attitudes towards motorcyclists raises a question whether such an effect would have any impact on behaviour in the real world, it has been argued that small significant effects in the context of hazard perception can have important ramifications when one considers the scale of the problem (Horswill and McKenna, 2004). On this basis, however, should we be worried by the suggestion in the data that the greatest improvement in attitudes towards the motorcycle group came at the slight expense of attitudes towards other road users? Again, the effect is small, but if we are arguing that the small improvement towards motorcycles could have ramifications in the real world, then we also need to be aware of the potential negative effects on other groups. There are a number of potential reasons why attitudes might have dipped slightly for these groups. It is possible that drivers' ratings for the non-motorcyclists reflected a change in the contrast between motorcyclists and other road users in light of the training intervention. Alternatively, drivers may divide a certain fixed amount of 'goodwill' among other driver groups (with the absolute amount linked to their overall satisfaction of their driving experience). The implication of this is that if we improve attitudes towards one minority group of road users we risk impairing attitudes to another, as the drivers simply reapportion an existing level of favourable sentiment towards other road users. While these hypotheses are purely speculative at the moment, they raise interesting questions for future research to ensure that, in the search for positive attitude change, we do not inadvertently provoke negative attitude change in an unexpected quarter. For the current results, however, we are comforted that the decline in favourable attitudes to other road users in some conditions is both slight and predominantly related to less vulnerable road users (including buses and LGVs), and is therefore likely to have less of a contribution to fatal or serious collisions than an impoverished attitudinal set towards motorcyclists might. For instance, a negative view of LGV drivers is more likely to produce more cautious behaviour around LGVs, whereas the lack of personal threat from a motorcycle might result in the opposite effect.

2.2.2 *Recollection of questions and answers, and self-reported attitude change*

The participants reported having above medium recollection (4.85 on a seven-point scale where seven is perfect recollection) of the questions from the first completion of the questionnaire (despite the items being presented in a different order), and medium recollection of their answers (3.61). They also reported not having approached the post-intervention questionnaire with any intention to respond either in a particularly identical manner to the pre-intervention questionnaire (2.92 on a

seven-point scale where seven would be a strong intention to do so) or in a particularly different manner (1.77). Finally, the participants reported having more positive attitudes towards motorcyclists after the intervention as compared with before the intervention (improving from 3.94 to 4.61).

A one-way between-groups ANOVA was performed on each of the ratings across the four groups of participants (memory for questions, memory for answers, intention to give the same answers on the post-intervention questionnaire, intention to give different answers on the post-intervention questionnaire, and the difference between pre- and post-intervention self-reported attitudes towards motorcyclists). The analyses revealed a significant group effect only on the difference between self-reported attitudes towards motorcyclists before and after the experiment ($F(3,132) = 5.3$, $p < 0.005$). Post hoc (Tukey HSD, Honestly Significant Difference) tests indicated significant differences between the various groups, which suggested that the greatest improvement in self-reported attitudes towards motorcyclists was due to the use of the motorcycle-based hazard video clips rather than the motorcycle simulator (see Figure 2.2).

Figure 2.2: Self-reported improvement in attitudes towards motorcycles

Note, standard error bars are included; $n = 136$; *$p < 0.05$; †$p < 0.01$.

Analysis of these final questions suggests that: (a) the post-intervention questionnaire is unlikely to be confounded due to memories or strategies; and (b) car drivers believe themselves to be better predisposed towards motorcyclists having watched the hazard perception clips. While the simulators, and even the car-based

control conditions, had an impact on the factors in the questionnaire, the simple self-report displays a clear preference for motorcycle hazard perception clips.

In summary, Study 1 attempted to enhance positive attitudes towards motorcyclists among car drivers by exposing them to some of the demands that motorcyclists face on the road. After the intervention, the participants had more empathic attitudes and fewer negative attitudes, as well as safer attitudes towards motorcyclists in respect to spatial understanding and perceptual knowledge. Self-reported attitude change suggests that the use of motorcycle hazard perception clips was more effective than the simulator, and the intervention was most effective for those car drivers who reported the most negative attitudes prior to viewing the clips or riding the simulator.

The results provide an opportunity for future safety activities to raise awareness of motorcycle safety among car drivers. Film taken from a motorcyclist's point of view appears to have the greatest effect on self-reported attitudes, as well as having an effect on the awareness of perceptual problems and empathy. Such film clips easily lend themselves to advertising campaigns, for instance.

3 STUDY 2: INVESTIGATING THE CAUSES OF T-JUNCTION AND CHANGE-LANE COLLISIONS BETWEEN CARS AND MOTORCYCLES

A number of studies have identified right-of-way violation crashes as the most common type of accident that motorcyclists face (Clarke *et al.*, 2007; Hancock, *et al.*, 1990; Hurt *et al.*, 1981; Wulf *et al.*, 1989). In the UK, the majority of right-of-way violation crashes occur when car drivers pull out of T-junctions, and to a lesser extent when a car changes lanes or performs a u-turn without awareness of an overtaking motorcycle (Clarke *et al.*, 2007).

Though many of these collisions are often attributed to 'Look But Fail To See' (LBFTS) errors, we have acknowledged in Section 1 that there are at least three reasons why a driver might pull into the path of a motorcycle: the driver may fail to **look** in the appropriate places, or they may look at the motorcycle, but still fail to **perceive** it. Finally, where a driver has correctly looked and perceived the conflicting motorcycle he/she may still fail to **appraise** the risk involved in continuing with his/her intended manoeuvre.
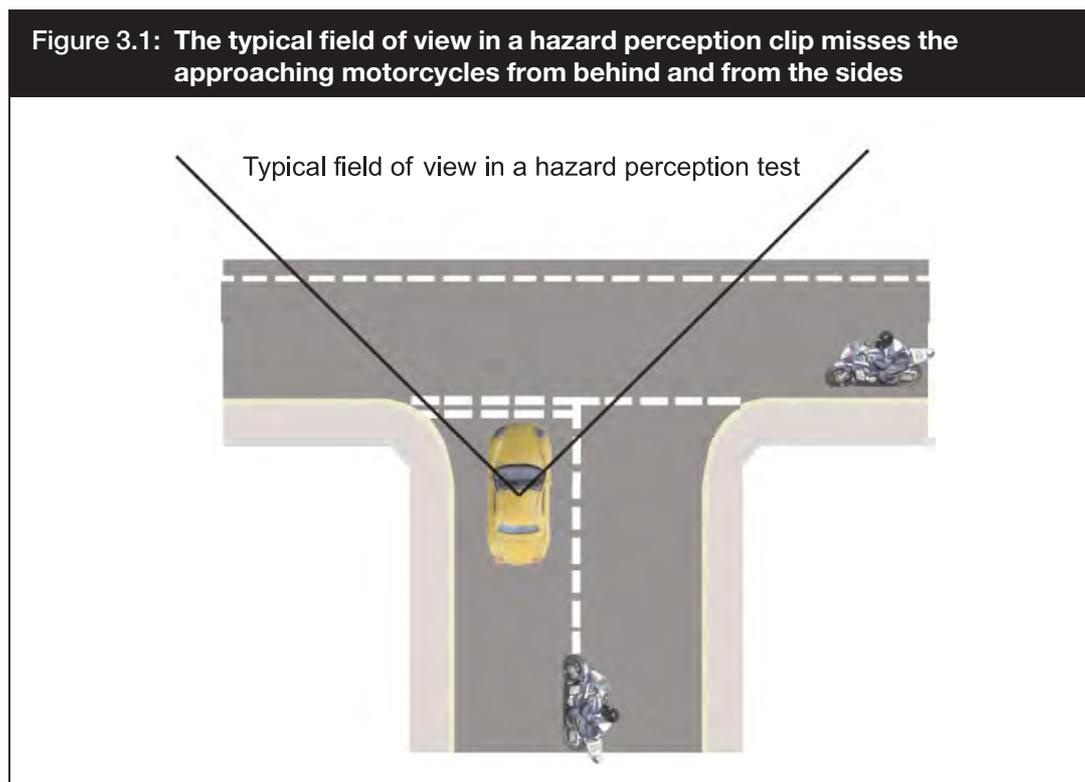
Study 2 was designed to assess driver behaviour in T-junction and change-lane scenarios to assess how they look for and process conflicting motorcycles. Through the application of eye-tracking technology it was intended to search for failures to look or perceive motorcycles, and if no differences were found then any risky behavioural decisions (deciding when to pull out from a T-junction) could then be mostly attributed to problems of appraisal.

In order to investigate these scenarios we first had to decide upon a medium through which to present them to drivers. The first option was to undertake eye-movement research in a real car, either on real roads or on a closed track. This was rejected for pragmatic and ethical reasons. Practically, with motorcycles accounting for only 1% of annual vehicle miles in the UK (Department for Transport, 2010a, b), one cannot guarantee a motorcycle encounter for every participant (and it would certainly be unlikely that the motorcycle would occur in the appropriate location to test LBFTS errors at junctions or when changing lanes). There are also ethical problems with placing drivers in a situation that we know to be hazardous. The closed-circuit option was also rejected, primarily on the grounds of cost and realism. LBFTS errors occur on busy roads with other traffic. It would not be practical to recreate the conditions for a LBFTS error for every participant.

The second option was to use a simulator. Unfortunately, many simulators have limited functionality when it comes to displaying details to the left and right of the driver (often a simulator configuration has the best digital projector producing the forward-facing view, while cheaper projectors are used for the periphery).

Furthermore, even the best interactive graphics are not as detailed as the real world. Decreased detail in textures, lighting, reflections, etc., can theoretically make it easier to spot motorcycles than would be the case in the real world. One last argument against the use of a simulator is that the results of Study 1 suggested that drivers were most greatly impacted by video clips of driving rather than a simulation.

The final option was therefore to use clips of driving, filmed from a moving car in a similar fashion to the hazard perception test clips used by the Driving Standards Agency (DSA) in their testing procedure for learner drivers. One problem with a typical hazard perception clip, however, is that they do not provide the field of view that would allow the driver to look for conflicting motorcycles in the two scenarios we had identified: When pulling out from a T-junction the driver needs to look nearly 90 degrees to the right and left of their current heading, while change-lane scenarios require the driver to be able to look in their mirrors. A typical hazard perception clip only provides approximately 60 degrees of visual angle to the front of the car, and contains no mirror information. Thus, such clips would leave the participant oblivious to whether motorcycles were approaching (see Figure 3.1).

Figure 3.1: **The typical field of view in a hazard perception clip misses the approaching motorcycles from behind and from the sides**

Typical field of view in a hazard perception test

Instead we decided to film a new series of clips with multiple cameras attached to a car providing a near 180 degree forward view, with additional cameras filming to the rear of the car to provide mirror information. This allowed us to film T-junction and change-lane scenarios with a range of conflicting motorcycles and cars. It was the intention that participants would watch these clips knowing that they had to press a

button to either pull out from a T-junction or change lanes on a multiple-lane carriageway when they felt it was safe to do so. We termed this the 'sanctioning manoeuvres task'. Section 3.1 gives a detailed account of how this task was developed.

In addition, it was our intention to compare both novice and experienced car drivers' performance on the T-junction and change-lane scenarios with a group of dual drivers with considerable experience of both riding a motorcycle and driving a car. We know that dual drivers have more favourable attitudes towards motorcyclists (Crundall *et al.*, 2008), that they have better hazard perception skills than ordinary car drivers (Horswill and Helman, 2003; Haworth *et al.*, 2005), and that they may be less likely to crash into other motorcyclists when they themselves are driving a car (Magazzù *et al.*, 2006). In the absence of any absolute guidelines for how one should deal with our test scenarios (beyond not sanctioning a manoeuvre that would lead to a crash), the dual drivers provide a useful benchmark against which to judge other drivers.

We therefore tested 25 novice drivers, 25 experienced drivers and 24 experienced dual drivers on the multiple-screen hazard perception rig (total $n = 74$). For both the T-junction scenarios and the change-lane scenarios we presented 10 clips with a conflicting car, 10 clips with a conflicting motorcycle and 10 clips with no conflicting vehicle (where we define a conflicting vehicle as one which would come into conflict with the participant should both vehicles continue on their current trajectory). The T-junction scenarios and the change-lane scenarios were randomly presented in a single block along with 12 additional clips (making 72 clips in total). These final 12 clips contained a specifically hazardous event (such as a car reversing from a driveway into the path of the film car). The participants were told to press a hand-held button when they decided it was safe to conduct the appropriate manoeuvre for each clip. While performing this primary task, the participants also had to be vigilant for any hazardous events, pressing a foot pedal to register their occurrence. This dual task design ensured that the participants did not devote all their attention to the sanctioning manoeuvres task at the expense of normal levels of road safety.

3.1   Method

3.1.1 *Participants*

Eighty-one participants volunteered to take part in the experiment, and were offered an inconvenience allowance of £10 for their time. Prior to any data examination, the data of five female participants were excluded from the novice group in order to make the male/female ratio of the three groups more similar (those with either the poorest calibration and/or with the largest number of missing trials due to system crashes). One experienced car driver was excluded because she had several of years of experience riding a scooter. Thus, there were 25 novice car drivers (mean

age = 20.6, SD = 2.2; range = 18–27; mean licence seniority = 1.6, SD = 0.6), 25 experienced car drivers (mean age = 33.4, SD = 8.5; range = 24–58; mean licence seniority = 14.8, SD = 7.9), and 24 dual drivers (mean age = 44.9, SD = 9.6; range = 27–62; mean car licence seniority = 25.7, SD = 11.3; mean motorcycle licence seniority = 20.0, SD = 11.0).
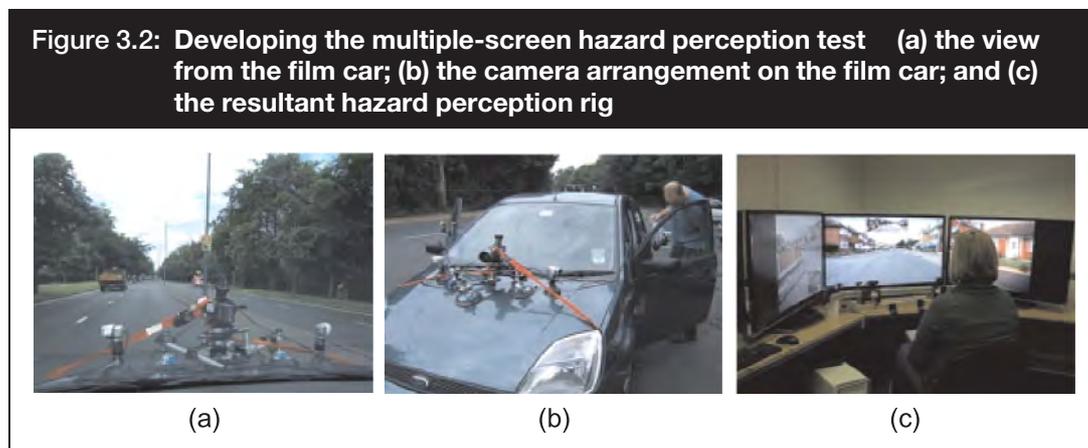
3.1.2 Design

The design of the study essentially combined two experiments in one. Both the T-junction experiment and the change-lane experiment had the same design, with 10 conflicting car clips, 10 conflicting motorcycle clips and 10 no-vehicle clips. In the T-junction clips, half of the conflicting vehicles approached from the left and half from the right (balanced across vehicle type). When crossed with three driver groups (novices, experienced drivers and dual drivers), this led to a 3 × 3 mixed design. In some of the analyses it was necessary to compare car clips and motorcycle clips across the three driver groups (2 × 3), while in other analyses it was possible to include the no-vehicle trials for the full 3 × 3 analysis. The 12 hazard clips were included to ensure that there were enough hazard events to reward the participants' vigilance for hazards across all 72 clips.

Response times and eye movements to the sanctioning manoeuvres task were recorded for analysis. Foot pedal response times to the hazards were recorded, but do not form part of the current analyses.

3.1.3 Filming

All clips were filmed around Nottingham in August 2008. Six digital video cameras were mounted externally to a film car using suction mounts. Three forward facing cameras, positioned on the bonnet of the car, recorded the front and side views, while three rear facing cameras, positioned on the side mirrors and on the roof of the car, recorded the view that one would see in the three mirrors (see Figure 3.2(a) and (b)). Most of the clips filmed were designed to allow hypotheses regarding car–

Figure 3.2: **Developing the multiple-screen hazard perception test** **(a) the view from the film car; (b) the camera arrangement on the film car; and (c) the resultant hazard perception rig**

(a)   (b)   (c)

motorcycle interactions – either at T-junctions or while changing lanes – to be investigated, whereas an additional set of hazardous scenarios were also filmed. The T-junction and change-lane scenarios all involved stooge vehicles co-ordinated through shortwave radio contact. In addition, the majority of the specific hazard clips were also staged. All clips were approved before filming began by an accompanying police escort who remained with the film crew. A variety of cars, motorcycles, outfits and helmets were used across clips. Both motorcycles and cars did not use daytime running lights. Their arrival at the junction was co-ordination via walkie-talkies, with the intention that they would arrive at the junction approximately two seconds after the participant's vehicle. This was considered appropriate in that it would not allow a safe response to be made without a failure in either looking, perceiving or appraising.

3.1.4 Editing and clip selection

Following the filming, the footage was edited using Adobe Premiere CS4 software into clips lasting between 10 and 30 seconds. The forward views were synchronised and the mirror information was inserted. The video stream from the rear-view mirror camera was inset at the top of the central screen, while the left- and right-side mirror video streams were inset into the bottom-right corner of the left screen and the bottom-left corner of the right screen, respectively. Three separate files were used for playback, across three large LCD screens. Custom software was designed for synchronising the playback of the three files across the three screens.

Once the clips had been filmed and edited, a pilot study was conducted, based on which 72 clips were chosen for the final playlist, including 30 change-lane scenarios (10 with a car, 10 with a motorcycle and 10 with no conflicting traffic), 30 T-junction clips (10 with a car, 10 with a motorcycle and 10 clips with no conflicting vehicles) and 12 hazard perception clips. In the T-junction clips, there was an equal number of cars and motorcycles that approached from the left and the right.

3.1.5 Playback system and experimental set-up

The playback system consisted of a PC workstation and three Toshiba 40XF355D televisions (40 inch). The central screen displayed the front view while the two lateral screens, positioned at a set angle of 120 degrees to the left and right of the central screen, displayed the side views (Figure 3.2(c)). Although the horizontal visual angle across the three screens was approximately 112 degrees (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 degrees. The pilot study did not reveal any problems with this squeezing of the visual angle, and the overall appearance was reported as realistic. A push button and a foot pedal were provided for participants to record their responses obtained to execute a manoeuvre and their responses to hazards, respectively.

3.1.6 Eye-tracking system

A Smart Eye Pro tracking system was used to record eye movements. The set-up consisted of four cameras positioned in front and to the sides of the participants, along the bottom border of the screens. Two infrared flashes were positioned between the external and internal cameras. Prior to data collection for each participant, the software (Smart Eye Pro 5.4) built a unique head model using facial features, following which a standard gaze calibration procedure was performed.

3.1.7 Procedure

Participants were told that they were about to watch a series of video clips taken from a car driver's perspective, where the central screen would display the front view from a moving vehicle, while the two lateral screens would display the side views. They were also told that mirror images would allow information from behind the vehicle to be attended. While viewing the clips they were asked to imagine that they were driving the car. It was explained that their task required them to press a button during each clip as quickly as possible when they thought it safe to make a particular manoeuvre. They were told that before each clip began they would hear a recorded voice telling them what that manoeuvre would be. They were told that in some of the clips the required manoeuvre would be to pull out of a T-junction (always turning right) whereas in others it would be changing lanes. Finally, participants were also asked to constantly monitor for hazards (e.g. pedestrians stepping into the road in front of their vehicle) and to press the foot pedal as quickly as possible to register their recognition of a hazard. Hazards were defined as any situations where the driver should change his or her driving behaviour to avoid immediate danger (i.e. braking, swerving, etc.).

Prior to each clip playing, the screen remained black while a recorded voice announced the manoeuvre (either 'at the T-junction ahead, press the button to turn right' or 'press the button to move into the right-hand lane'). Specific hazard clips were preceded by dummy manoeuvre instructions. Responses to the sanctioning manoeuvres task were not analysed for these clips however.

Each clip played until the participant sanctioned the manoeuvre, or the car was about to make the manoeuvre itself. The pilot study suggested that that all clips with conflicting traffic were considered to leave enough time to make a safe response before the clip ended. Despite this, one of the change-lane scenarios proved to get very few responses, suggesting that participants did not think it was safe enough to commit to the manoeuvre at any point. As detailed in Section 3.2.2, this clip was removed from all analyses. Button responses were recorded and participants were informed on-screen whether they had or had not pressed a button.

3.2   Results

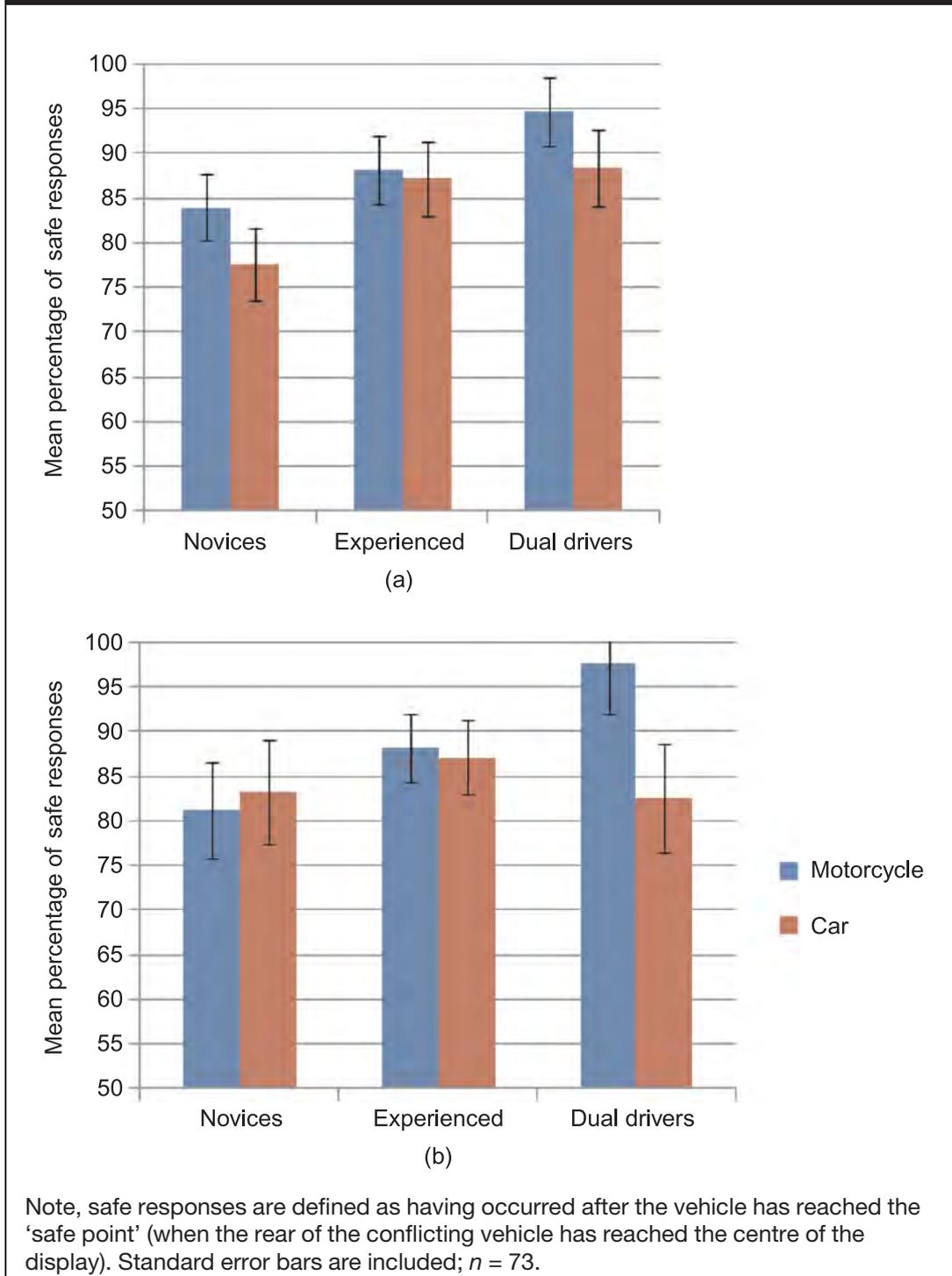### 3.2.1   T-junction scenarios

In a pilot study four expert raters (driving psychologists) viewed the T-junction clips and rated them as to how safe it would be to make an early manoeuvre from the junction rather than waiting for the conflicting traffic to pass. They had three options to choose from: safe to pull out without waiting, risky to pull out, and definitely unsafe to pull out without waiting. Safe responses scored one point, risky responses scored two and unsafe decisions scored three points. Mean ratings for the T-junction clips ranged from one to three, with a mean of 2.5. Five T-junction clips (three cars and two motorcycles) received an average rating below two, suggesting that a driver might safely pull out in front of the conflicting vehicle with a minimal risk of collision. While these clips were left in the experiment to provide sufficient variation in the approach times of conflicting vehicles, they were removed from the calculation of the percentage of safe responses (the percentage of clips in which the participant pressed the button after the conflicting vehicle had passed the junction) and the calculation of response times (RTs) relative to the safe point (i.e. the point at which the rear of the conflicting vehicle has reached the centre of the central screen, reflecting an absolute point at which it is safe to begin the manoeuvre). This produced negative RTs, reflecting the button being pressed during the approach of a conflicting vehicle, and positive RTs, reflecting a response made after the conflicting vehicle had passed. The removal of those clips with an average risk rating below two ensured that all the responses made before the safe point which contribute to the analyses are considered risky. Prior to analysis any responses that were three standard deviations away from the mean RT for each clip were removed. This protected against participants making a very early response which they considered safe (despite the raters thinking otherwise).

The mean percentage of trials on which participants responded after the safe point was analysed with a 2×3 analysis of variance (ANOVA) with two types of conflicting vehicle (motorcycles and cars) and three driver groups of varying driving experience (novice, experienced and dual drivers). One dual driver was omitted from the analysis due to missing data.

The main effect of vehicle ($F(1,70) = 7.2$, MSe = 106, $p < 0.01$) revealed that motorcycle clips received more safe responses than car clips (89% versus 84%). There was also an effect of driving experience revealed in the *a priori* contrasts, with dual drivers making more safe responses than novices ($p < 0.05$). The two main effects can be noted in Figure 3.3(a). While the experienced drivers have ostensibly no difference in their percentage of safe responses across the motorcycle and car clips, this did not result in a significant interaction. It is possible, however, that the different ages of the participant groups had a confounding influence upon the results. We attempted to statistically remove the potentially confounding influence of age (partialling out the effects of age through the use of an analysis of

covariance (ANCOVA)). The resultant adjusted means do bring the interaction to the fore, suggesting that the dual drivers do have the greatest percentage of safe responses in motorcycle clips compared with the other groups ($F(2,69) = 4.1$, MSe = 96, $p < 0.05$; Figure 3.3(b)).

Figure 3.3: The mean percentage of safe responses   (a) shows the unadjusted means; and (b) contains means adjusted for age

Note, safe responses are defined as having occurred after the vehicle has reached the 'safe point' (when the rear of the conflicting vehicle has reached the centre of the display). Standard error bars are included; $n = 73$.

Unfortunately the statistical conditions under which an ANCOVA should be conducted may have been breached (both the within and between-subject factors show heterogeneity of the regression slopes primarily due to the truncated age range in the novice group). While this interaction adheres to our predictions, suggesting that the dual drivers are the safest in relation to motorcycles, we do not know if this result is merely due to the 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. Regardless of whether age is partialled out of the above analysis, it is clear that dual drivers are giving the safest responses.

A similar 2×3 ANOVA was conducted on the response times (RTs). The main effect of vehicle ($F(1,70) = 15.5$, MSe $= 0.42$, $p < 0.001$) revealed more cautious responses to the motorcycles than to cars (621 ms versus 197 ms). These RTs are positive, showing that the average response time did fall after the conflicting vehicle had passed, though negative RTs from responses prior to the safe point also contribute to the means. The results suggest that, overall, drivers are giving the motorcycles a greater safety margin than they give to conflicting cars. There was again an effect of driving experience revealed in the *a priori* contrasts, with dual drivers having longer RTs than novices ($p < 0.05$). The means are displayed in Figure 3.4, showing that novices give the most dangerous responses (their means are lowered by a larger number of risky responses before the safe point). In absolute terms, the greatest safety margin is given by dual drivers to motorcycles, supporting the hypothesis that dual drivers respond more safely to motorcyclists on the road than other drivers.

Figure 3.4: The mean response times to make a decision to pull out, relative to the safe point
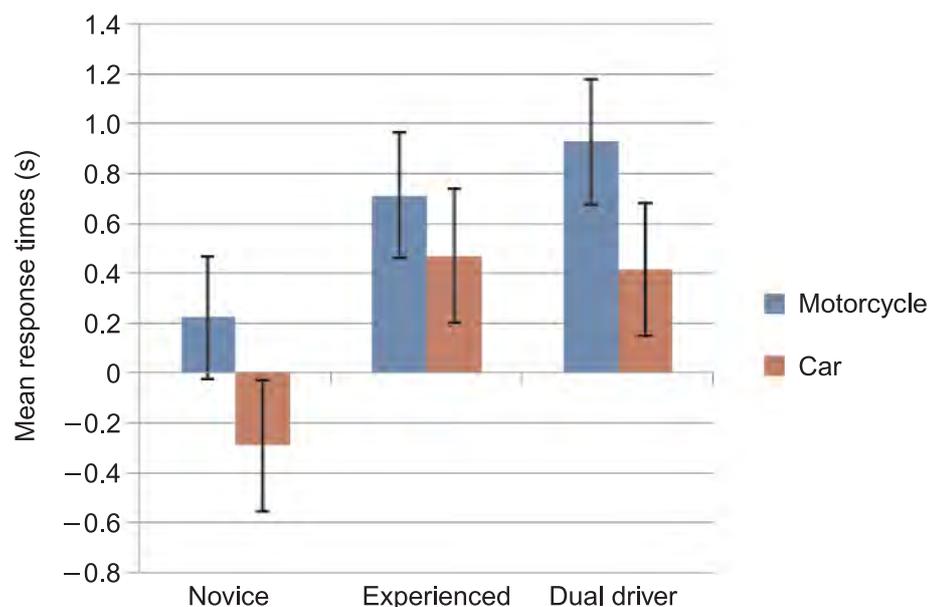
Note, standard error bars are included; $n = 73$.

Response times were also compared between groups for the no-vehicle trials. RTs for these trials were calculated relative to the time when the participant's vehicle stops at the give-way line, with negative numbers reflecting decisions made prior to the car stopping at 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 slowly than novice drivers (790 ms versus 235 ms), with experienced drivers falling in-between (513 ms). This suggests that increased experience (especially of riding a motorcycle) leads to significantly more conservative decisions to pull out from T-junctions. 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. Regardless of the unknown contribution of age to this experiential effect, it is clear that the slower responses are made by the dual drivers whom we would expect to be safer.

3.2.1.1 Do dual drivers have different scanning strategies to other drivers at junctions? – mean eccentricity and spread of search

If dual drivers respond differently to motorcycles than other drivers do, we must question why this is so. According to our description of the processes involved in a typical LBFTS accident (see Figure 1.1), the other drivers may not give such safe responses to motorcycles because: (a) they do not look in the appropriate places or adopt sub-optimal visual strategies; (b) they may look at the motorcycle, but not process it (a true 'Look But Fail To See' error); or (c) they may look and process the conflicting motorcycle, but then fail to appraise it correctly. From the button responses we can tell that there are differences in the way the driver groups deal with the junctions, but in order to assess the contribution of these different potential causes we refer to the eye movements of drivers on approach to the junctions, and during the decision-making process of when to pull out.

Two key eye-movement measures that we hypothesised may relate to drivers' abilities to spot approaching traffic at junctions are how far down the junction (either to the left or right) the drivers search (which we term **mean eccentricity**), and how widely do they search (e.g. do they scan from left to right at junctions? – we call this measure **mean spread**).

To calculate mean eccentricity we took the average eye location in the horizontal axis for every participant relative to the centre of the central screen in pixels. The mean eye location was calculated across either four temporal bins (for no-vehicle trials) or six temporal bins (for all comparisons of car and motorcycle trials). Each bin is a period of time during the trial lasting one second in length. For the no-vehicle trials, these temporal bins comprised the four seconds prior to the driver's car stopping at the junction, while the car and motorcycle comparisons included an additional two seconds following the car having stopped at the give-way line. The reason for this discrepancy is that over 50% of all participants consistently

responded to no-vehicle trials before the participant's car had stopped at the junction, which would have led to a lot of missing data with a six bin analysis. Conversely, most responses on conflicting trials were made after stopping at the junction, allowing the analysis to be extended. Those trials with conflicting vehicles where an early response was still considered to be a safe decision according to our raters (two motorcycle and three car clips) tended not to produce eye movements across all six bins (as participants often clicked much earlier on these clips than on the more risky clips). Any clip that did not provide data for all six bins was not included in the means for that participant.

Within each bin the x co-ordinates of each eye movement sample (measured at 60 Hz) 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.
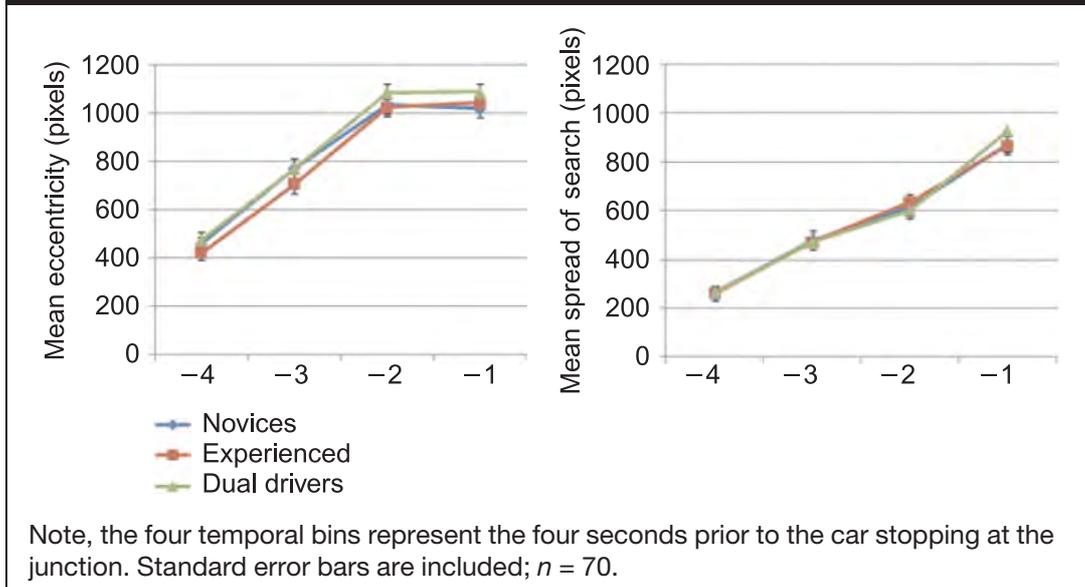
To reflect the spread of the driver's visual search, we took the standard deviation of the absolute horizontal co-ordinates for eye location samples (in pixels), calculated for each of the four temporal bins on the approach to the junction and the two bins following the car having stopped at the junction. This measure provides an indication of how widely the eyes were scanning across the scene.

Initially, both measures were compared across the three driver groups and across four temporal bins for just the no-vehicle trials. This provides an understanding of whether the driver groups differ in how they search a junction for an approaching vehicle ('Do they look in the appropriate location?') without the presence of a conflicting vehicle influencing the data.

Mean eccentricity was subjected to a 3×4 (group x bin) ANOVA using only data from no-vehicle trials. Two novices, one experienced driver and one dual driver were removed from the analysis due to missing data in some of the cells. There were no differences between the groups in how far down the junction they looked, nor did this interact with the time-to-junction bins which covered the four second approach to the junction. However, the temporal bins did show a main effect ($F(3,201) = 471$, $MSe = 12,120$, $p < 0.001$). Planned repeated contrasts revealed that the extent of the gaze to the left and right increased from four seconds before the car stopped at the give-way line (bin 1) until it reached a plateau in the second and first second prior to the car stopping (bins 3 and 4). This suggests that drivers increase the extent of their search until two seconds before they stop ($Fs(1,67) > 200$, $ps < 0.001$; see Figure 3.5(a)), at which point they appear to need to search no further down the junction before the majority make the decision to pull out. The lack of group differences suggests that all drivers look a comparable distance down the junction.

The mean spread of search measure (standard deviation of horizontal co-ordinates) was also compared across the driver groups and temporal bins for the no-vehicle

Figure 3.5: (a) The mean eccentricity of horizontal gaze location and (b) the mean spread of search of horizontal gaze locations for all groups of drivers across four temporal bins

Note, the four temporal bins represent the four seconds prior to the car stopping at the junction. Standard error bars are included; $n = 70$.

trials. Again there were no group differences, but there was a main effect of time-to-junction ($F(3,201) = 392$, MSe = 12,367, $p < 0.001$). The planned repeated contrasts showed that the spread of search increased significantly across each of the four temporal bins without reaching a plateau. This mostly mirrors the mean eccentricity analysis, though mean eccentricity levelled out in the final two bins, whereas the measure of spread did not (see Figure 3.5(b)). The interaction between group and time-to-junction was not significant.

To summarise the analysis 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. While all participants increased their spread of search across the four-second approach to the junction, the extent to which they looked down the junction plateaued over the final two seconds of approach.

Following the analysis of those trials with no approaching vehicles, a second series of analyses were undertaken to compare trials with conflicting cars and conflicting motorcycles. Both mean eccentricity and mean spread were subjected to $2 \times 3 \times 6$ ANOVAs comparing cars with motorcycles across the three driver groups and across the six temporal bins of the time-to-junction factor (four seconds before the give-way line and two seconds after the participant's car had stopped at the junction). Whereas the rationale with the no-vehicle analyses was to assess whether the dual drivers search junctions with a different scanning strategy (which may give them more chance of spotting a vehicle should it appear), the rationale behind the 'car versus motorcycle' analyses is to assess what influence the actual type of vehicle has upon search strategies. If there are differences in the visual search on car and

motorcycle trials, this suggests that the two vehicles are being processed differently. For these analyses, 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 = 12,875, $p = 0.059$), 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 = 11,385, $p = 0.082$), though it did interact with the time-to-junction ($F(5,350) = 5.5$, MSe = 7,526, $p < 0.001$). Specifically, repeated contrasts suggested that the eccentricity of visual search in car and motorcycle trials diverged significantly in the final temporal bin (between one and two seconds after the participant's car stopped at the junction; ($F(1,70) = 7,1$, MSe = 39,142, $p = 0.01$)). From Figure 3.6(a) it can be seen that eccentricity on motorcycle trials reduces to a much greater extent in the final bin than on car trials. While there is no omnibus significance[1] for the three-way interaction between vehicle, time-to-junction and driver group, the *a priori* contrasts suggest that the vehicle x time-to-junction interaction is moderated by driver group when specifically looking at the two seconds following the car stopping at the give-way line ($F(2,70) = 4.5$, MSe = 39,141, $p < 0.05$). Interestingly, it appears that the novice drivers and the dual drivers have similar patterns, following the general pattern noted in the two-way interaction between vehicle and time-to-junction, whereas the experienced drivers fail to reduce their gaze eccentricity on motorcycle trials in the final temporal bin (see Figure 3.6).

Taken together, the results from the conflicting vehicle clips suggest that:

- there is marginal evidence that dual drivers have the greatest eccentricity of search and experienced drivers have the least;

- in the final temporal bin (one to two seconds after stopping at the junction) participants tend to reduce the eccentricity of their search more so on motorcycle trials than car trials;

- assuming that dual drivers provide the safest behaviour (as suggested in the literature and the response times analysis), 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); and

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1   ANOVA produces a series of omnibus *F* values. These *F* values refer to whether there is an overall significance between the various conditions within one or more factors. It does not, however, tell you which particular condition is different to which other condition. Follow-up analyses are usually required that compare specific condition means. *A priori* contrasts are a type of follow-up analysis, but as they are planned in advance of the omnibus calculation (according to theory), then it is permissible to report significant *a priori* contrast effects even if the omnibus calculation is not significant.

Figure 3.6: The mean eccentricity of horizontal gaze across six temporal bins for car and motorcycle clips for (a) all drivers combined; (b) novice drivers; (c) experienced drivers; and (d) dual drivers

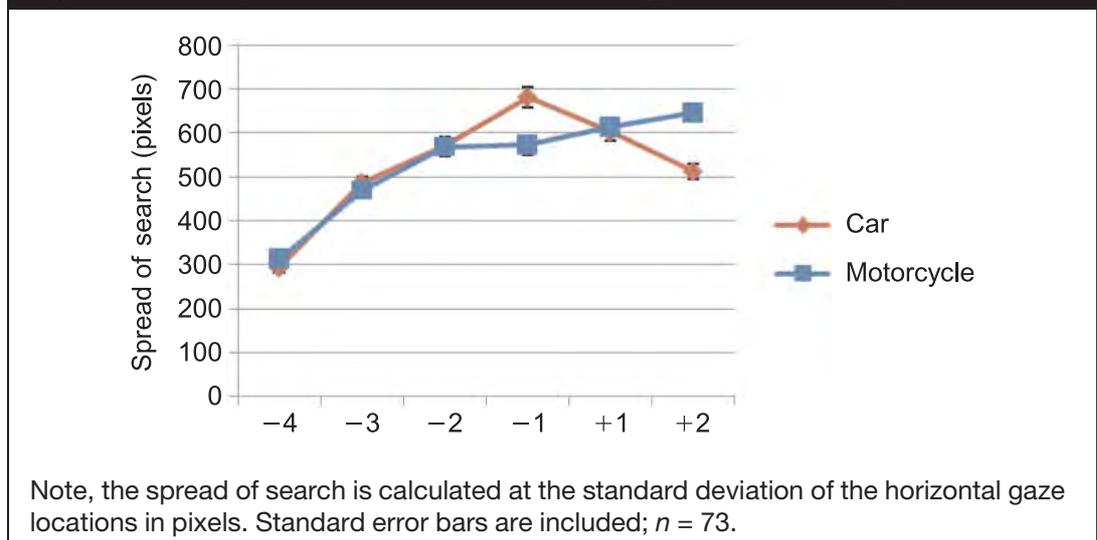Note, standard error bars are included; $n = 73$.
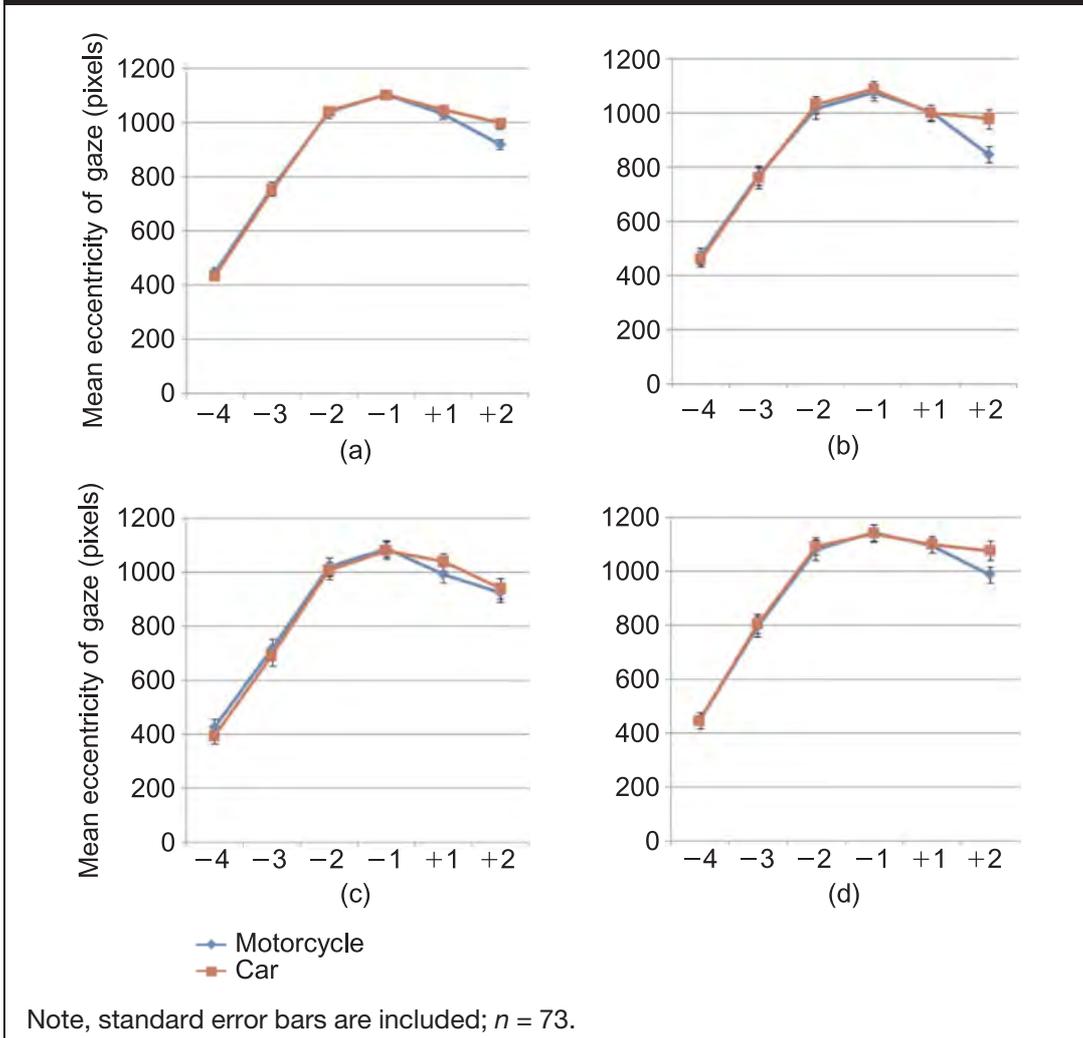
- novice drivers behave similarly to dual drivers – it is the experienced drivers who do not use this strategy, suggesting that perhaps an over-learned strategy encourages them to search beyond a motorcycle once it has been spotted, or perhaps reduces the chances of spotting the motorcycle at all.

This analysis suggests that the experienced car drivers might have the greater problems with spotting and processing motorcycles, either looking past them in the first instance and failing to spot them, or having spotted them deciding not to monitor them closely, but instead to search beyond them for the next potentially conflicting vehicle. While in this study the response time measure was possibly not sensitive enough to pick up this group difference in visual strategies, it remains possible that this visual difference could still have an effect in occasional real-world situations where drivers pull out in front of a motorcycle based on initial information about its speed and trajectory, rather than based upon a constantly updated prediction derived from continued monitoring.

The measure of spread of search was then subjected to a $2 \times 3 \times 6$ ANOVA comparing the car trials with the motorcycle trials across driver groups and the six temporal bins of time-to-junction. An interaction between vehicle and time-to-junction was noted ($F(5,350) = 16.5$, MSe $= 13,462$, $p < 0.001$). Repeated contrasts showed that the spread of search on car and motorcycle trials diverged in the final second of approach (bin 4). In the first three bins, the spread of search increases equally for car and motorcycle clips, but in the final second before the junction, the spread of search significantly increases on car trials compared with motorcycle clips. However, by the sixth bin (the 2nd second after stopping at the junction) the spread becomes narrower than that in the motorcycle clips (Figure 3.7). The results suggest that the spread of search peaks for the car clips in the final second of approach, perhaps resulting from attentional capture by the early fixation of a conflicting car. Conversely, the 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.

Figure 3.7: The spread of search across vehicle type and the six temporal bins

Note, the spread of search is calculated at the standard deviation of the horizontal gaze locations in pixels. Standard error bars are included; $n = 73$.

3.2.1.2 Do dual drivers look at approaching motorcycles more quickly, or for longer than other drivers?

In order to ascertain a more direct measure of whether the average driver fails to look at approaching motorcycles, or whether they fail to process approaching motorcycles, the eye movements were subjected to a more exacting analysis. In addition to the numerical data analysed in the previous section (mean eccentricity and spread of search), the eye tracker also outputs a video of the three-screen clips with a moving spot overlaid on top of the video, reflecting what a particular participant was looking at on the video at any one time (see Figure 3.8). This requires a frame-by-frame analysis of the video overlay files, which is a very labour-intensive process, especially considering the size of the experiment and sample. Nonetheless, we believed it would be beneficial to undertake this analysis for the

T-junction clips to assess whether these fine grain measures of fixation demonstrate any further differences between the driver groups in how they look at and process approaching cars and motorcycles. Those clips which were not considered risky by our raters were removed from these analyses (cf. response time analysis). One novice, two experienced drivers and one dual driver were removed from the analysis due to missing data.

Figure 3.8: **A composite view of all three screens in a T-junction scenario**

Note, the current scenario shows a motorcycle approaching from the right. The green circle overlaid on the motorcycle is the eye gaze cursor, which shows that the participant was looking at the motorcycle at this point.

In coding the T-junction clips we were concerned primarily with recording exactly when and for how long participants looked at the conflicting vehicles at the junction.[2] The first analysis we conducted was simply to compare 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 with 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. As all the approaching vehicles had varying onset times relative to the participant's approach, this time-to-look measure was calculated relative to the point at which the conflicting vehicle reached the junction (in a similar manner to the RTs shown in Figure 3.4). The 2×3 ANOVA (vehicle x 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

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2   A gaze upon a conflicting vehicle tended to fall within the boundary of the actual vehicle on the screen. Gazes outside this boundary were only considered to have landed on the conflicting vehicle if (a) gaze calibration was problematic for a participant, (b) the eye cursor was still within 1.5 degrees of the vehicle, and (c) the eye cursor moved with the conflicting vehicle.

cars sooner than motorcycles (4.35 versus 2.86 seconds before the conflicting vehicle reached the safe point).

Several measures of gaze duration were recorded and analysed. The length of gaze is usually interpreted as the amount of time devoted to processing a stimulus. Longer gaze durations reflect difficulty 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. It may be that motorcycles are harder to process because they are less salient, more visually complex, and are 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 (MGD; total gaze duration/ number of gazes – this gives an indication of overall processing difficulty). A gaze was calculated as the summation of the frames of the video starting when the eye cursor landed on the conflicting vehicle to when the eye left the vehicle. If the eye returned to the same vehicle during the same clip, a second gaze was calculated.

The FGD produced an interaction between vehicle type and driving experience ($F(2,67) = 3.1$, MSe = 0.06, $p = 0.05$). As can be seen in Figure 3.9, this was due to experienced drivers producing longer first gazes on conflicting cars compared with conflicting motorcycles, while the dual drivers have the reversed pattern, with their longest first gaze on the approaching motorcycle.

Figure 3.9: The average FGD upon the conflicting vehicle

Note, standard error bars are included; $n = 70$.
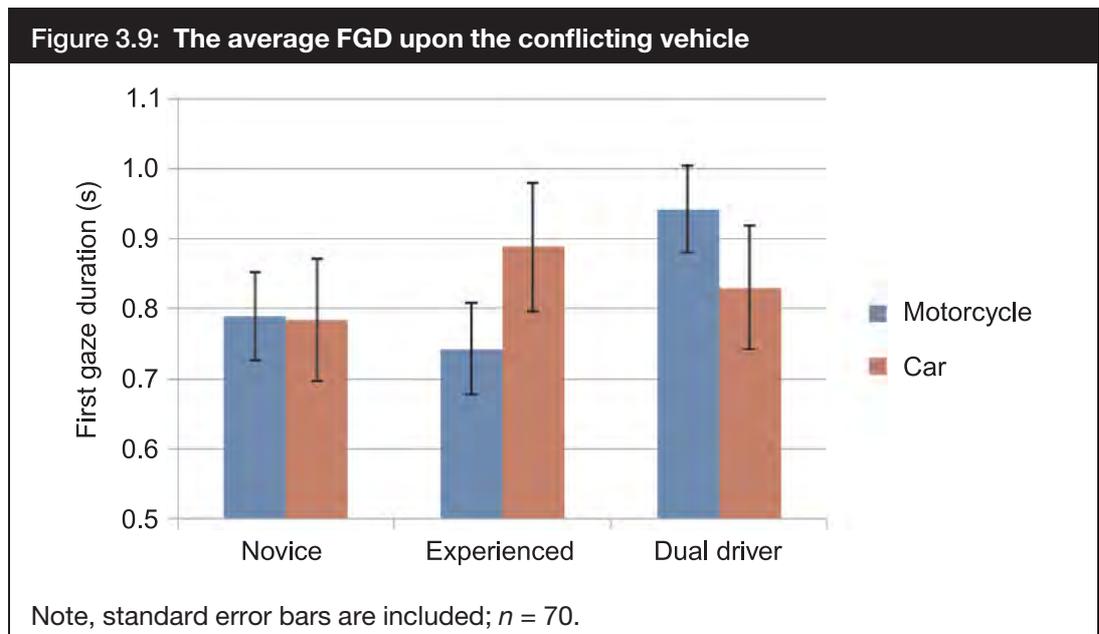
Analysis of the MGD on the conflicting vehicles produced marginal evidence of an interaction ($F(1,67) = 3.6$, MSe = 0.04, $p = 0.067$), with dual drivers having greater mean gaze durations on conflicting motorcycles than all other groups (Figure 3.10).Taken together these two results suggest that dual 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 that they have been looking at a motorcycle, or at least that they have decided, for whatever reason, not to process it any further.

Figure 3.10: MGD upon the approaching vehicle

Note, standard error bars are included; $n = 70$.
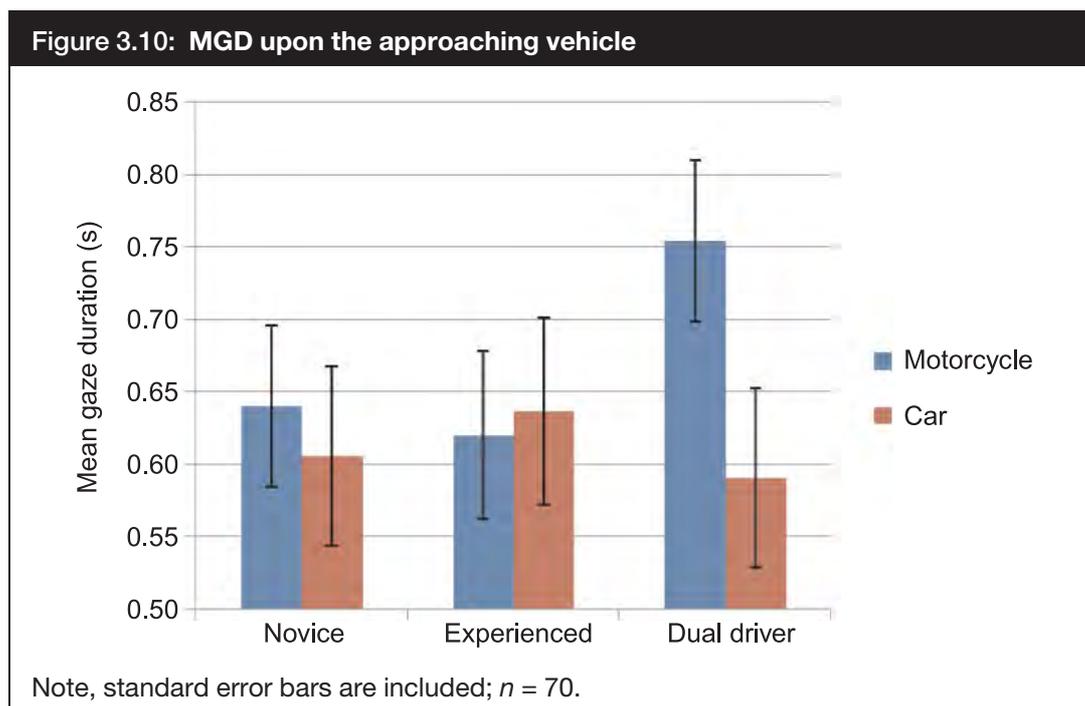
3.2.2 Change-lane scenarios

In a pilot study, four expert raters (driving psychologists) viewed the change-lanes clips and rated them as to how safe it would be to make an early manoeuvre between lanes rather than waiting for the conflicting traffic to pass. They had three options to choose from: safe to change lanes without waiting; risky to change lanes without waiting; and unsafe to change lanes without waiting. Safe responses scored one point, risky scored two and unsafe decisions scored three points. Mean ratings for the change-lane clips ranged from 2.25 to 3, with a mean of 2.85. These clips were rated as more risky than the T-junction clips because, in order to prevent the participants from making a response as soon as the clip started, the conflicting vehicle had to be visible from the beginning of each clip. On this basis, all responses prior to the safe point (Figure 3.11) can be considered as risky. As with our calculation of responses to T-junction clips, RTs for the change-lane clips were calculated relative to the safe point (with negative RTs reflecting risky behaviour,

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Figure 3.11: The safe point for change-lane clips (taken from the right-hand screen of the hazard perception rig)

Note, the safe point for change-lane clips was defined as the time at which the passing vehicle had overtaken the participant's vehicle to such an extent that the middle of the rear of the vehicle was aligned with the rightmost edge of the inset right-side mirror.

and positive RTs reflecting safer behaviour). As any decision to pull out before the safe point on the conflicting clips was considered risky by the raters, there was no requirement to remove early responses using a three standard deviation rule, as we did with the analysis of T-junctions.

The first analysis compared the percentage of trials on which participants responded after the safe point using a 2×3 ANOVA with two types of conflicting vehicle (motorcycles and cars) and three driver groups (novices, experienced and dual drivers). One car clip was removed from the analyses as very few participants thought there was a safe point at which to pull out.

The main effect of vehicle was significant ($F(1,71) = 6.87$, MSe $= 169$, $p = 0.01$), with 88% of responses to motorcycles occurring after the safe point, while only 83% of responses to conflicting cars occurred after the safe point. No other factors were significant.

A similar 2×3 ANOVA was conducted on the RT data. None of the effects approached significance levels ($ps > 0.10$), suggesting that there were no differences in the way that novices, experienced drivers and dual drivers respond to the conflicting traffic.

A 1×3 ANOVA compared driver groups' response times for the no-vehicle clips to assess whether one group was more cautious than the others even in the absence of a

conflicting vehicle. Average response times to no-vehicle trials were 3.2 seconds, though no differences were found between the groups.

3.2.2.1 Do dual drivers look in different places to other drivers when changing lanes?

Eye movements to the change-lane clips were analysed by first categorising eye location during each clip. The categories of interest were the rear-view mirror, the right-side mirror and the right screen, though the central screen (Ahead) and the left screen (Left) were also calculated for purposes of displaying the overall proportional allocation of gaze (Figure 3.12). The Left category also included any gazes upon the left mirror. The conflicting vehicle could always be seen in the rear-view mirror and the right-side mirror from the beginning of each clip, but would disappear from the rear-view mirror approximately 1.7 seconds before disappearing from the right-side mirror. The right screen contained the right-hand lane, which was the target destination of the participant. For most of the car clips, the conflicting car was still

Figure 3.12: The mean proportion of time that drivers spend looking in each of five categories of the road scene during change-lane clips — the numbers reflect the mean time taken to first fixate the category in seconds

Note, the categories are rear-view mirror (RVM), right-side mirror (RSM), the left screen (Left), the central screen (Ahead) and the right screen (Right).
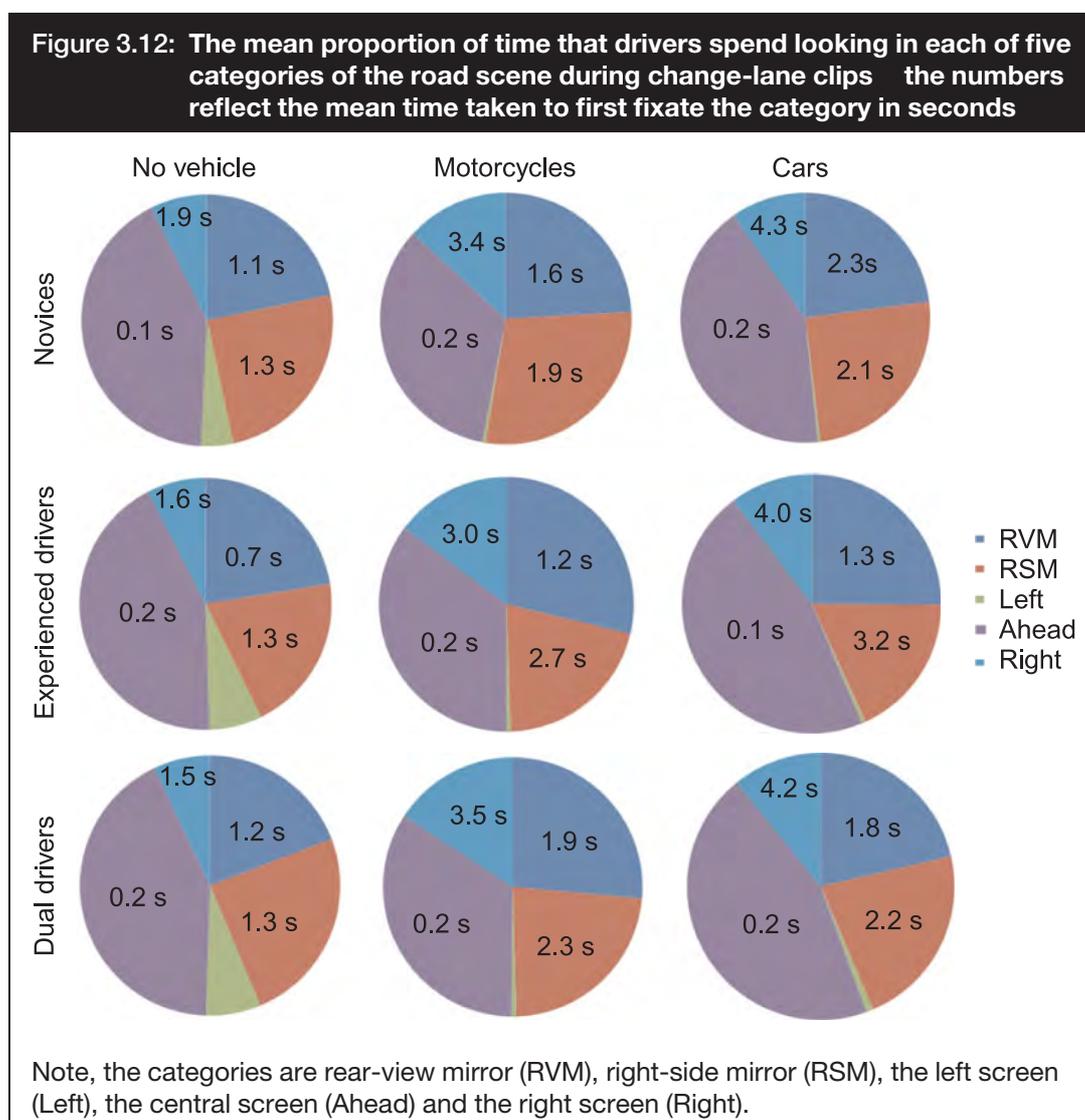
visible in the right-side mirror while entering the right screen, whereas for most motorcycle clips the conflicting motorcycle exited the right-side mirror before entering the right screen. Responses were considered 'safe' if the participant pressed the button after the conflicting vehicle had reached the safe point. For change-lane clips, the safe point was defined as the time at which the conflicting vehicle had overtaken the participant's vehicle to such an extent that the middle of the rear of the vehicle was aligned with the rightmost edge of the inset right-side mirror (see Figure 3.11). Thus, the conflicting vehicle was far enough ahead of the participants to allow drivers to decide to initiate the manoeuvre.

Measures of gaze within each category of interest include the time taken to first look within that category (e.g. the time from the start of the clip that it takes for a participant to look in the rear-view mirror), the duration of the first gaze (the total of all fixations within a category from the first time a participant looks at the category to the first time they look somewhere else), the MGD (the average length of all gazes within a particular category), and the total gaze duration on each category as a percentage of the time between clip start and the participant pressing the button. A series of two-way ANOVAs did not reveal any significant differences between motorcycle and car clips in the duration that the target vehicle was visible in either the rear-view mirror, right-side mirror or on the right screen (Fs < 1.7, ps > 0.10). The same results were found for the total duration of any vehicle being visible in the three areas of interest.

All analyses were based on a 3×3 ANOVA with three levels of vehicle (no-vehicle, conflicting car, conflicting motorcycle) and three levels of experience (novices, experienced drivers and dual drivers). Simple contrasts were used to compare driver groups (novices to dual drivers, and experienced drivers to dual drivers), while Helmert contrasts were used for the vehicle trials (comparing no-vehicle trials with the average of car and motorcycle trials, and also directly comparing car trials with motorcycle trials).

Rear-view mirror

Analysis of the time taken to first look in the rear-view mirror revealed an effect of vehicle ($F(2,142) = 11.4$, MSe $= 1.0$, $p < 0.001$). Helmert contrasts revealed that all participants looked at the rear-view mirror more quickly in the no-vehicle clips compared with the conflicting vehicle trials ($F(1,71) = 30.5$, MSe $= 1.1$, $p < 0.001$), though the speed with which participants fixated the rear-view mirror in the motorcycle and car clips did not differ (with means of 1.0, 1.6 and 1.8 seconds for no-vehicle, motorcycle and car clips, respectively). The *a priori* contrast comparing experienced drivers with dual drivers provided marginal evidence for a difference, with experienced drivers fixating the rear-view mirror on average 1.0 second after the start of the clip compared with the 1.6 seconds of dual drivers (novices were closer to the dual drivers with 1.7 seconds).

Analyses of the FGD also identified an effect of vehicle ($F(2,142) = 67$, MSe = 37,062, $p < 0.001$). The contrasts revealed that the no-vehicle trials produced the shortest first gaze on the rear-view mirror compared with the conflicting vehicle trials, and motorcycle clips induced significantly longer first gaze durations on the rear-view mirror than car clips (with 405 ms, 769 ms and 626 ms for no-vehicle, motorcycle and car clips; $Fs(1,71) > 21$, MSe > 58,091, $ps < 0.001$). The *a priori* interaction contrasts also suggested an interaction between driving experience and the motorcycle and car clips ($F(2,71) = 3.1$, MSe = 70,793, $p = 0.05$). As can be seen from Figure 3.13, this interaction appears to be driven by dual drivers producing longer first gazes on the rear-view mirror in the motorcycle clips compared with the other two groups.

Figure 3.13: **Mean duration of the first gaze on the rear-view mirror**

Note, standard error bars are included; $n = 74$.
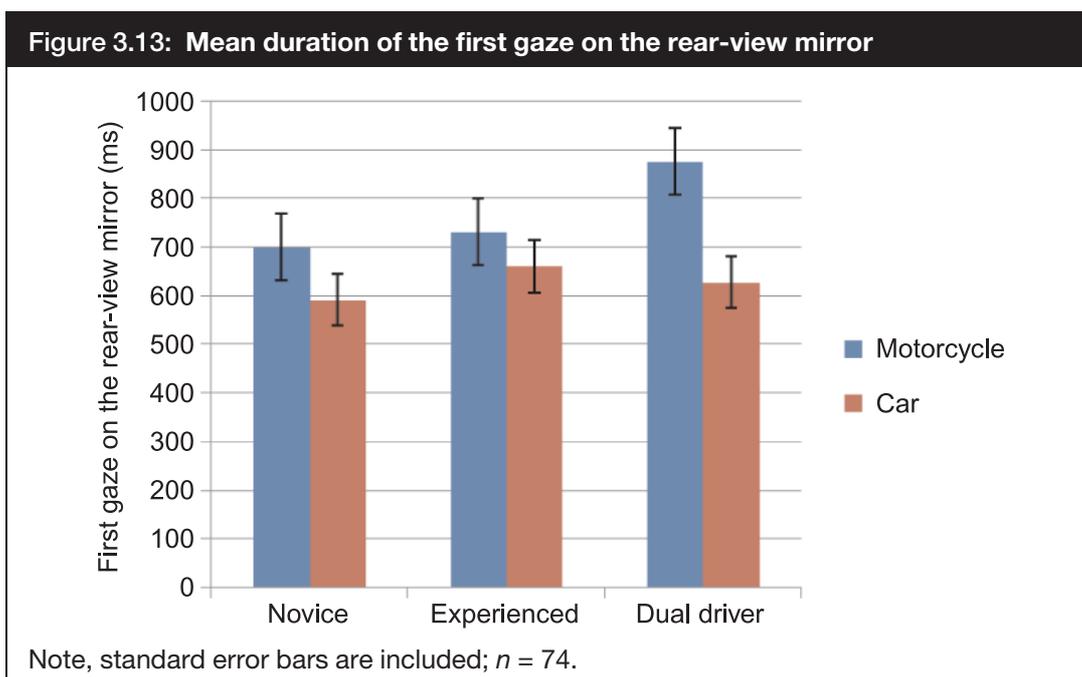
The analysis of the MGD also revealed an effect of vehicle ($F(2,142) = 82.2$, MSe = 16,613, $p < 0.001$) which is explained by a significant interaction between vehicle and driving experience ($F(4,142) = 2.5$, MSe = 16,614, $p < 0.05$). Figure 3.14 again suggests that this is due to longer gazes by the dual drivers on the motorcycle clips.

Finally, an analysis of the percentage of time that the eyes were devoted to the rear-view mirror identified a main effect of vehicle type, with contrasts showing that no-vehicle clips resulted in the smallest percentage of attention being devoted to the rear-view mirror compared with the combined motorcycle and car clips ($F(1,71) = 14.2$, MSe = 70, $p < 0.001$), while the motorcycle clips garnered the greatest portion of attention compared with the car clips ($F(1,71) = 17.5$, MSe = 45, $p < 0.001$; with means of 21%, 26% and 23% for no-vehicle, motorcycle and car clips, respectively).

Figure 3.14: Mean gaze durations on the rear-view mirror

Note, standard error bars are included; $n = 74$.
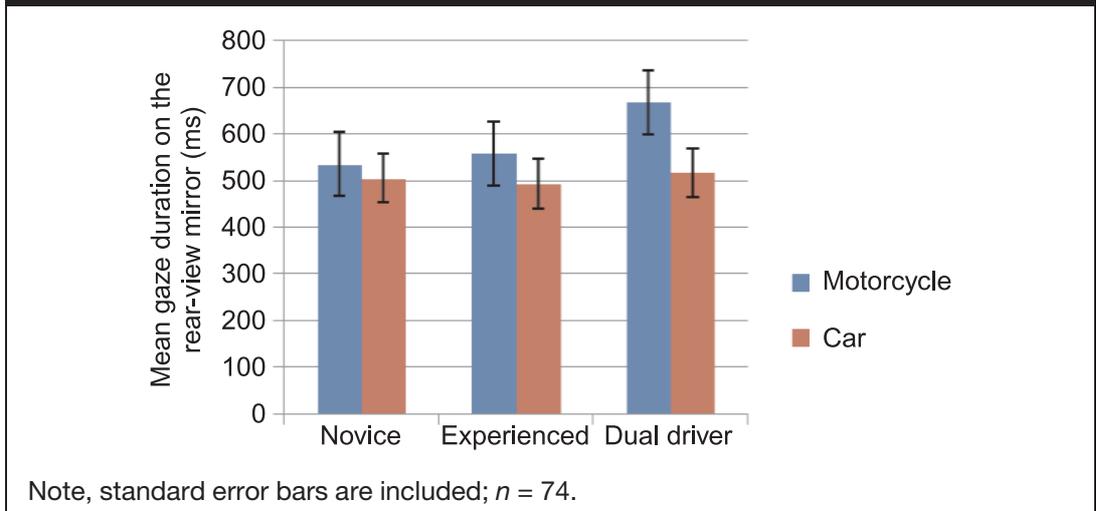
Right-side mirror

The analysis of the time taken to first look in the right-side mirror revealed an effect of vehicle ($F(2,142) = 32.07$, MSe $= 0.96$, $p < 0.001$), with conflicting traffic trials producing later gazes to the right-side mirror than the no-vehicle trials ($F(1,71) = 47.5$, MSe $= 1.9$, $p < 0.001$). This effect is further moderated by an omnibus interaction between experience and vehicle type ($F(4,142) = 2.6$, MSe $= 0.96$, $p < 0.05$). The contrasts suggest that the effect lies in the comparison of no-vehicle trials to the combined conflicting vehicle trials ($F(1,71) = 3.0$, MSe $= 1.9$, $p = 0.055$). Figure 3.15 suggests that the experienced drivers delay their fixation on the right-side mirror to the greatest extent in the presence of a conflicting vehicle.

Figure 3.15: Time taken (seconds) to first fixate the right-side mirror

Note, standard error bars are included; $n = 74$.
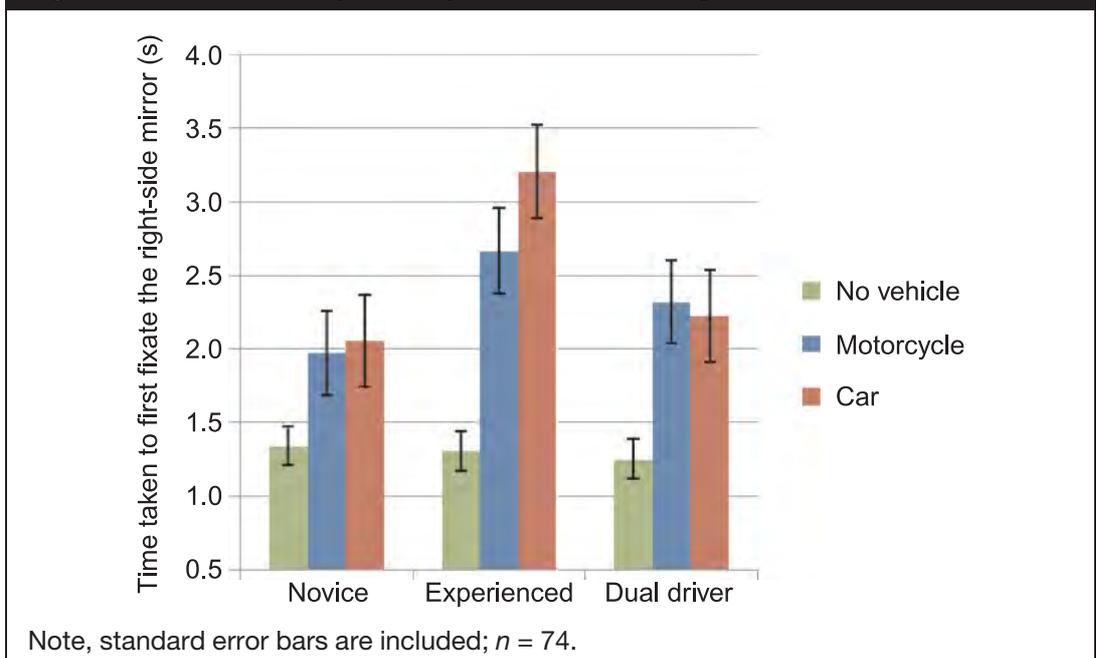
The analysis of the duration of the first gaze on the right-side mirror revealed an effect of vehicle ($F(2,142) = 22.96$, MSe = 43,728, $p < 0.001$) and a significant effect of driving experience ($F(1,71) = 4.9$, MSe = 62,449, $p < 0.01$), but the interaction was not significant. With regard to the main effect of vehicle, no-vehicle trials produced the shortest first gazes upon the right-side mirror compared with the conflicting vehicle trials ($F(1,71) = 34.5$, MSe = 69,408, $p < 0.001$), and motorcycle clips received longer first gazes than car clips on the right-side mirror ($F(1,71) = 5.5$, MSe = 82,368, $p < 0.05$). Simple contrasts for the effect of experience revealed that the experienced drivers had a much shorter average FGD than dual drivers (388 ms versus 572 ms; $p < 0.05$), while novice drivers were similar to the dual drivers (589 ms).

The analysis of the MGD on the right-side mirror revealed an effect of vehicle ($F(2,142) = 20.66$, MSe = 14,445, $p < 0.001$) and a significant effect of driving experience ($F(1,71) = 4.42$, MSe = 178,211, $p < 0.05$), but the interaction between vehicle and driving experience was not significant ($F(4,142) = 2.48$, MSe = 0.10, $p = 0.10$). The two main effects followed the same pattern as the first gaze durations: experienced drivers had a shorter MGD than dual drivers (while novices were very similar to the dual drivers: 315 ms, 451 ms and 474 ms, respectively), and no-vehicle trials produced the shortest mean gazes on the right-side mirror ($F(1,71) = 28.5$, MSe = 29,461, $p < 0.001$). In addition, motorcycle clips produced longer mean gazes on the right-side mirror than car clips ($F(1,71) = 3.9$, MSe = 18,500, $p = 0.05$).

The analysis of the percentage of time that participants spent looking at the right-side mirror revealed a significant effect of vehicle ($F(2,142) = 2.99$, MSe = 34.06, $p = 0.05$), but the effect of driving experience and the interaction were not significant. Exploring the main effect of vehicle with the contrasts suggested that the right-side mirror on motorcycle clips received a small but significantly greater proportion of the total gaze durations than the car clips (24.1% versus 21.8%; $F(1,71) = 8.8$, MSe = 45, $p < 0.005$).

Right screen

For all eye-movement measures on the right screen (time to fixate, first gaze duration, mean gaze duration, and the percentage of total gaze duration allocated to the right screen), only the factor of vehicle was significant. For the time taken to fixate the right screen, participants were quickest in the no-vehicle trials and slowest in the car trials ($F(2,142) = 53$, MSe = 2.2, $p < 0.001$, with no-vehicle trials slower than vehicle trials, and motorcycle trials slower than car trials, both at $p < 0.001$). To ensure that the slower gaze into the right screen for motorcycle clips compared with car clips was not caused by cars simply reaching the right screen sooner than motorcycles (i.e. reaching the safe point more quickly), we compared the exposure times of cars and motorcycles from the start of the clip up to the safe point. While there was a considerable amount of variation between the clips, there was no

evidence of a systematic variation favouring one vehicle over the other ($t(18) = 0.43$, $p = 0.67$). Instead we suggest that drivers look to the empty lane sooner in car clips, possibly because motorcycles demand more attention (necessitating longer gazes into the mirrors). The mean times to look into the right screen (averaging 3.0 seconds) were all less than the mean safe point, which was, on average, 6.8 seconds for motorcycles and 6.3 for cars. No other effects were significant in the analysis of time taken to first look at the right screen.

The analysis of first gaze durations identified short first gazes on the right screen for no-vehicle clips compared with vehicle clips, as did the analysis of mean gaze durations. Mean gaze durations to the right screen also revealed longer average fixations for motorcycle clips (306 ms) compared with car clips (241 ms, $F(1,71) = 17.7$, MSe $= 12,695$, $p < 0.001$). Gazes on the right screen in the absence of a conflicting vehicle were, however, much shorter (110 ms). The percentage of total gaze followed the same pattern, with a main effect of vehicle ($F(1,71) = 14.2$, MSe $= 70$, $p < 0.001$), and contrasts suggesting the right screen gets the least attention in the no-vehicle trials (7.3%) compared with the conflicting vehicle trials ($F(1,71) = 41$, MSe $= 47$, $p < 0.001$), within which motorcycle clips resulted in a greater proportion of attention to the right screen than car clips (14.6% versus 10.4%; $F(1,71) = 57$, MSe $= 23$, $p < 0.001$).

3.3   Discussion

The first thing to note from both the T-junction and change-lane scenarios is that a greater number of safe and more cautious responses are made to motorcycles than cars. 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. Alternatively, the more cautious responses may be made because most of the participants do not encounter motorcycles on the road with great frequency, and therefore they treat a motorcycle as a more novel stimulus worthy of a cautious response just because it is different.

It would be unfair to the vast majority of drivers, however, to suggest that such safe behaviour directed towards 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, despite having to ride past cars waiting to pull out from T-junctions and passing vehicles that may want to change lanes. Car drivers do not want to have a crash, and it is reasonable to assume 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 judgement is made too hastily, which may result in a crash. While it is undoubted 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

benchmark. Even when participants try to project a safe image, 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 the T-junction analyses of response times, comparison across the driver groups did reveal that the dual drivers gave significantly more cautious responses than the novice drivers whether or not there was a conflicting vehicle. While it is possible that the dual drivers are subject to age-related slowing of response times, they were also consistently more cautious than the experienced drivers with whom they had a greater overlap in age distributions. This supports the experiential hypothesis rather than the potential age confound. Furthermore, the gap between novices' and dual drivers' responses is over half a second in all conditions. The magnitude of this difference suggests that it cannot all be due to age-related slowing and that the dual drivers use different criteria for initiating a manoeuvre. Certainly when we attempted to partial out the effects of age, this merely exaggerated the effects of dual drivers' safer responses towards motorcycles. The fact that more cautious responses are evident on the no-vehicle trials suggests that this is an anticipatory strategy, rather than one which is triggered by the presence of conflicting vehicles. The eye movement measures from the T-junction scenarios have provided insights into how drivers visually approach junctions. All drivers consistently increased their spread of search, yet the mean furthest eccentricity plateaued more than one second before the car stopped at the give-way line. All drivers performed similarly. This suggests that drivers have selected the extent of the range of information that they will use to inform a pull-out decision more than a second before their vehicle stops. On some occasions this might include the farthest focus of expansion if visible from before the junction, though if the focus of expansion is hidden until the participant's vehicle has reached the give-way line, then this suggests that they might decide that they have enough information without checking further down the road once they have reached the junction. This is understandable if the farthest point down the road is so far away that any conflicting vehicle that appeared would not threaten the safety of the intended manoeuvre.

The fact that the driver groups do not differ in their approach to no-vehicle junctions suggests that dual drivers (at least when imagining they are driving a car), do not use any specific search strategy on approach to the junction in anticipation of seeing a conflicting vehicle (yet once they have reached the junction they will take longer to make a decision as evident in the RTs).

There was also an interesting result in the eccentricity of search after the participants' car had stopped at the junction. Novice and dual drivers both reduced the eccentricity of their search in the final bin (the 2nd second after stopping at the give-way line) on motorcycle trials, but not on car trials. This suggests that there is something about the presence of a motorcycle that drags attention towards the centre of the scene, as if they are more likely to follow the motorcycle towards the

junction, whereas with cars they are happy to continue with a relatively eccentric search (suggesting that they are perhaps monitoring the car through peripheral vision). Experienced drivers either have better peripheral vision and can monitor the motorcycle peripherally, or they do not choose to monitor (or perhaps are not aware that they are not monitoring) the motorcycle's approach.

This suggests that the novices and dual drivers are using a similar strategy. While in absolute terms these two groups still differ on some measures (the dual drivers have greater eccentricity of search than the novices), their patterns are similar. This suggests that while novices and experienced drivers both differ from the dual drivers in some aspects relating to motorcycles at T-junctions, these differences have different underlying causes. Whereas the novice drivers are displaying problems typical of inexperienced drivers (limited area of search, risky responses) they are at least adopting a similar visual search strategy to that of the dual drivers. The experienced drivers, however, appear to choose a different strategy. Whereas novice driver differences are potentially due to capacity limitations, experienced driver differences are due to adoption of inappropriate strategies. The fact that novice drivers adopt appropriate strategies may be because they are still adhering to strategies imparted to them while learning to drive, or it may be that the strategy is dictated by capacity limitations (and the dual drivers adopt this capacity-defined strategy because they are aware that conflicting motorcyclists are more demanding than conflicting cars).

Perhaps the most telling results of the T-junction analysis came from the frame-by-frame coding of the eye location. The 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 results show no difference between FGD on either car or motorcycle for the novices, which are also comparable to the FGD on motorcycles for the experienced drivers, and to the FGD on cars for the dual drivers. The dual drivers had longer FGDs on the motorcycles, however, while the experienced drivers had longer FGDs on the cars. Again this suggests that both the novice and experienced drivers diverge from the behaviour of the dual drivers for different reasons.

In the introduction to the use of eye movement measures we suggested that longer gaze durations should be given to motorcycles than to cars. This is indeed the case for the dual drivers. We also said that shorter gazes on motorcycles than cars would suggest inappropriate levels of processing, possibly providing evidence for LBFTS errors. The fact that experienced drivers have shorter initial gazes on the motorcycles than on the cars does suggest that either they have not realised that they were looking at a motorcycle in the first instance, or they have disregarded it in favour of looking elsewhere. This fits with the eccentricity data which suggest that novices and dual drivers follow the motorcycle towards the centre screen, whereas the experienced drivers look past the motorcycle and focus further down the road.

In summary of the T-junction analyses it appears that dual drivers' safer responses are characterised by later decisions, even on the no-vehicle trials, suggesting that they are more cautious at T-junctions per se, rather than just in the presence of conflicting vehicles. They also, however, gave the most cautious responses to motorcycles. Their eye movements suggested no difference in their approach to no-vehicle junctions, though when motorcycles appeared they looked at them for longer as they followed the motorcycle's approach. Novices adopted a similar strategy in following the motorcycle, though they looked at them for less time (as did the experienced drivers). This, therefore, suggests that novices are susceptible to a failure of perceiving. The experienced drivers showed the most convincing data for a potential LBFTS error, with shorter initial gazes and shorter overall gazes compared with the dual drivers.

The nature of the change-lane scenarios required a different approach to analysing the eye data. Eye movements were categorised into five areas of interest: the rear view mirror, the right side mirror, the right screen (containing the intended destination of the manoeuvre), and the forward and left screens (though the latter two were not included in analysis). Despite the lack of differences between groups in the behavioural response times, the eye-movement analyses revealed several interesting effects.

First it is interesting to note that the order in which all categories were first inspected remained the same over almost all conditions. Participants tended to look ahead first (which is unsurprising as this is the central screen), then to the rear-view mirror, then to the right-side mirror and finally to the right-hand lane (right screen). The only exception to this occurred with novice drivers in the conflicting car clips, who looked at the right-side mirror before looking in the rear-view mirror.

Both of the mirrors and the right screen were fixated early in the no-vehicle trials, suggesting that the presence of a conflicting vehicle is related to the eyes remaining on the forward view for longer. At this point in time the conflicting cars and motorcycles are only available in the mirrors, which suggests that the drivers are picking up some peripheral information that there is additional clutter in the mirror, which then delays their first gaze to either of the mirrors. When the eyes moved to one of the mirrors, dual drivers tended to look at the rear-view mirror later than experienced drivers, but then at the right-side mirror earlier than experienced drivers. One might assume that this would mean experienced drivers would spend much longer looking at the rear-view mirror than the dual drivers. This was not the case in all conditions, however, as dual drivers had longer first gazes on the rear-view mirror in the motorcycle clips, and longer mean gaze durations. This suggests that the experienced drivers might have looked at the rear-view mirror first during conflicting vehicle trials, but they did not stay there for long, presumably returning to the forward view more frequently than the dual drivers.

We suggest the following explanation: first, all drivers pick up information about visual clutter (potential conflicting vehicles) peripherally through the mirrors.

Knowing that their subsequent fixations on the mirrors will therefore take longer (which they do), the participants hold off moving the eyes from the central screen until they have assessed that they have enough headway to the vehicle in front to make a longer than average excursion to the mirrors. Once they have decided that this is the case, all drivers tend to look to the rear-view mirror first (with the exception of novices in the car clips). Experienced drivers look to the rear-view mirror sooner than dual drivers, but this is at the expense of fully processing the headway safety, and they are therefore more likely to return to the forward view. The dual drivers, however, spend longer processing the forward view which then allows them a slightly, but significantly, longer gaze upon the rear-view mirror. The dual drivers process the information in the rear-view mirror faster than the experienced drivers (due to a less interrupted initial gaze) and, therefore, make the saccade to the right-side mirror before the experienced drivers do.

To summarise the eye movement analyses on the change-lane scenarios, dual drivers used the rear-view mirror as much as other drivers, though they delayed the point at which they first look at it, and when they did look at it, they concentrated their time into longer gazes. The same pattern was evident with the right-side mirror, though only in comparison with the experienced drivers. The novices behaved more like the dual drivers in respect to the right-side mirror. Again we see that the novices and experienced drivers diverge from the dual drivers' behaviour in different ways. Novices do make good use of the side mirror, but not so much use of the rear-view mirror. Experienced drivers fail to adopt the dual drivers' strategy for either of the mirrors, suggesting that their visual search is much less focused: they spend the same amount of time looking in the mirrors, yet do so using shorter gazes, implying that they are switching more frequently between the areas of interest.

This is a very important finding. Traditional research which compares novice and experience drivers has often suggested that experience reduces fixation and gaze durations due to the increased processing speed that comes with increased experience. Shorter gazes allow increased sampling of the scene which is typically viewed as a positive result. For the first time, however, we now have evidence that, in certain situations, these reduced gaze durations are not considered optimal in all situations. Certainly, compared with the dual drivers, it seems that experienced drivers should be prepared to increase individual gazes in order to fully process conflicting motorcycles.

In conclusion, it appears that the increased safety associated with dual drivers is characterised by longer gazes on motorcycles (in T-junctions) and in mirrors (during change-lane scenarios). To varying extents the other driver groups tend not to emulate the dual drivers' behaviour, although novice and experienced drivers diverge from the benchmark behaviour in different ways, suggesting different underlying causes. These results perhaps provide the first indication in the field of transportation psychology as to how oculomotor behaviour may underlie anecdotal reports of 'Look But Fail To See' errors.

4   STUDY 3: ASSESSING THE POTENTIAL FOR TRAINING INTERVENTIONS USING THE THREE-SCREEN HAZARD PERCEPTION TEST

Study 2 identified several discrepancies in the behaviour of novice and experienced drivers relative to the dual drivers. Study 3 was an initial attempt to modify car drivers' behaviour in relation to motorcycles, with the aim to make non-dual drivers' behaviour more like that of the dual drivers. At this point in the research it is too early to expect definitive training interventions to be designed, but the hope was to identify which behaviours might be susceptible to modification and how this might best be achieved.

Three training interventions were devised, based upon the results of our previous studies and of our initial analysis of Study 2. These interventions were based around the three components of the behavioural chain identified in Figure 1.1 – looking, perceiving and appraising.

The **look training** intervention was the most prescriptive. Based on preliminary analysis of gaze locations in Study 2, we devised a series of instructions to describe where a driver should look when pulling out of a junction or changing lanes. These instructions were based on the dual drivers' strategies.

The **perceive training** intervention was designed to lower drivers' perceptual thresholds for identifying a motorcycle. The rationale behind this is that if a driver looks directly at a motorcycle, but does not initially realise what it is, the eyes may move away without generating awareness of what they looked at. We presume two levels of processing within a fixation which are similar to the two levels of lexical access that are suggested in one of the most influential models of eye movements in reading (the E-Z Reader model; e.g. Reichle *et al.*, 2003). In this model, when the eye lands on a word (or, in our case, a motorcycle) a familiarity check ensues. Completion of this familiarity check leads the oculomotor system to begin planning the next eye movement. If the object or word seems to require more attention, the subsequent plan for the next eye movement can be cancelled. However, if the participant does not realise that the word or object needs more attention until it is too late, then the eye movement goes ahead regardless. When the eye lands on a car, a familiarity check will identify it as something worth spending a little more time on, and thus the subsequent eye movement will be delayed while the driver focuses on the car. A motorcycle, however, might not provide enough information to reach the threshold of the familiarity check and, therefore, the eye may move without the observer realising that they were looking at a motorcycle. This theoretical interpretation of the 'Look But Failed To See' (LBFTS) error offers an opportunity for training. If we can lower the threshold of drivers to the images of motorcycles, then it is possible that a fixated motorcycle may meet the criteria of the familiarity

check, resulting in the next eye movement being postponed while the driver processes the motorcycle.

In an effort to induce a lower threshold for motorcycles in car drivers, we devised a test that required drivers to hold an image of a motorcycle in their mind before searching for it through an array of road pictures. This might result in the drivers becoming more sensitive to images of motorcycles, and thus lead them to realise they are looking at a motorcycle and prioritise it for further processing.

Finally, the **appraisal training** intervention attempted to encourage the more cautious responses of dual drivers using the motorcycle-based hazard perception clips from Study 2. As these showed the greatest improvement in self-reported attitudes to motorcycles, it was hoped that this would give the drivers a better understanding of how risky an early manoeuvre can be from the perspective of a motorcyclist, and therefore lead to moderation in their own risky responses.

4.1 Method

4.1.1 Participants

Eighty-seven participants volunteered to take part in the experiment. Prior to examination of any data, 17 participants were excluded from all analyses for one of several reasons: poor eye calibration, prior motorcycle experience, and outlying age/ driving experience. This left 25 drivers in a group who received appraisal training (AT; mean age = 23.08, SD = 6.41; mean licence seniority = 4.16 years, SD = 4.78; range = 18–35) of which 10 were males; 23 drivers in the look training (LT) group (mean age = 20.78, SD = 4.06; mean licence seniority = 2.83, SD = 3.01; range = 18–37) of which 11 were males; and 22 drivers in the perception training (PT) group (mean age = 22.91, SD = 5.25; mean car licence seniority = 4.64, SD = 4.96; range = 18–38) of which eight were males.

The control group was comprised of data from 24 participants from Study 2 (mean age = 22.2, SD = 4.78; mean licence seniority = 4.29 years, SD = 4.9; range = 18–35) of which 10 were males. The participants from Study 2 were selected on the basis of age matching. The three trained groups were combined and age ranked. A number of control participants equal to the mean number of participants across the three groups were then selected from the novice group, and to a lesser extent from the experienced group, to match the ages of the 24 participants that fell in the middle of the age rank across the intervention groups. During the selection process the experimenters were blind to the actual performance in Study 2 of any potential candidate for the control group.

The participants were offered an inconvenience allowance for their time. All of them had normal or corrected-to-normal vision.

4.1.2 Look training

The look training (LT) group undertook the same test as used in Study 2. However, following the initial instructions, the LT group were given additional instructions specifying how to look for vehicles in both T-junction and change-lanes trials. For change-lane scenarios the instructions explained that when deciding whether it is safe to change lanes there are five important places that they will need to check in order to make a safe manoeuvre. Thus, they were encouraged to check:

1. the road immediately ahead; then

2. the rear-view mirror for an overview of the situation behind (and to look for long enough to identify any hazards); then

3. the side mirror to identify any immediately overtaking vehicles (explicitly specifying not to just give the side mirror a cursory glance or they may miss some vehicles which are harder to see, such as motorcycles); then

4. the blind spot (though it was pointed out that, while this is important in the real world it could be omitted from the laboratory test); and finally

5. their destination lane, ensuring that they have enough space to move into the lane.

This followed the initial results obtained from the dual drivers in Study 2.

At T-junctions, participants were encouraged to try to look as far down the road as possible on approach, and to be aware of obstacles that prevent them from seeing far down the road (e.g. parked cars, hedges). They were also told that they should be aware of the four main danger areas of a T-junction. The **far** distances in both directions give information about approaching vehicles which may reach the junction soon, while the **near** locations inform of any immediate hazard (e.g. a passing car). They were encouraged to look **far** and then **near**. They were also told not to just glance quickly at the **far** location, but give themselves enough time to spot if an approaching vehicle is actually there as, when looking at **far** locations, approaching vehicles can be small and indistinct. It was also stressed that they should not omit checking the **near** location before making a decision.

The actual instructions for the LT group can be found in Appendix 2. They were given to participants on a one-to-one basis as written guidance prior to undertaking the sanctioning manoeuvres task.

4.1.3 Perception training

This training group participated in a test designed to encourage drivers to hold images of specific motorcycles in visual short-term memory while searching for them in visual arrays of road scenes. While sitting in front of a computer monitor they were shown an image of either a car or (more importantly) a motorcycle. The

images were small and presented in the centre of an otherwise blank screen for one second. Immediately after this the participants were presented with an array of road scenes which they had to search. Their task was to search for the vehicle they had just seen in isolation within one of the road scenes in the array. The array could contain 8, 12 or 16 pictures (see Figure 4.1), and 50% of the arrays contained the memorised vehicle in one of the pictures, while 50% did not. The rational behind this experiment was to enforce a reduction in drivers' processing thresholds for motorcycles through repeated exposure and the need for them to hold the image in visual memory in order to complete the task.

Figure 4.1: A sample screen from the visual search that forms part of the perception training
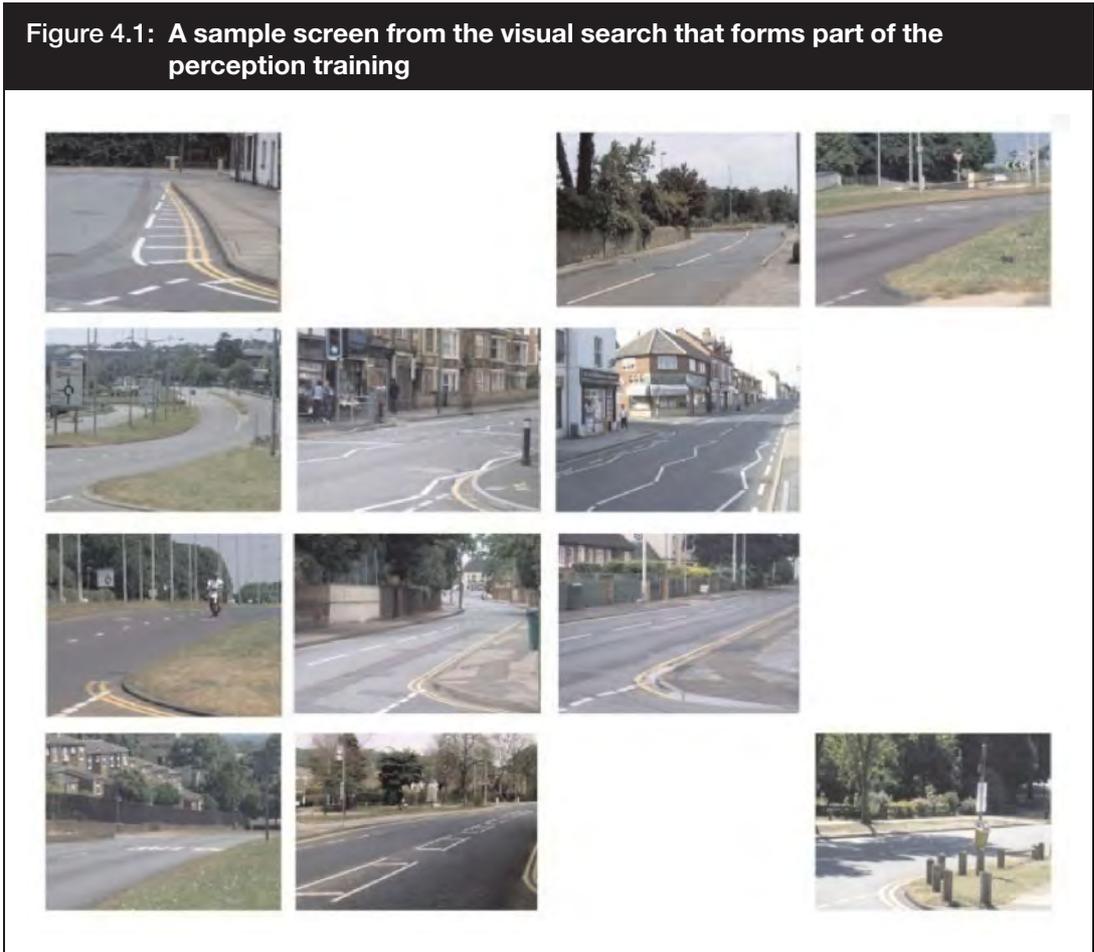
4.1.4 Appraisal training

Prior to undertaking the sanctioning manoeuvres task, the drivers in this training group watched the 15 motorcycle hazard clips developed for Study 1. They were encouraged to consider the level of danger from the motorcyclist's point of view while responding to the hazards.

4.1.5 Multi-screen sanctioning manoeuvre task

Following the particular intervention received by each group, all participants engaged in the multi-screen sanctioning manoeuvres task. The task was identical to the task in Study 2 (for further details, see Section 3.1).

4.2 Results

4.2.1 T-junctions

The responses from participants in the Look Training (LT) group, the Perceive Training (PT) group and the Appraisal Training (AT) group were compared with data from the control group.

Those clips that were considered least risky by our panel of raters were excluded from the analyses (cf. Study 2). Furthermore, one participant was removed from the PT group due to failing to make a response on the majority of trials. Mixed ANOVAs (analysis of variance) compared the groups across the vehicle condition. Planned simple contrasts were used to probe any group differences through comparisons of each training group with the control group.

Analysis of the percentage of safe responses (responses made after the safe point) and analysis of response times (RTs) relative to the safe point both acknowledged a significant effect of vehicle, though there was no main effect of training group and no interaction between the two factors. The vehicle effects ($p < 0.05$) merely reiterated the main effect noted in Study 2, with motorcycle clips receiving a higher percentage of safe pull-outs (87% versus 83%) and more cautious response times relative to the safe point (699 ms versus 208 ms). A 1×4 mixed ANOVA comparing group RTs on no-vehicle trials (calculating RTs from the time the participant's vehicle stops at the give-way line) also failed to show any group differences.

In Study 2, dual drivers gave more safe responses and had more cautious RTs overall. It was hoped that one of the training interventions would move participants' behaviour closer to that of the dual drivers (which would have been evident through comparison with the age-matched control group). Unfortunately, no training benefit was noted.

Eye movements were analysed in a similar fashion to Study 2, with mean eccentricity and mean spread of search calculated for the four seconds of approach to a junction on no-vehicle trials, and the four seconds of approach plus two seconds after stopping at the give-way line for trials with conflicting vehicles. These temporal bins make up the factor **time-to-junction**. The same participant from the PT group was removed from these analyses as in the RT analysis. The mean eccentricity and mean spread of search for the no-vehicle trials were similar to the no-vehicle trials in Study 2, with main effects of time-to-junction ($p < 0.001$)

showing that mean eccentricity peaked between two and one seconds before stopping at the give-way line, while spread of search increased throughout all four seconds of approach to the junction. There were no effects of group, or interactions.

A $2 \times 6 \times 4$ ANOVA comparing motorcycle and car clips across six temporal bins of time-to-contact and across the four groups revealed an interaction between vehicle and time-to-junction ($F(5,450) = 14.0$, MSe $= 6,812$, $p < 0.001$). The pattern of results was identical to that noted in the mean eccentricity scores of Study 2, with reduced eccentricity in the two seconds that followed stopping at the give-way line for the motorcycle clips compared with the car clips. Training did not moderate the effect, suggesting that the interventions neither improved the sensitivity shown to motorcycles or appreciably reduced them (as would have been evidenced in direct comparisons between the training groups and the control group).

Analysis of the spread of search across the six bins also revealed an interaction with vehicle type ($F(5,450) = 336$, MSe $= 18,297$, $p < 0.001$). The spread of search was comparably narrow across motorcycle and car clips in the first temporal bin (four seconds before stopping), but then the spread of search on car clips rapidly increased on approach to the junction, whereas the motorcycle clips encouraged a more measured increase in spread of search up to and beyond stopping at the junction. Again, this interaction was not moderated by an effect of training.

4.2.2 Change lanes

The responses from participants in the LT group, the PT group and the AT group were compared with data from the same control group used for the Study 3 T-junction analyses. The measures chosen for analysis were identical to those used in the analysis of the change lane trials in Study 2. The same participant that was removed from the T-junction analyses in Study 3 was also removed from these analyses, due to only making a small number of responses.
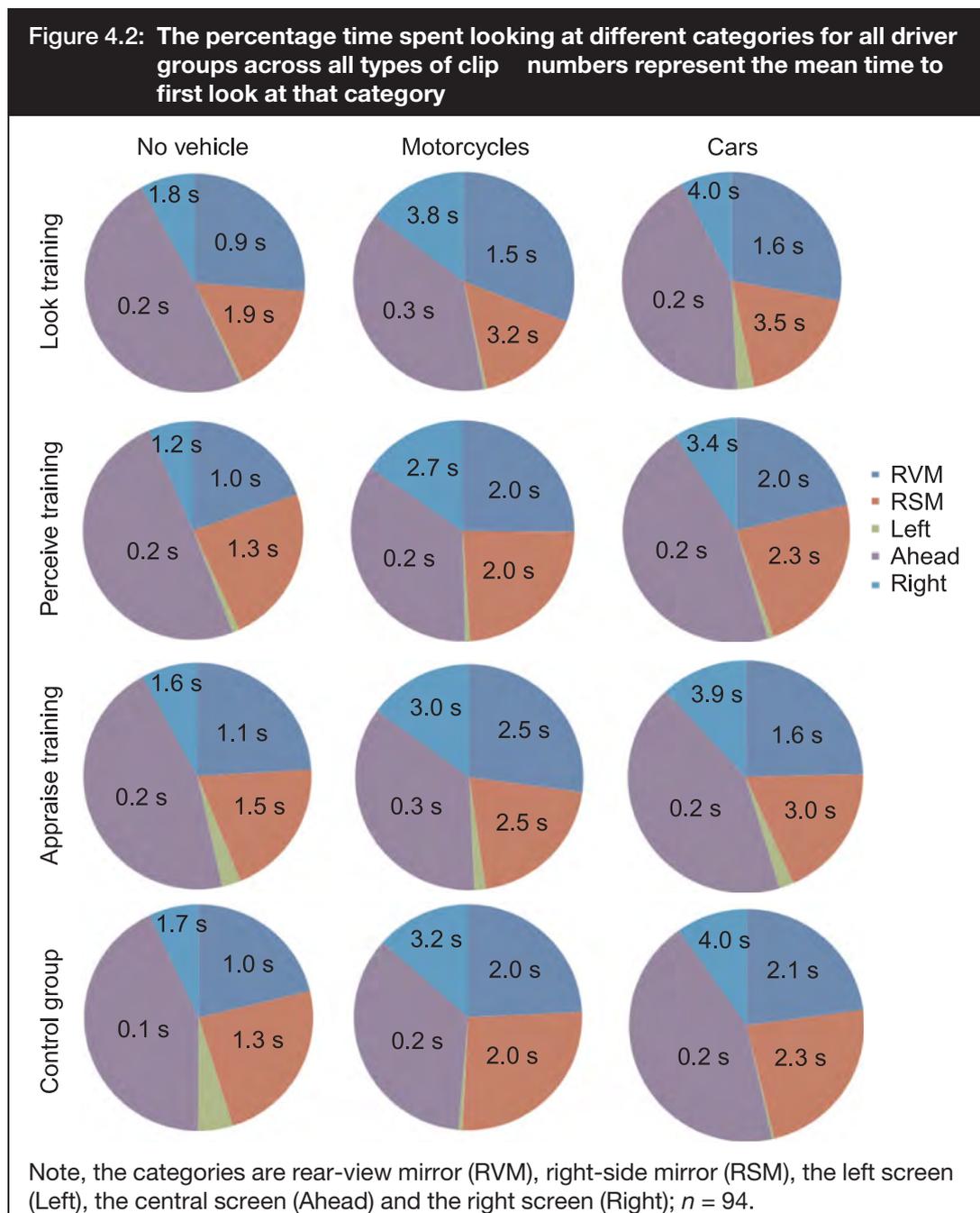
The first analysis compared the percentage of trials on which participants responded after the safe point using a 2×4 ANOVA with two types of conflicting vehicle (motorcycles and cars) and four driver groups (the three training groups and the control group). One car clip was removed from the analyses as very few participants thought there was a safe point at which to pull out. This was the same clip that was removed from the analysis of change-lanes data in Study 2.

The main effect of vehicle was significant ($F(1,90) = 14.7$, MSe $= 94.5$, $p < 0.001$), with 91% of responses to motorcycles occurring after the safe point, while only 86% of responses to conflicting cars occurred after the safe point. No other factors were significant. A similar 2 x 4 ANOVA was conducted on the RT data, but no significant effects were forthcoming.

A 1×4 ANOVA compared driver groups' response times for the no-vehicle clips to assess whether any of the training interventions had resulted in more cautious behaviour in the absence of conflicting vehicles compared with the control group.

No group effect was found. The closest effect was found in the *a priori* contrasts, with marginal evidence for LT drivers taking longer than control group drivers to make a response (3.56 versus 3.03 seconds, $p = 0.09$).

All eye-movement analyses were based on a 3×4 ANOVA with three levels of vehicle (no-vehicle, conflicting car, conflicting motorcycle) and four training groups (LT, PT, AT and control group). Simple contrasts were used to compare each of the trained groups with the control group, while Helmert contrasts were used for the vehicle trials (comparing no-vehicle trials with the average of car and motorcycle trials, and directly comparing car trials with motorcycle trials). Overall gaze percentages for each condition, along with the mean time taken to fixate each category, are shown in Figure 4.2.

Figure 4.2: The percentage time spent looking at different categories for all driver groups across all types of clip   numbers represent the mean time to first look at that category

Note, the categories are rear-view mirror (RVM), right-side mirror (RSM), the left screen (Left), the central screen (Ahead) and the right screen (Right); $n = 94$.

4.2.2.1 Rear-view mirror

One further participant from the AT group was removed due to missing data. The average time taken to first look at the rear-view mirror was 1.5 seconds after the start of the clip. Analysis revealed an influence of the presence or absence of a conflicting vehicle for the time to first look in the rear-view mirror ($F(2,178) = 32.6$, MSe = 0.54, $p < 0.001$). Helmert contrasts showed that participants looked in the rear-view mirror more quickly in the no-vehicle clips than in the conflicting vehicle trials ($F(1,89) = 55.9$, MSe = 0.9, $p < 0.001$), with marginal evidence that, for motorcycle clips, there were earlier gazes to the rear-view mirror than for car clips ($F(1,89) = 3.6$, MSe = 1.0, $p = 0.06$; with means of 1.0, 1.6 and 1.8 seconds for no-vehicle, motorcycle and car clips, respectively).

The first gaze duration (FGD) in the rear-view mirror was different depending on clip type ($F(2,178) = 54.9$, MSe = 38,046, $p < 0.001$). Helmert contrasts revealed that FGD was shorter in the no-vehicle trials than in the conflicting vehicle trials ($F(1,89) = 89.6$, MSe = 68,159, p<0.001), and there was marginal evidence for shorter FGDs in the car clips compared with the motorcycle clips ($F(1,89) = 3.5$, $p = 0.06$; with 426 ms, 708 ms and 659 ms for no-vehicle, motorcycle and car clips). The *a priori* contrasts offered marginal evidence to suggest that LT participants have longer initial gazes on the rear-view mirror than the control group (684 ms versus 561 ms; $p = 0.078$).

A vehicle effect was also found for the mean gaze duration (MGD) on the rear view-mirror, ($F(2,178) = 75.7$, MSe = 18,159, $p < 0.001$), with shorter gazes on no-vehicle trials ($F(1,89) = 116.5$, MSe = 34,457, $p < 0.001$), and shorter gazes on the rear-view mirror in car clips compared with motorcycle clips ($F(1,89) = 5.3$, MSe = 26,693, $p < 0.05$; with means of 389 ms, 617 ms and 578 ms for no-vehicle, motorcycle and car clips, respectively).

More interestingly, the main effect of driver group was significant ($F(3,89) = 3.86$, MSE = 32,482, $p < 0.05$). Simple contrasts revealed longer gazes on the rear-view mirror for the LT group compared with the control group (617 ms versus 443 ms; $p < 0.001$), and longer gazes for the AT group compared with the control group (544 ms versus 443 ms; $p = 0.05$).
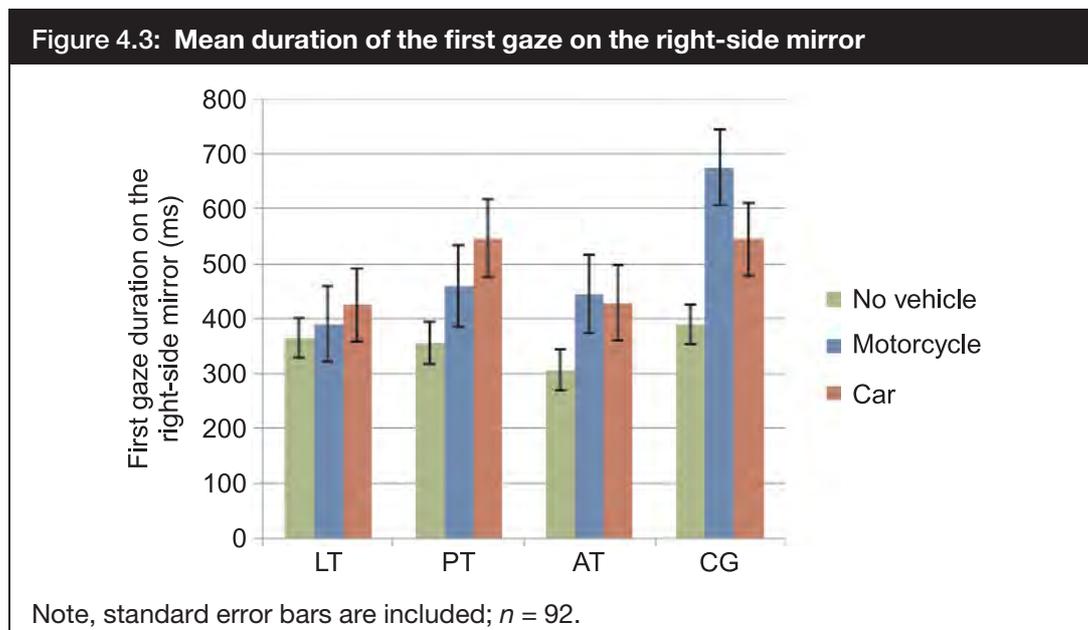
Finally, analysis of the percentage of time devoted to looking at the rear-view mirror was less with no-vehicle trials compared with the combined vehicle trials ($F(1,89) = 11.9$, MSe = 70.2 $p < 0.001$), and was greater for motorcycle clips than car clips ($F(1,89) = 11.4$, MSe = 41.6, $p < 0.001$; with means of 23%, 27% and 25% for no-vehicle, motorcycle and car clips, respectively).

4.2.2.2 Right-side mirror

Two members of the AT group were removed from the analyses of gaze to the right-side mirror due to missing data. The average time that participants first looked at the right-side mirror was 2.2 seconds, over half a second later than the first glance to the rear-view mirror. Analysis showed the same effect of vehicle presence as found with the rear-view mirror ($F(2,176) = 39.1$, MSe $= 0.87$, $p < 0.001$, with no-vehicle trials inducing faster gazes to the right-side mirror than trials with conflicting vehicles ($F(1,88) = 64.0$, MSe $= 1.5$, $p < 0.001$), and marginal evidence to suggest that motorcycle clips have sooner glances to the right-side mirror than car clips ($F(1,88) = 3.2$, $p = 0.079$; with means of 1.5, 2.4 and 2.6 seconds for no-vehicle, motorcycle and car clips, respectively).

There was a significant group effect ($F(3,88) = 4.1$, MSe $= 1.18$, $p < 0.01$). Simple contrasts showed that the time to first fixate the right-side mirror was longer for the LT group than for the control group (2.8 seconds versus 1.9 seconds; $p < 0.01$).

First gaze duration on the right-side mirror differed according to the presence of conflicting vehicles ($F(2,176) = 15.7$, MSe $= 35,499$, $p < 0.001$), with shorter FGDs on the no-vehicle trials than the combined motorcycle and car trials ($F(1,88) = 26.3$, MSe $= 63,460$, $p < 0.001$). Contrasts also revealed that LT and AT groups had shorter first gazes on the right-side mirror ($ps < 0.05$), which were primarily due to the reduction in FGDs on the motorcycle clips (which produced a significant interaction ($F(6,176) = 2.6$, MSe $= 35,499$, $p < 0.05$)). As can be seen in Figure 4.3, the longer first gazes from the control group to the right-side mirror are significantly reduced with training of any sort.

Figure 4.3: Mean duration of the first gaze on the right-side mirror

Note, standard error bars are included; $n = 92$.

Mean gaze duration on the right-side mirror showed the same effect of the presence of a vehicle ($F(2,176) = 16.2$, MSe = 19,788, $p < 0.001$), with no-vehicle trials receiving shorter gazes on the right-side mirror than the conflicting vehicle trials (334 ms, 443 ms, and 429 ms for no-vehicle, motorcycle and car trials; $F(1,88) = 20.0$, MSe = 47,596, $p < 0.001$). The analysis of the percentage of gaze devoted to the right-side mirror showed the same pattern, with contrasts identifying shorter percentages of gaze in the right-side mirror on no-vehicle trials compared with the combined vehicle trials ($p < 0.001$) and longer gaze percentages on motorcycle clips than car clips ($p < 0.001$; with 23%, 27% and 25% for no-vehicle, motorcycle and car clips, respectively).

Group contrasts also revealed that the LT group had a smaller percentage of gaze devoted to the right-side mirror than the control group (15.9% versus 24.6%; $p < 0.05$).

4.2.2.3 Right screen

One PT participant was removed as she never fixated the right screen. The average time taken from the start of the clip to first look into the right screen (looking at the intended destination lane) was 2.8 seconds, suggesting that drivers tend to use both mirrors before considering the space available in the destination lane. All drivers looked at the right screen sooner in the no-vehicle trials than in the vehicle trials ($F(1,89) = 89$, MSe = 3.5, $p < 0.001$), and sooner in the motorcycle trials compared with the car trials ($F(1,90) = 12.7$, MSe = 2.3, $p < 0.001$; with means of 1.6, 3.1 and 3.7 seconds for no-vehicle, motorcycle and car clips, respectively).

The duration of the first gaze on the right screen was also found to depend on clip type ($F(2,178) = 22.9$, MSe = 10,918, $p < 0.001$). The duration of the first gaze was shorter for the no-vehicle trials than for the conflicting vehicle trials ($F(1,89) = 40.6$, MSe = 18,386, $p < 0.001$). It made no difference whether the vehicle was a car or a motorcycle (with means of 174 ms, 267 ms and 260 ms for no-vehicle, motorcycle and car clips, respectivley).

Mean gaze duration on the right screen showed shorter gazes for no-vehicle compared with the combined vehicle trials ($F(1,89) = 91.2$, MSe = 12,397, $p < 0.001$) and longer gazes on the right screen in motorcycle clips when compared with car clips ($F(1,89) = 23.3$, MSe = 7,891, $p < 0.001$), with means of 167 ms, 300 ms and 255 ms for no-vehicle, motorcycle and car clips, respectively. There was a main effect of training ($F(3,89) = 2.64$, MSe = 9,237, $p = 0.05$), with simple contrasts suggesting that MGD was significantly longer for the LT group than the control group (277 ms versus 201 ms, $p < 0.05$), and offering marginal evidence for a significant lengthening of MGD in the AT group (251 ms, $p = 0.068$).

The interaction between the two factors was also significant ($F(6,178) = 2.3$, MSe = 6,105, $p < 0.05$). As can be seen in Figure 4.4(a) the greatest difference

Figure 4.4: (a) Mean duration of the first gaze on the right screen and (b) mean percentage duration of gaze on the right screen
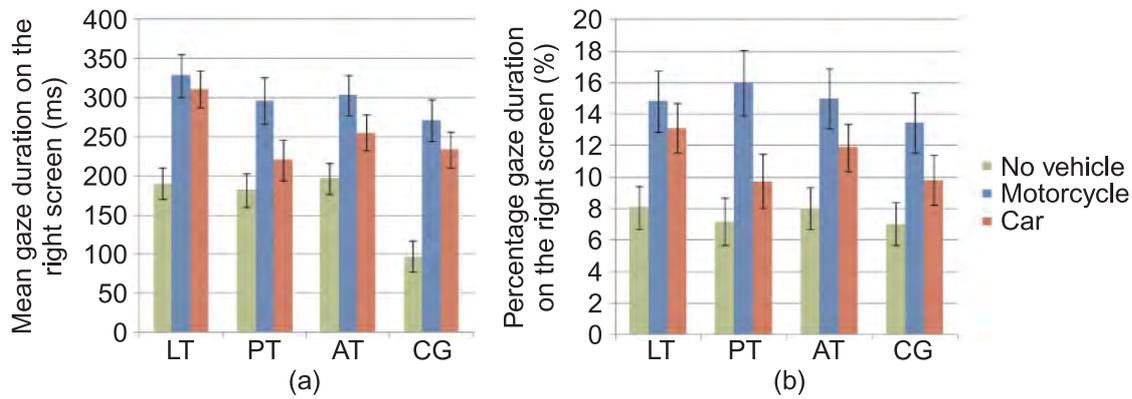
Note, standard error bars are included; $n = 93$.

between the four groups is that the control group have much shorter gazes on the no-vehicle trials, though it is also noticeable that the PT group, and to a lesser extend the AT group, both have longer gazes on motorcycle clips than on car clips; a difference which is less noticeable in the control group. While the LT group's mean gazes are equal for motorcycle and car clips, in absolute terms they are somewhat greater than those of the control group. It appears that look training has increased MGDs on the right screen regardless of the conflicting vehicle, whereas the perception training (and possibly the appraisal training) have vehicle-specific influences.

The percentage of time spent looking at the right screen also depended on clip type, with motorcycle clips resulting in a greater proportion of time looking to the right screen compared with car clips ($F(1,89) = 51.8$, MSe $= 24.1$, $p < 0.001$), though both conflicting vehicle clips resulted in greater percentages of gaze compared with the no-vehicle trials ($F(1,89) = 77.6$, MSe $= 34.6$, $p < 0.001$). The interaction contrasts also revealed that the groups differed in their percentages of gaze to car and motorcycle clips ($F(3,89) = 3.2$, MSe $= 24.1$, $p < 0.05$). As can be seen in Figure 4.4(b), the greatest difference between groups comes in the comparison of the PT group with the control group. While the two groups do not differ with regard to gaze on the right screen in car clips, the PT group greatly increase their gaze percentage on motorcycle clips, driving the interaction.

4.3   Discussion

Many of the results found in Study 3 accord with those found in Study 2. Motorcycles were generally responded to more safely, and many of the patterns of eye gaze noted in Study 2 were evident in the eye movements of the three training groups.

With regard to the T-junction scenarios, none of the training interventions had an impact on the responses to pull out, or upon the eye movements, when compared with the control group. While this is not definitive evidence against the use of information designed to improve the detection of and response to motorcycles at T-junctions, it is a clear sign that simple common-sense interventions (e.g. telling people where to look) may not necessarily lead to the expected improvements. It is possible that, with further iterations, these initial training interventions could change behaviour (especially considering the impact of the training interventions in the change-lane scenarios), though it is also possible that the combination of the bottom-up factors (e.g. the perspective of the junction) and capacity limiting factors (e.g. novice drivers' limited ability to take on new information in light of the existing demands that come with minimal driving experience) define the eye-movement strategies used at T-junctions. Certainly the evidence that individuals can implement eye-movement advice is limited (Dewhurst and Crundall, 2008), and the current results underline the fact that simple interventions may not lead to common-sense outcomes.

It should be noted, however, that the majority of our samples were akin to novice drivers. In Study 2 it was found that there were perhaps more differences in eye movements between the dual drivers and the experienced drivers. Therefore, part of the failure of the interventions to influence eye movements may be due to the groups already employing effective strategies. Despite this, the novice drivers still produced the least cautious responses in Study 2. If their eye-movement strategies were not to blame for this, then presumably it was a failure to correctly appraise the risk. In such cases, one might hope the appraisal training would have led to more cautious responses, yet it did not. It is possible that the appraisal training was too subtle, however. An alternative appraisal training technique that explicitly teaches drivers to respond later to oncoming motorcycles may be more effective than indirectly attempting to induce more cautious appraisal through encouraging empathy with the motorcyclists and the hazards they face on the road.

The training results for the change-lane scenarios were more interesting, though certainly not straightforward. The LT group came closest to producing more cautious RTs to conflicting vehicles, though this was not significant ($p = 0.09$). They did, however, produce longer gazes on the rear-view mirror (as did the dual drivers in Study 2), however they also had shorter gazes on the right-side mirror (more like the experienced group of Study 2), and longer gazes on the right screen (which did not differentiate between the driver groups in Study 2). Considering the instructions given to the LT group, these results make sense. They were told to sample all the areas in the following sequence – straight ahead, rear-view mirror, right-side mirror and then the right screen to look at the destination lane. As they were already focusing on the central screen when the clips started, this did not require much planning. However, they then made a controlled eye movement to the rear-view mirror as instructed. As this was their first area of inspection they put more effort into processing objects in the rear-view mirror than they otherwise might have done.

Then, having realised they have spent what might seem an inordinate amount of time on the rear-view mirror, they make a shorter gaze upon the right-side mirror in order to catch up with their instructions. Finally, they move to the right screen. This is where the instructions stop, and apparently so did the LT group's visual search (resulting in longer and unwarranted gazes).

Again, it appears that training eye movements has revealed problems with the process as much as with the scenario of interest. It seems that the LT group have tried to follow their instructions, but this only results in the desired behaviour early on in the chain of gazes and leads to disproportionate oculomotor behaviour later in the visual search sequence.

In summary of Study 3, the training interventions had a greater impact on the change-lane scenarios than on the T-junction scenarios. This suggests that behaviour in T-junction scenarios may be defined more by exogenous factors and capacity limitations than by intentional strategies, at least in the samples used here. While the effects were more pronounced in the change-lane scenarios, the training did not always have the desired effects. A greater understanding needs to be had of the interplay of explicit instruction, exogenous demands and the capacity limitations of the drivers targeted for instruction. The fact that instruction in where to look (and to a lesser extent for the other two training groups) had an impact on eye-movement behaviours shows promise in that these behaviours can be modified. Unfortunately, the literature on eye-movement training is far from complete in prescribing the best method to achieve desired outcomes without inadvertently causing problems elsewhere in gaze behaviour. On a positive note, however, none of the training interventions made participants produce more risky responses.

5 GENERAL DISCUSSION

This research was undertaken to increase our understanding of why car drivers collide with motorcycles, and to offer some advice as to how we might be able to reduce these collisions.

The first study was concerned with car drivers' attitudes and empathy towards motorcyclists, and we have demonstrated that both these measures, along with awareness of the perceptual problems associated with spotting motorcycles, can be improved with an intervention that focuses upon hazard perception. While the impact on the factors underlying the questionnaire suggested that taking a motorcyclist's perspective was not necessary to induce these specific improvements, the drivers reported that their overall opinion towards motorcyclists had become more favourable following the presentation of hazard perception clips from a motorcycle.

Why did the simulator not create such a feeling? First it is possible that our participants enjoyed the simulator too much. If they treated it as a glorified computer game, then they are less likely to have been impacted by it. Secondly, as we had the motorcycle simulator on a manual setting, the drivers (with no motorcycle experience) would have had to devote a considerable amount of attention to the manual controls. Despite two practice runs, their inexperience with the motorcycle controls may have reduced the amount of spare attention required to fully comprehend the nature of the hazards, or may have provided them with an excuse for why the hazards appeared so dangerous (with the implication that they may feel the events would be less hazardous for riders who are familiar with the controls). The video-based hazard clips, however, provide no such excuses. As the video clips merely test visual skills rather than motor co-ordination, and all drivers assume they have a certain level of skill in spotting hazards, any surprises that they encounter would more likely be interpreted as gaps in their own hazard skill, rather than a lack of knowledge of how to control a motorcycle.

The self-reported success of the hazard perception video clips opens opportunities for new safety interventions using the motorcyclist's perspective. However, we also added the caveat that mixing perspectives appeared to entail a cost. Thus, having a television commercial which contains both a driver's perspective and a motorcyclist's perspective might actually reduce the impact of one perspective presented in isolation.

The second study aimed to develop an immersive hazard perception test that would provide the participants with visual information beyond that of a simple single-screen hazard perception test. Through the inclusion of side screens and mirror information we were able to create of series of clips that allowed participants to

check those areas of the visual scene where conflicting traffic would first appear in the T-junction and change-lane scenarios.

Not only did the resultant system have good face validity as reported by participants, it identified crucial differences between our driver groups. While many of these differences were located in the eye-movement data, even the more coarse response time (RT) measures revealed differences in the T-junction scenarios. Considering the artificial nature of any laboratory situation, we believe that this is testament to the realistic nature of the clips.

Importantly, however, we have been able to demonstrate an oculomotor basis for potential 'Look But Fail To See' (LBFTS) errors in the laboratory. We believe this is the first time that this has been done in the field of driving psychology. The shorter gaze durations of the novice and experienced driver groups on conflicting motorcycles and on the mirrors in Study 2, compared with those of the dual drivers, suggest that those participants with specific motorcycle experience processed the conflicting motorcycles for longer.

In the field of eye-movement research one would typically assume that longer gaze durations are a symptom of inexperience, or difficulty dealing with a particular stimulus due to the higher processing demands it places on the perceiver. Research has even shown these two influences to interact. Chapman and Underwood (1998) found that even though all drivers increased the length of their gazes upon hazards while watching a hazard perception test, inexperienced drivers suffered the greatest increase in these durations.

Thus, we might expect that if novices were aware of the motorcycles then they should have longer gazes on these areas than the dual drivers. Instead they have shorter gazes in the T-junction trials and comparable length gazes to the dual drivers on the mirrors in change-lane trials. Equally, one should expect that the experienced drivers, while having shorter gazes than the novices on hazardous and conflicting vehicles, should have equal (if not longer) gazes upon conflicting motorcycles than the dual drivers. Instead they have shorter gazes on both the motorcycles in the T-junction scenarios and the mirrors in the change-lane scenarios.

It seems that the appearance of conflicting motorcycles has changed the typical patterns of eye-movement data that one might expect from ordinary driving situations. Furthermore, this change is in a direction that we predicted. We suggested that motorcycles should be harder to process than cars because they are less salient, more visually complex, are more novel, and have greater manoeuvrability (which increases the degrees of freedom in trying to predict what they will do next). Thus, we predicted that motorcycles would require longer gazes than cars. If all drivers processed the conflicting motorcycles to the same degree then we would also expect experienced drivers to have equal or longer gazes on motorcycles compared with dual drivers, and novices to have the longest gazes (both

due to varying levels of inexperience in processing motorcycles). However, we anticipated that the novice and experienced drivers might not process the motorcycles to the same extent as dual drivers. The shorter gazes on motorcycles from these two groups suggest that this is indeed the case.

The question remains as to why this happens. A true LBFTS error might suggest that the shorter gazes are due to a new eye movement being initiated before the driver has fully appreciated what they are looking at. Alternatively, the 'familiarity check' (cf. Reichle *et al.*, 2003) might have identified a motorcycle, yet the novice and experienced drivers do not prioritise the motorcycle for further immediate processing.

From our earlier research, however, it appears that drivers do have a considerable understanding of how difficult it is to see motorcycles in the scenarios we have used. It is not parsimonious to suggest, therefore, that such drivers consciously decide not to focus on the most hazardous event in the scene. In the T-junctions, for instance, the experienced drivers recognise the threat from the conflicting car and therefore give longer gazes; the suggestion that they consciously do the opposite with motorcycles does not seem likely. Instead we suggest that the experienced drivers move away from the motorcycle before realising how important it is to focus upon it, which then requires re-fixation at a later point. This could be because they completely fail to perceive it (to them it is just another stretch of empty road; a true LBFTS error), or, more realistically, it takes them longer to process the importance of the motorcycle. Once an eye-movement program reaches a certain (non-labile) stage, it cannot be cancelled, even though the viewer might have just processed enough information to recommend staying on the object (Reichle *et al.*, 2003). Thus, just as the driver realises that additional gaze is required, they find their eyes moving to a new area of the visual scene.

It is also likely that the decision to pull out has a labile and non-labile stage. During the labile stage, drivers search for information to stop them from pulling out. If they do not find enough information to reach the threshold to cancel the manoeuvre, then the behavioural plan to pull out is triggered and becomes unstoppable (this is not the same as the behaviour actually beginning; it is the triggering of the intention to pull out which is irreversible). The driver will continue to process information during the non-labile stage of the behavioural plan, which raises the possibility that they will suddenly reach the criterion threshold and realise that their action is likely to lead to a collision. Unfortunately, by this stage it is too late and the behaviour goes ahead.

This interpretation of the results has ramifications for legal decisions. Many serious right-of-way violation accidents may go to court, with the violator accused of dangerous driving. In such cases it is not uncommon for experts in the field, including the current authors, to be asked to advise on the authenticity of LBFTS errors. The data we have reported here suggest an oculomotor basis for how such errors might occur. We even suggest that, as perceptual information may still be

gained after the intention to manoeuvre has been triggered (though this is still prior to the car actually pulling out), the driver could perceive the motorcycle before the crash and feel as if they should have been able to do something about it, even though at that point the collision was unavoidable. Thus, not only might car drivers Looked But Fail To See motorcycles, some drivers involved in collisions might not realise that this contributed to their collision. We could argue that 'Look But Fail To See In Time' might be a better (if more long winded) description, which would remove the suggestion that the driver must have had no knowledge of the motorcycle until after they had begun the dangerous manoeuvre.

It should be noted, however, that our evidence provides no judgement on blame or fault. It could be argued that an LBFTS error is an occasionally unavoidable error of the perceptual system (albeit one which is influenced by top-down factors such as specific motorcycle experience), which can increase the possibility of a collision. Alternatively, one could argue that drivers should be able to compensate for any potential errors by maintaining a high level of vigilance at all times. Our research does not attempt to mitigate the blame of any individual, but merely to understand the causes.

The nature of the differences between experienced and dual drivers, and novices and dual drivers, suggests that the two non-riding groups diverge from our benchmark for different reasons. Novices often mirrored the pattern of results of the dual drivers, though at an overall reduced level. This suggests that they are adopting better strategies than experienced drivers, perhaps because they have still retained strategies learned during formal driving instruction. Despite this, their absolute measures are often below that of the dual drivers (e.g. they follow the same pattern of eccentricity in T-junctions as dual drivers, though their eccentricity is less in absolute terms), which may reflect capacity limitations due to inexperience.

The experienced drivers, however, sometimes show measures which are comparable with dual drivers in absolute terms, but then do not show the same relative patterns. For instance, the failure to discriminate between motorcycle and car clips in the eccentricity measure at T-junctions suggests that they are doing something different to the dual drivers. We suggest that the difference between the novice and experienced driver comparisons might be due to experienced drivers using over-learned strategies in all instances. While novices might still be open to low-frequency events, such as the appearance of motorcycles (primarily because **all** driving events are still novel for very new drivers), more experienced car drivers might have settled into a set of expectancies about driving, which makes the appearance of certain novel items harder to deal with. If one spends 20 years looking down a junction expecting to see an approaching car, this is likely to create a greater bias towards perceiving a car over a motorcycle than for the novice driver who may have spent less than a year doing the same thing.

This raises the possibility that the highly experienced drivers should be the main target audience for any intervention. Certainly our initial attempts at training drivers to adopt the search, processing and appraisal strategies of dual drivers did not have clear-cut beneficial results. While we have already discussed some of the potential problems with training, it is possible that if we had targeted a more experienced cohort the effects might have been more positive.

In conclusion, we have identified a number of differences between dual drivers and other driver groups in the way they deal with conflicting motorcycles. The evidence supports the use of dual drivers as a gold standard, and has identified potential underlying causes for LBFTS errors. In doing so we have created a valid experimental rig which is unprecedented in its ability to present high-definition video clips across a wide visual scene. While our initial attempts at training will perhaps have greater benefit for our theoretical understanding of instruction on visual search and processing than on improving drivers' ability to spot motorcycles, we remain confident that continued research in this area will bear fruit in the future.

6 ACKNOWLEDGEMENTS

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APPENDIX 1: The full 30 items from the online questionnaire used in Study 14

The response options for questions 1–27 were as follows:

○   ○   ○   ○   ○   ○   ○

Disagree   No opinion   Agree
strongly   strongly

Q1   'Company car drivers are more likely to speed than the average car driver.'

Q2   'When driving in interweaving streams of fast-moving traffic, with many other drivers often changing lanes, I am constantly aware that motorcycles can be more difficult to spot than under normal driving conditions.'

Q3   'Bus drivers often pull away from bus stops without waiting for an adequate gap.'

Q4   'Bus drivers are more careful than other drivers.'

Q5   'It is difficult to estimate the speed of approaching motorcycles while waiting to turn at a junction onto a main carriageway.'

Q6   'Most LGV (large goods vehicles) drivers will tailgate the car ahead.'

Q7   'When waiting to turn at a junction onto a main carriageway I find that approaching motorcycles are as easy to spot as approaching cars.'

Q8   'When riding a motorcycle, taking risks is part of the thrill.'

Q9   'Drivers generally do not pay enough attention to traffic signs.'

Q10   'Motorcyclists tend to have headlights on more often than car drivers in the daytime to increase visibility.'

Q11   'Other motorists should take extra care to look for motorcyclists.'

Q12   'Bus drivers are typically more law-abiding than car drivers.'

Q13   'When a car and a motorcycle collide, it is typically the fault of the motorcyclist.'

Q14   'Taxi drivers change lanes without checking their mirrors more often than other drivers.'

Q15   'Motorcycles are easily hidden from view by parked vehicles and other parts of the road environment, e.g. buildings or overgrown vegetation.'

Q16   'When a car and a truck collide, it is typically the fault of the truck.'

Q17   'I have similar personal characteristics to the average motorcyclist.'

Q18   'Many people who have passed their car driving test would find it relatively easy to pass the bus driving test.'

Q19   'It costs less to repair the average motorcycle after a minor accident, compared with an average car.'

Q20   'Car drivers are typically more law-abiding than motorcyclists.'

Q21   'Taxi drivers have fewer accidents than average car drivers when their (taxi drivers') higher mileage is taken into consideration.'

Q22   'It is easier to pass the current motorcycle test than the current car driving test.'

Q23   'Most car drivers do not know their stopping distances at different speeds.'

Q24   'Pedestrians often step onto zebra crossings without looking for approaching traffic.'

Q25   'Motorcycles are usually easy to spot even against a "cluttered" background (containing road signs, adverts etc.).'

Q26   'White van drivers rarely wear seat belts.'

Q27   'Most car drivers do not check their blind spots when changing lanes.'

Q28   'When a motorcyclist overtakes a car at 40 mph what size of gap should be left between the car and the passing motorcycle in order to remain safe?' (Response options ranged from 1 to 7 feet)

Q29   'What proportion of the width of a truck does a car occupy?' (e.g. 70% would indicate that a car was a fifth of the width of a truck and 100% would mean it was the same width as the truck)
(Response options ranged from 70 to 100% in 5% increments)

Q30   'What proportion of the width of a car does a motorcycle occupy?' (e.g. 20% would indicate that a motorcycle was a fifth of the width of a car and 80% would mean it was the same width as the car)
(Response options ranged from 10 to 70%)

# APPENDIX 2: Instructions for T-junctions and changing lanes for the look group in Study 3

How to search for vehicles at T-junctions
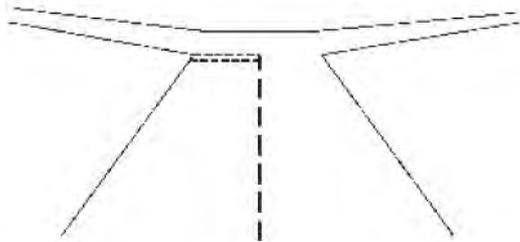
When you approach a t-junction you should try to look as far down the road as possible. Be aware of obstacles that prevent you seeing as far down the road as you would like to (e.g. parked cars, hedges)
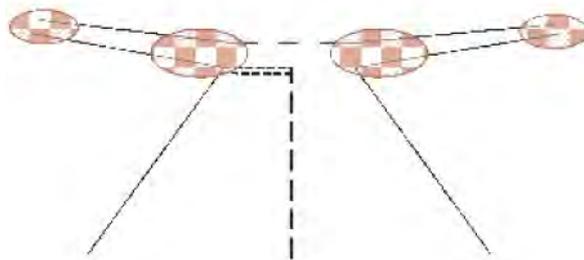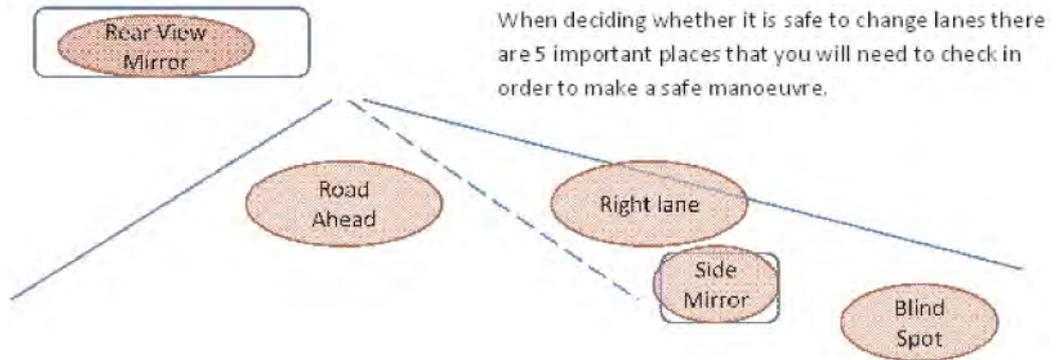

Safe drivers are aware of the 4 main danger areas of a t-junction. The FAR distances in both directions give you information about approaching vehicles which may reach the junction very soon, while the NEAR locations inform you of any immediate hazard (e.g. a passing car).
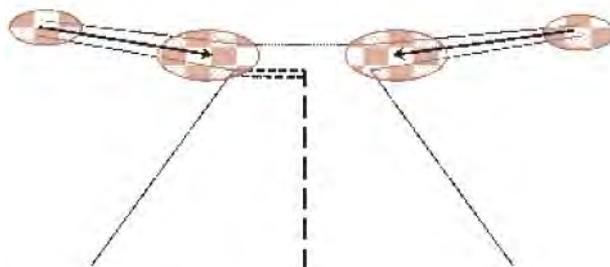
Good drivers tend to look FAR and then NEAR. When looking at the FAR location approaching vehicles can be small and indistinct. Don't just glance quickly at the FAR location; give yourself enough time to spot if an approaching vehicle is actually there.

How to search for vehicles when changing lanes

When deciding whether it is safe to change lanes there are 5 important places that you will need to check in order to make a safe manoeuvre.

1. First check the road immediately ahead. Are you too close to the vehicle ahead to make the necessary visual checks to change lanes? If so, slow down and increase the gap before checking your mirrors.

2. Good drivers tend to look at the rear view mirror first, when deciding to pull out. This gives an overview of the situation behind. Are there any vehicles that are closing in too quickly, who look like they may be about to overtake you? Drivers often underestimate the value of the rear view mirror when changing lanes. Make sure you look at the rear view mirror for long enough to identify any hazards behind you.

3. Good drivers then look at the side mirror. This should identify any immediately overtaking vehicles. Don't just give the side mirror a cursory glance or you may miss some vehicles which are harder to see, such as motorcycles. Look at the side mirror long enough to satisfy yourself that there is no approaching hazard.

4. Check the blind spot. In our test you cannot check your blind spot (if you look over your shoulder you will only see the laboratory!). However in the real world it is important to remember this vital check.

5. Finally check the lane you intend to move into. Ensure that you have enough space to move into the lane. If the new lane has traffic in it you will not be able to accelerate into this lane