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Car Drivers' Skills and Attitudes to Motorcycle Safety: A Review

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EXECUTIVE SUMMARY

This report proposes a framework for interpreting the literature and evidence on car drivers' skills and attitudes towards motorcyclists. The framework relates attitudes, knowledge and skills/strategies to three behaviours: Does the driver look at the motorcyclist? Does the driver realise that it is a motorcyclist? Does the driver correctly decide whether the motorcyclist poses a hazard? The additional factor of stimulus-driven influences ('bottom-up' influences) is included in the framework.

The review of the literature first identifies a number of bottom-up factors such as A-frame obscuration, movement and conspicuity. One particular bottom-up influence seems especially relevant: spatial frequency (the width of the vehicle). Global Precedence theory suggests that we extract low spatial frequency items from a visual scene first (including wide vehicles such as cars). Thus we are more likely to miss narrow motorcycles, which are considered to be high spatial frequency items.

Whether a driver *looks* at a motorcycle can be dependent on many things, including experience and practice with particular road contexts, learned regularities of specific road environments, and the extent of peripheral vision. Attitudes can indirectly influence whether drivers make all appropriate visual checks, and on the basis of the literature review it is suggested that speed may be an important mediating variable. If intentions to speed actually result in higher speeds, then visual search is constrained. Going through a junction at speed reduces the time available for appropriate visual checks.

Whether a driver realises that they are looking at a motorcycle is a more subtle question. In theory a driver could look directly at a motorcycle yet not *perceive* it. This is the truest form of the Looked But Failed To See error (LBFTS). This again potentially relates to the spatial frequency of the motorcycle, but also to expectations and previous exposure. Empathy with the motorcyclist's plight appears important. Drivers with relatives who ride motorcycles have been reported to have fewer collisions with motorcyclists and have better observation skills in regard to motorcycles.

It is possible that a driver looks at an approaching motorcycle, and even perceives the motorcycle, yet still makes a manoeuvre that leads to a collision. This could occur because they misjudge whether it poses a potential risk, or fail to *correctly appraise* the approaching motorbike. One of the key theories is the 'size-arrival effect'. According to this theory, approaching speed is related to the size of the vehicle. The consequence of this is that the narrower image of the motorcycle compared to the car may result in the driver over-estimating the time of arrival.

The final conclusion summarises the factors of importance and argues for future directions for research in this area to help reduce motorcycle accidents on UK roads.

1 AN INTRODUCTION TO THE PROBLEM

The most recent figures reveal that 23,326 motorcyclists (including moped and scooter riders) and pillion passengers were injured in reported accidents in Great Britain in 2006. Of the injuries sustained, 5,885 were considered serious and 599 motorcyclists and passengers were killed. Deaths among motorcycle users accounted for 19% of fatalities in 2006 and 9% of all road traffic casualties were motorcyclists (Department for Transport, 2007a).

The number of newly registered motorcycles, scooters and mopeds rose by 7.7% between 2006 and 2007, with over 127,000 being registered in 2007 (MCIA, 2007), and between 1996 and 2006 motorcycle traffic saw a rise of 38% (Department for Transport, 2007b). There are also increasing numbers of older motorcyclists returning to the road after a long break on fairly powerful machines, perhaps explaining why KSI casualties in age groups between 30 and 59 have increased in the last 10 years. Ormston Dudleston, Pearson and Stradling (2003) found that motorcyclists in Scotland aged over 30 have accounted for an increasing proportion of casualties since 1997.

The increasing exposure to danger that motorcyclists face demands an analysis of the types of accident that they are typically involved in. Just such an in-depth study was undertaken by Clarke, Ward, Bartle and Bartle (2004). From an analysis of police accident reports they identified the most prevalent types of motorcycle accident. The top three were as follows:

1. **Right of way violation (ROWV) accidents:** these occur when a vehicle pulls out of a side road onto a main carriageway without giving way to an approaching motorcycle. In these accidents there appeared to be a marked problem with other road users seeing the motorcyclists. In many observation-failure cases of this type, the motorcycle was so close to the junction that there appeared to be no explanation as to why they had not seen it, even when looking in that direction. This is commonly referred to as a ‘Looked but Failed to See’ (LBFTS) error.
2. **Loss of control on a bend, corner or curve:** this type of accident is almost always regarded as primarily the fault of the motorcyclist rather than other road users, and it was shown that such accidents are more associated with riding for pleasure than accidents of other types.
3. **Motorcycle manoeuvrability accidents:** Clarke *et al*. (2004) identified a sub-group of cases that were specifically related to the way motorcyclists are able to manoeuvre. When all accident cases were examined where the rider was judged to be at fault, 16.5% involved a motorcyclist overtaking other vehicles. ‘At-fault’ riders had a tendency to be slightly younger than the rest of the sample, and also were found to be riding machines of a higher engine capacity than other accident-involved riders. However, motorcycle accidents also

> occurred when riders took the opportunity to pass slow-moving or stationary traffic, which is often referred to as 'filtering'. Although only slightly more than 5% of the whole sample identifiably involved a rider filtering, other drivers were more than twice as likely to be considered at fault in such accidents as the motorcyclists involved. 'At-fault' drivers typically failed to take effective rear observation before manoeuvring out of (or between) lines of stationary or slow-moving traffic.

Similar accident types have been identified in studies from around the world. One of the most widely quoted in-depth US studies, by Hurt *et al.*, (1981) highlighted the high frequency of ROWVs and single-vehicle accidents on bends in a sample of over 3,000 motorcycle accidents, mirroring two of the key accidents types identified by Clarke *et al*. (2004). Hurt *et al*. found that, in multiple vehicle accidents, the driver of the other vehicle violated the motorcyclist's right of way and caused the accident in two-thirds of all such collisions.

More recently in Australia, Haworth *et al*. (2005) reported that approximately half of all motorcycle accidents resulting in injury involved collisions with other vehicles, and that the majority of these collisions were most probably due to a ROWV on the part of the other road user. Lynham *et al.* (2001) showed that failure to give way to a motorcyclist was a common cause of fatal accidents, and usually occurred at T-junctions and crossroads. Accidents involving motorcycles at intersections have also been found to have a higher statistical probability of severe injury or death for motorcycle riders, when compared with non-intersection accidents (de Lapparent, 2006). In Scotland, Sexton *et al.* (2004) found that motorcycle accidents on built-up roads tended to be the fault of motorists making a turn or a u-turn in front of motorcyclists who were filtering through traffic or overtaking.

The second most prevalent accident noted by Clarke *et al*. (2004) typically does not involve another vehicle and is best addressed through media campaigns, training and improved signage aimed at the motorcyclists. However, ROWVs and those accidents caused by a mismatch between drivers' expectations and motorcycles' manoeuvrability (such as a car making a u-turn into the path of a filtering motorcycle) require a mixed approach with as many resources targeted at the car drivers as at the motorcyclists. One example of driver-targeted interventions is the recent 'THINK' bike campaign, which includes a television commercial demonstrating the key message: 'Take longer to look for bikes'. While this appears to be sound advice, there are many factors that may need to be considered when future interventions are designed. It is quite possible that advertising campaigns may fail to reduce these types of accident for a number of reasons. For instance, are the typical drivers that engage in ROWVs likely to pay attention to these advertisements? Are they likely to be persuaded by them? Is the failure to see the motorcycle due to drivers making just a single quick glance down the road before pulling out? And if it is, would this be better solved by two quick glances or by one longer glance? Such questions need to be addressed prior to future interventions being put in place. For instance, if drivers are more concerned with making a specific pattern of eye movements (**look right, look left, look right again**) then they may forget to actually process what they look at (see Section 3.3.3). A pertinent theory to the current issue is presented in Findlay and Walker's (1999) model of saccade generation. Their model suggests that eye movements are controlled by two processing centres that are in constant competition. The **fixate** centre keeps the eyes in one place, and continues to process the current stimulus, while the **move** centre continually places demands on the oculomotor system for the eyes to move to a new area of interest. These two centres actively inhibit each other, so if the information at the point of fixation is extremely important the fixate centre will inhibit the move centre. However, if the move centre is more active, then the eyes will be dragged away from the point of fixation, potentially before the viewer has finished processing what they were looking at. It is possible that explicitly learned strategies ('look right, look left, look right again') artificially inflate activation in the move centre to the detriment of the fixate centre. In other words, if drivers are more concerned about where to look next according to some trained pattern, they might be less likely to process what they actually look at.

The aim of this literature review is to assess the evidence concerning those factors that are important when designing an intervention which targets car drivers with the aim of improving car–motorcycle interactions. The following section provides a framework for interpreting the literature.

2 A FRAMEWORK FOR INTERPRETING THE LITERATURE

When identifying the many factors that can influence a behaviour that is as complex as driving, one must first clarify the exact actions that are of interest. In the current report we are concerned with car drivers' behaviour in relation to motorcyclists. More specifically, we are interested in the behaviour of drivers that leads to accidents. As noted in the previous section, there are two key accidents that provide a good focus for this review. The first type is right of way violations (ROWVs), particularly with cars pulling out onto a main carriageway and colliding with oncoming motorcycles. The second type involves the driver failing to anticipate the possibility of a motorcycle appearing in certain situations, such as when a motorcyclist is filtering through traffic.

On a simple level this behaviour can be explained in terms of vision. The most recent figures (Department for Transport, 2006) show that 'failure to look properly' was the most frequently reported contributory factor in all GB road accidents, being found in nearly a third of cases. But just what does it mean to 'look properly' in order to avoid a collision with a motorcyclist? In the case of the ROWVs, drivers often report that they looked but failed to see the oncoming motorcycle (e.g. Clarke *et al*., 2004). The 'Looked but Failed to See' (LBFTS) error is a well-documented self-reported cause of accidents. In a review of this phenomenon, Brown (2002) discusses a re-analysis of data taken from a previous large accident survey (Sabey and Staughton, 1975) which identified LBFTS errors as the most important perceptual factor contributing to unimpaired drivers' errors during daylight. One problem with the veracity of LBFTS errors is that the accident may still have been caused by the driver not looking at all. Certainly in the case of a u-turn accident with a filtering motorcycle, one might be tempted to believe that a failure to look in a mirror is more likely than an LBFTS error. Alternatively, if they did look and see the motorcycle they may have misjudged the level of risk it posed. Whereas these two potential causes (a failure to look and a failure to judge) place the responsibility for the accident directly with the driver, an LBFTS cause implies that the driver behaved appropriately and the accident happened **despite** their actions rather than **because** of them. Therefore drivers may report an LBFTS error regardless of the real cause of the accident. It may even be the case that introspection is so poor, or memory for actions preceding an accident is so distorted, that drivers genuinely believe that they looked but failed to see, despite this belief being based on an inaccurate reconstruction of events.

These three potential causes provide the behaviours that will form the focus of this review. Each cause represents a different point in the visual process where a breakdown could lead to an accident, and can be represented as three questions:

1. Did the driver look at the motorcycle?
2. Did the driver perceive the motorcycle?
3. Did the driver correctly appraise the motorcycle?

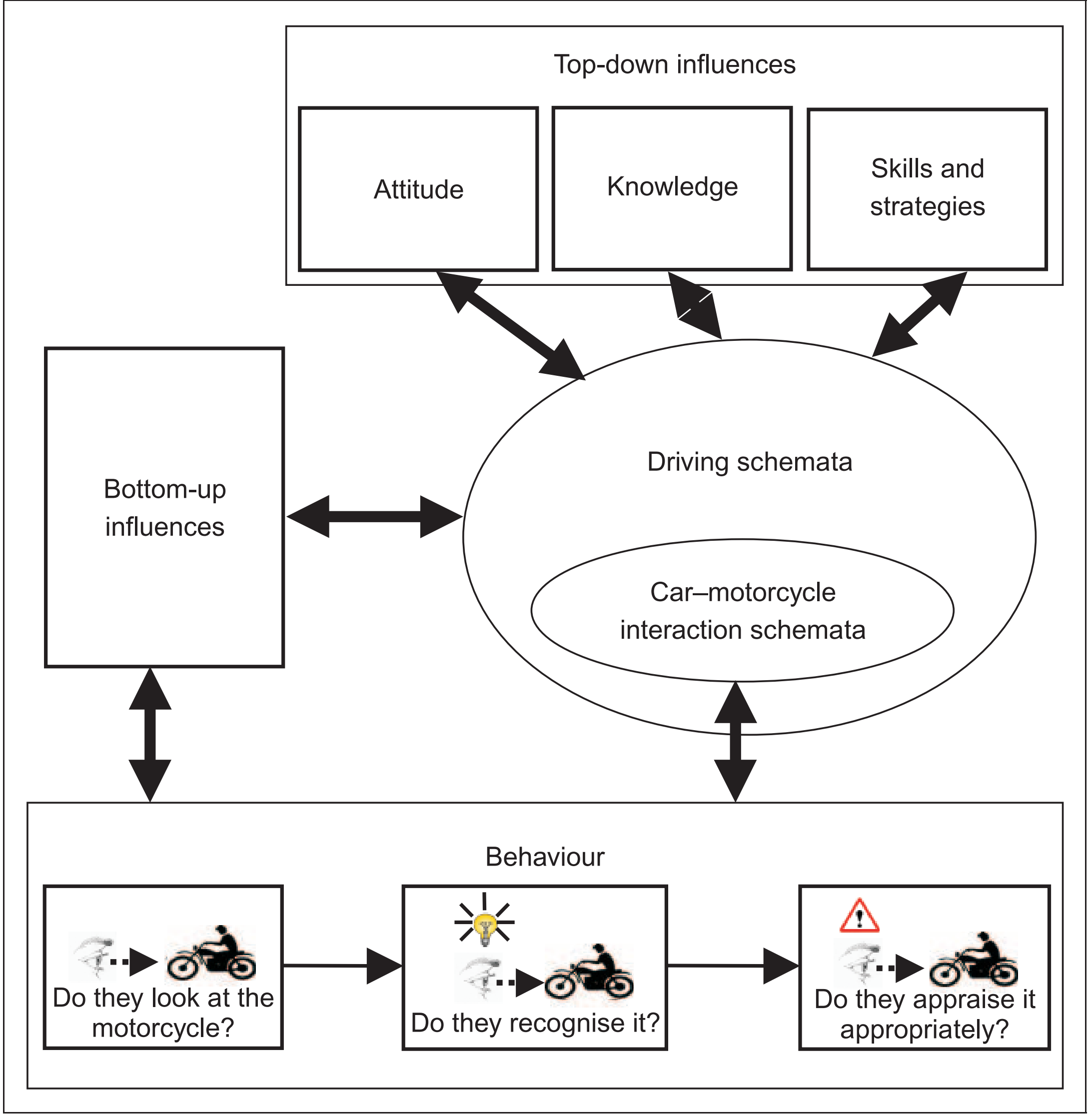
The first question refers to whether the driver oriented their eyes in the direction of the motorcycle. Eye movements consist of two parameters: fixations and saccades. Fixations occur when the eye remains relatively stable in one location in the visual scene. Typical fixations last approximately 200–300 ms, though this depends on the task and the intention of the individual (Rayner, 1998). It is during such fixations that all processing of the visual scene occurs, with longer fixations generally reflecting more difficult processing. For example, fixations during text reading are typically longer on difficult words compared with easy words (Rayner and Polletsek, 1989). Saccades are sudden and extremely fast jumps of the eye to new locations (so fast that all visual input ceases during a saccade), and they are often aided by head movements if the distance to be covered is large (e.g. over 20 degrees). The question 'Did the driver look?' asks whether the driver made a saccade in the direction of the motorcycle (e.g. looking to the right at a T-junction, or looking in a mirror before making a u-turn). In addition, we must be concerned with exactly where the eye landed following a saccade in the general direction of the motorcycle. Simply looking to the right at a T-junction does not necessarily imply that one looks at the oncoming motorcycle. If one looks far off into the distance, then though the head turns and the eyes jump in the direction of the motorcycle, the subsequent fixation may still not land on the motorcycle if it is relatively close to the driver's vehicle. As we shall see in the following section, the distance of any stimulus from the fixation point is crucial to detection. The fixation point describes the location in the world at which the most sensitive part of the retina is aimed. The acuity of the retina at this point is very high but covers a very small area (approximately 2 degrees of visual angle (Rayner, 1998)). Objects which fall outside this area around the fixation point will be presented on a part of the retina with less acuity and therefore will be harder to detect.

The second question asks whether the driver perceived the motorcycle. It is not sufficient for the driver to simply look directly at an oncoming motorcycle. In addition they must identify and categorise the object as a motorcycle before an appropriate behaviour can be chosen. This highlights a common fallacy, often termed the eye-mind assumption (cf. Underwood, 1992). This early view of eye movement researchers suggested that whatever the eye is looking at is what the mind is currently processing. It is often the case, however, that fixations do not represent current cognitive processes. Not every commuter who stares out of a moving train window is interested in railway embankments. Instead they are more likely to be remembering previous events or planning future ones. Measuring the eye movements of these train passengers would therefore give little insight into their cognitive processes. The same principle can apply to drivers, even though their eye movements may appear to be actively seeking out information. As we shall see when we assess the evidence in the following section, it could be possible for the driver to look directly at a motorcycle yet completely fail to register it. This would be the truest form of an LBFTS accident.

The final question is concerned with whether the driver correctly appraises the level of risk that is posed by a motorcycle. This question assumes that the driver has looked at and registered the motorcycle, yet still needs to make a decision as to whether that motorcycle poses a threat. At T-junctions this is likely to be represented as a gap judgement decision (i.e. 'can I pull out safely before the motorcycle reaches me?') and will be based on several factors including the perceived distance of the motorcycle and the perceived speed that it is travelling at.

Together these three questions provide a focused definition of driver behaviour for the purposes of this review, and define the output level of the framework shown in Figure 2.1.

Figure 2.1: A framework describing the factors that influence the detection, discrimination and appraisal of a motorcycle



We propose that the most immediate influence on these (and all other) driving behaviours derives from driving schemata. A schema is a mental structure that helps us to organise the world and guide our behaviours in specific situations. The rules and guidelines that make up each schema are abstracted from specific occurrences so that they can be applied to new events. Bartlett (1932) used the term 'schema' to describe the act of categorisation. We do not need to see every type of monkey to understand that any particular animal is a monkey. Instead we apply our generalised knowledge of what constitutes a monkey to each instance, and if the schema fits then we accept the animal as a monkey. Bartlett's work was developed by Schmidt (1975) and Norman and Shallice (1986), who described how a motor-response schema could guide actions. The notion of a set of abstracted rules that dictate how one interacts with an environment is still highly relevant and has been applied to driving by Land and Furneaux (1997). They describe a series of schemata that must tell the individual where to look in a given situation, what to expect there, and what to do dependent on that information. They also point out that these schema are rarely taught, but are instead built up from exposure to situations from which the abstracted rules are extracted. This may pose a problem for some drivers as the relatively low frequency of car–motorcycle interactions may mean that they have not had the opportunity to fully develop their motorcycle schemata.

There may be an overall driving schema which contains very general rules (look in your mirrors regularly, look ahead and scan horizontally, use the tangent point of curves to steer, etc.), though there will be many sub-schemata for more specific events. For instance it is likely that we have a specific schema that allows us to successfully navigate roundabouts. Any new roundabout can be navigated through reference to the rules of the schema. Roundabouts which diverge from the norm can, however, lead to problems because drivers may apply an inappropriate schema. For instance, traffic light controlled roundabouts are in the minority in the UK which may lead drivers to occasionally apply a normal roundabout schema on approach. Despite the driver being permitted to go at a green traffic light, he or she may still decelerate and even stop if there is traffic on the roundabout which would normally have priority, even though it is actually stopped at a red light. In the typical roundabout schema the important rule is that if there is traffic on the roundabout, one should stop and give way. This is usually judged with one or two short fixations on approach. On a traffic light controlled roundabout, the driver may fail to look at the traffic light as this does not form part of the typical schema (especially if it is on green). The driver is more likely, however, to notice standing traffic on the roundabout. The fixation on the traffic may be so quick that speed information is not processed in time, or the urge to give way may be so great that it overcomes the conflicting information that the traffic is stationary. Thus the approaching driver stops at a green traffic light on a roundabout slip road when he or she actually is permitted to go. This may be dangerous if a following driver is using the correct schema and is therefore unprepared for the driver in front to brake.

While driving schemata guide the actions of drivers in all car–motorcycle interactions, it is the influences that help shape the schemata that are of real interest. We tentatively suggest that these should include the following:

1. Drivers' attitudes – the conceptions and misconceptions that all drivers hold about driving. These attitudes could concern themselves (e.g. 'I'm an excellent driver'; 'I can safely maintain a short headway') or other drivers (e.g. 'Motorcyclists are risk-takers'), or the environment (e.g. 'These traffic lights change to red too quickly. You have to jump them whenever possible').
2. Drivers' knowledge – a driver's understanding of the true nature of the world (or lack of it) will inform his or her actions and help shape attitudes.
3. Drivers' skills and strategies – driving skills and strategies are developed through training, practice and exposure. These skills may include knowing where to look while performing certain manoeuvres, how to handle the vehicle, and how to make informed decisions about specific driving situations (such as determining whether a particular occurrence is hazardous and, if so, what action should be taken to reduce the risk).

These three influences represent 'top-down' information. This represents the individual imposing their will upon the environment, choosing what to look at, what to process and how to react. Unfortunately, negative attitudes and incorrect beliefs may lead to incorrect schemas that could increase the possibility of car–motorcycle accidents. There is, however, the potential that targeted training interventions could also influence schema development, possibly offsetting any negative influences of attitudes and beliefs, and making up for a lack of valuable exposure to these situations. The visual skills are especially important, and previous research has demonstrated that drivers with inappropriate or incomplete driving schemas will have poorer visual skills compared with expert drivers (Underwood *et al.*, 2002a).

These top-down influences are often in competition with 'bottom-up' influences. By this we mean the physical properties of the visual world, such as colour and movement, which attempt to attract our attention to certain items (yet make it harder to detect other items). Bottom-up influences are generally discussed in terms of peaks on a saliency map (Logan, 1996; Henderson *et al.*, 1999), whereby the largest peak is the sum of all the attention-grabbing features at that point in space. The larger the peak, the more likely that particular location will be fixated next (see Findlay and Gilchrist, 2005). In order to fully reflect the impact of top-down factors, they must be considered in the light of this competition. As the bottom-up factors reflect the raw input that drivers receive, it makes sense to begin by discussing these influences in the following section, before considering each of the top-down influences in turn.

3 FACTORS THAT MAY INFLUENCE DRIVERS' BEHAVIOUR IN CAR–MOTORCYCLE INTERACTIONS

3.1 Bottom-up factors

Some features in a visual scene are inherently more salient, or 'attention-grabbing', than others. A sudden movement in peripheral vision might attract attention, or the most colourful advertisement on a page might ensure you look at it first. Currently researchers are developing computational models that attempt to predict which item in a scene one is most likely to look at first on the basis of the raw image. One of the most successful models so far is that of Itti and Koch (2000) who combined quantitative measures of orientation, intensity and colour to produce a saliency map. This saliency map gives numerical values to every point in a visual scene based on a combination of the three bottom-up features. The highest score is the location that should be fixated first. In reality, however, participants in laboratory experiments only tend to follow the predicted pattern if they are allowed a 'free search' unfettered by a specific task. As Yarbus (1967) noted however, when the participant has a specific goal in mind, the pattern of fixations and saccades changes. For instance, asking participants to interpret the emotions in a picture of a group of people will result in fixations on the people's faces. If the task is to identify where the picture was taken, then the individuals in the picture become less important. In either case, however, it is unlikely that the pattern of fixations will reflect pure bottom-up saliency (Underwood and Foulsham, 2006). Instead there is often an interaction between bottom-up and top-down information that leads to a certain search strategy (Crundall, 2005). While the following sections will look at varying top-down influences, this section will examine the relative importance of bottom-up factors in car–motorcycle interactions.

3.1.1 Movement

One of the most salient features in a visual scene is movement. This has been demonstrated many times in simple laboratory-based experiments (e.g. Rauschenberger, 2003). If one object is moving while everything else in the scene remains static, then this will result in attention capture by the moving target. When one is driving however, the observer is also moving, which generates an optic flow field and requires the visual system to make calculations extrapolating local movement from global movement. This tends to be easiest when the local movement goes against the optic flow. For instance, a motorcycle travelling down a side road, away from the current path of the driver, will move in the same direction as the optic flow. While this movement may still be detectable (as typically it will be faster than the rate of optic flow), its salience will be less than that of movement that goes against the flow. Fortunately, this means that a motorcycle approaching a junction that will intersect with a driver's path should attract more attention than a motorcycle moving away from the junction (though, as we shall see below, this is highly dependent on the angle of approach).

A recent study conducted by Underwood *et al*. (2003a), demonstrated how dynamic driving stimuli can capture attention. The study compared eye movements of participants watching video clips of driving. Each clip was paused at a particular point and participants' memory for items that were presented 4 to 8 seconds prior to the pause were probed. The eye movement records showed that central objects and dynamic objects both received more fixations than other objects, and they tended to be remembered better when probed by the subsequent question. There was also an interaction between whether the object was involved in a hazardous event and whether the object was moving or not. This showed that hazardous, dynamic objects (usually those objects that threaten to collide with the observer's vehicle) received the most fixations. Underwood *et al*. (2003a) suggested that there might even be some form of Time To Collision (TTC) calculation that contributes to a low-level saliency map.

Not all movement is salient however. Take for instance a motorcycle moving towards a driver, either on the opposite side of the carriageway or overtaking from behind, or even when the driver stops at a T-junction and looks to the right. If the alignment of the motorcyclist and the driver is retained throughout the approach of the motorcycle, then the driver may fail to perceive any movement. Instead of movement against the optic flow, the image of the motorcyclist merely expands on the retina with decreasing distance. At relatively far distances the amount of expansion on the retina is very small. For instance, a motorcycle with a head-on horizontal profile of 80 cm will only produce an image of 0.9 degrees of visual angle on the retina at a distance of 50 metres. At 40 metres the image will have only increased to 1.1 degrees. Assuming a horizontal visual field of 140 degrees, this increase represents a horizontal change to 0.16% of the visual scene. Considering all the other changes that may occur simultaneously (pedestrians, other traffic), this is an extremely small change relative to the decrease in distance and is close to the threshold needed to spot a change in optical expansion (Hoffman and Mortimer, 1994).

This phenomenon has been called motion camouflage, and was first reported as a stealth technique used by male hoverflies in their attempts to sneak up on female hoverflies with the intention of mating (Srinivasan and Davey, 1995). Humans are just as susceptible to this effect however. Anderson and McOwan (2003) asked participants to shoot down approaching missiles in a virtual 3D environment. They found that participants responded later to motion-camouflaged missiles than to missiles which involved some lateral movement.

Motion camouflage tends to break down at very near distances, as the increases noted in the image size become larger as the moving object gets very close. Edwards

(2005) illustrated this ‘looming’ effect using a series of four photographs of a stationary Ford Ka on the inner lane of a straight three-lane highway, taken at progressively shortening distances. Even as the distance halved between the first two photographs, and halved again for the third photograph, it could be seen that the image of the stationary car remained similar in size, in proportion to the approaching driver’s windscreen. It was only in the last frame, representing the final few metres of approach, that the image of the stationary car suddenly grew to large proportions. It would seem reasonable to assume that the same phenomenon could manifest itself in the case of a stationary observer watching the approach of a small object like a motorcycle along a straight section of road. Unfortunately, the driver’s decision to pull out may be made before the retinal image of the motorcycle begins to expand noticeably.

The UK Motorcycle Action Group (MAG UK, 2006b) have suggested specific accident avoidance strategies for motorcyclists approaching junctions. These focus on increasing ‘x-motion’ (i.e. lateral angular motion) to an observing driver at a junction, for example inducing a gentle weave, usually to the right, which would have the effect of counteracting any motion camouflage that may be occurring from the viewpoint of an emerging driver. They also cite anecdotal accounts of preventative measures that have been taught by some driving instructors, such as encouraging drivers at junctions to rock the car forward and back as they look left and right. Both techniques (increasing lateral angular motion by both motorcyclists **and** the drivers observing them) have been recommended by some advanced driver groups, for example ADVANCE (2005) (Dumfries and Galloway Group of Advanced Motorist and Motorcyclists).

3.1.2 Colour and luminance

It is generally assumed that more colourful objects are more likely to attract attention. In the Itti and Koch (2000) computational model of saliency, colour is one of the key components that are used to calculate overall saliency. Motorcyclists often use the element of colour in the form of fluorescent or other brightly coloured clothing to increase the likelihood that an observing driver will see them. An epidemiological study by Wells *et al*. (2004) reported that, after adjustment for potential confounding variables, drivers wearing reflective or fluorescent clothing had a 37% lower risk of motorcycle-crash-related injury, compared with other riders.

While such researchers are often very good at partialling out the confounding effects of demographic and exposure variables, they are less likely to partial out confounding factors at a stimulus level. The problem with colourful stimuli is that they are inherently confounded with luminance. In simple laboratory experiments luminance and colour can be separated, and recent studies that have used isoluminant colour onsets have failed to find that attention is caught by colour per se (Theeuwes, 1995; Cole *et al*., 2005). Instead the luminance of the stimuli appear to be of greater importance. In regard to the real world however, deciding whether bright colours attract attention because of luminance or colour is less important than the overall increase in conspicuity that they produce.

The work of Hole *et al.* (1996) is, however, a warning not to rely solely on the traditional advice to motorcyclists to make themselves more conspicuous. From studies of participants searching static images for motorcycles, they found that the success of conspicuity aids depended on the background context. For instance, luminance contrast appeared to be more important than luminance per se (e.g. headlights at twilight will be more effective than in the middle of the day). Research into motorcycle conspicuity has produced mixed results (cf. Yuan, 2000); and deliberately increased conspicuity in general has been found not to have been as effective an aid in avoiding accidents as might have been assumed. For instance, Langham *et al.* (2002) found that stationary police vehicles (which are designed to be very conspicuous) were driven into by unobservant drivers on a remarkably frequent basis. They suggested that these accidents do not occur because the police vehicle is hard to see but because of higher-order cognitive reasons, such as vigilance failure or an incompatibility between expectation and reality.

With regard to motorcycles, one of the key recommendations is to use daytime running lights (DRL). In a critical appraisal of a European review of research into DRL, Knight *et al.* (2006) concluded that mandatory DRL would indeed reduce accidents, though they acknowledged that the size of the effect was debateable. One problem with mandatory DRL for both cars and motorcycles, noted by Knight *et al.*, is that if an oncoming motorcycle obscures one of the headlights of a car following behind, then this may further confuse a driver waiting to pull out at a junction.

3.1.3 *Spatial frequencies*

Spatial frequency is a measure of how rapidly a property changes in space. A commonly used form of visual stimulus consists of vertical bars where the lightness varies according to a sinusoidal function. In this simple case the spatial frequency of the stimulus is just the frequency of the sinusoid used to generate the pattern. In general, stimuli with fine detail, including sharp edges, have high spatial frequency while those where the stimulus properties change more slowly in space have low spatial frequency.

The spatial frequency of cars and motorcycles, or the size of the image they present on the retina at the same distance, is very different. Cars are relatively large and tend to present a relatively wide block of moving colour (a relatively low spatial frequency). Motorcycles, however, present a very narrow and detailed image which can be harder to spot against a cluttered background with a high frequency texture (such as road markings, traffic signposts and trees; an example of a relatively high spatial frequency). Over the past decade evidence has accumulated to support a global-precedence theory of how the visual system parses scenes (Hughes *et al.*, 1996; Loftus and Harley, 2004; Schyns and Oliva, 1994), whereby low spatial frequency information (in this case cars) tends to be processed before high spatial frequency information (motorcycles). On the vast majority of occasions a quick glance down the road may succeed in spotting a car as this low frequency object is likely to ‘pop out’ of the visual scene (e.g. Sagi, 1988). High frequency motorcycles, however, may be missed because they may require a visual strategy more akin to a serial search, that is, they will not be spotted without a careful and effortful search of the visual scene.

Oliva and Torralba (2006) suggested that global processing is not an alternative to a more fine-grain local image analysis but, instead, provides a quick overview of the scene which feeds forward into a more detailed visual search, constraining and directing local feature analysis in visually cluttered scenes. In many instances, however, drivers will not benefit from the feed-forward properties of such ‘global contextual priming’ (Torralba, 2003) as they may well make a decision just on the global information gathered during the first fixation, without engaging in a subsequent fine-grained search. The pressure on drivers to make quick decisions may arise from many sources. For instance, spending too long looking in mirrors before overtaking on the motorway might reduce one’s chances of spotting the car ahead suddenly braking. Other less safety conscious reasons may include a desire to shorten a journey time by minimising unnecessary stops at give-way junctions (requiring a quick decision to be made on the immediate approach). Though this seems to provide an impossibly brief time window to process a complete scene (with each fixation lasting approximately one-quarter of a second), there is evidence that participants in laboratory experiments can report the content of a picture with presentations of 200 to 300 ms. For instance, participants may report seeing a harbour scene even though the picture was presented for a fraction of a second. This quick, high-level representation of visual scenes has been termed **gist** (cf. Oliva and Torralba, 2006). Drivers may perform a similar high-level categorisation of roads within a similar timeframe, possibly within a single fixation. The outcome of this quick categorisation may be as simple as **safe** or **unsafe**. However, global precedence theory suggests that this rapid categorisation is most likely to be made up from low frequency information. Thus a **safe** categorisation may be incorrectly made if an approaching motorcycle slips through the spatial frequency filter.

3.1.4 Saccade landing positions

When the eyes move, their landing position is determined primarily by a pre-saccadic planning process. This plan may be programmed in response to bottom-up saliency, or due to top-down factors (as we shall see in later sections), though it is most likely to be a mixture of the two. Different objects in the visual scene will compete to attract attention, and if there is a highly salient bus shelter advertisement next to a motion-camouflaged, low spatial frequency motorcycle, then the bus shelter advertisement may be looked at first (see Crundall *et al.* (2006) for an experimental procedure that demonstrates the ability of bus shelter advertising to distract attention away from the road). We would not however expect a driver to make a decision to pull out from a side road on the basis of looking at an advertisement. In all likelihood, if the driver did fixate the advertisement first, he or she would then reorient their attention to check for traffic.

There is, however, a more subtle effect of competing saliencies that drivers may be less aware of yet could still lead to a failure to see an oncoming motorcycle. Saccades are not always accurate and a considerable number of eye movements may either undershoot or overshoot their target. Findlay (1992) reported a ‘centre of gravity effect’ whereby bottom-up factors can influence the landing position. While a strict theory of bottom-up saliency would suggest that, of two objects in the visual scene, the eyes will be drawn to the most salient, the centre of gravity effect demonstrates that, under certain conditions (such as the relative close proximity of the two stimuli), the saccade will land in-between the two objects, albeit closer to the most salient. This is easily conceptualised with regard to the size of the two objects. As the larger of the two objects is likely to be more salient, the eyes will land closer to the larger object, as if gravitational forces exerted by the two objects compete, with the larger object winning. This gravity effect will disappear if the two objects are too far apart from each other, and the eyes will be more likely to land directly upon the larger object.

With regard to driving behaviour, the centre of gravity effect has important implications for whether an approaching motorcycle is likely to be looked at. If there is another, more salient stimulus on the road, then the eye will be dragged away from the motorcycle. If a motorcycle and a car are within close proximity, then a saccade made by a driver waiting to pull out at a T-junction is likely to land closer to the car. If a second saccade is made (often termed a corrective saccade to make up for the lack of accuracy of the first saccade), then the eyes are likely to move directly to the car, potentially completely missing the motorcycle. If the car and motorcycle are at the same distance from the driver at the junction, and they continue to travel side-by-side at the same speed towards the junction, then it would not matter that the driver makes a decision to pull out on the basis of the car. However, the motorcycle could already be closer to the driver than the other car, and could be travelling at a higher speed. If the brief visual search of the scene convinces the driver that the approaching car is the main hazard, simply because they did not see the motorcycle, then the driver risks a collision.

3.1.5 Obscuration

The bottom-up factors discussed so far are concerned with the ability of motorcycles to attract attention, especially relative to other objects and vehicles in the visual scene. One basic factor that precludes any possibility of bottom-up salience attracting attention is obscuration. If, for instance, an oncoming motorcycle overtakes an approaching lorry just before a junction, then a driver at a T-junction may not have any opportunity to see the motorcycle. If the driver pulls out based on a safety judgement about the distance and speed of the lorry, they may risk a collision with the overtaking motorcycle. Both drivers and motorcyclists can be made aware of this form of obscuration, with the hope that drivers subsequently resist making hasty decisions in the face of high-sided vehicles that could be obscuring other traffic, and that motorcyclists will refrain from overtaking manoeuvres on the approach to junctions or side roads.

Parts of the road can also be obscured by the windscreen pillar (or ‘A’ pillar). In an early report, the Road Research Laboratory (1963) reported that a typical region of obscuration of around 4 degrees would be enough to obscure the rear profile of a car at 60 feet (approximately 18.3 metres away). They further demonstrated how a zone of obscuration could theoretically track a small-moving object such as a pedestrian, cyclist or motorcyclist; for example, on the approach to a roundabout. They recommended that ‘A’ pillars should be designed to be as thin as possible, and preferably less than 2 inches (approximately 5.1 cm) wide, including the window frame.

Vehicle design has changed considerably since 1963, and vehicle ‘A’ pillars have become thicker in an attempt to increase vehicle occupant safety. The Department for Transport (2005) have highlighted the possible risks posed by thicker ‘A’ pillars in newer cars, and have commissioned ongoing research into the problem, with a view to considering whether amendments to current international regulations are necessary. Motorcycle rider groups, such as the UK Motorcycle Action Group (MAG UK, 2006a), and the motorcycling press (e.g. *Bike*; see Beach, 2004) have a history of highlighting this issue – MAG UK (2006a) believe that an EU directive on pillar design contains loopholes that manufacturers are actively exploiting. In particular they referred to the practice of strengthening pillars with an additional small non-opening quarter-light and extra support strut, which would theoretically be likely to restrict vision to a much greater degree than that highlighted by the Road Research Laboratory over 40 years ago. Both *Bike* (2004) and MAG UK (2006a) quote former Rover/British Leyland chief engineer Spen King, who believes that current EU regulations, which allow 6 degrees of view obscuration from a car’s ‘A’ pillar, are enough to allow a car in side profile to be potentially out of view at a distance of 50 metres.

Attempts to solve the ‘A’ pillar obscuration problem have included designs of a semi-transparent metal latticework and Plexiglas pillar by Volvo, which has appeared in the company’s ‘Safety Concept Car’ (SCC), a prototype first unveiled in 2001 (Volvo Group, 2006). Alternatively, a driver-based approach could raise awareness of the problem, and suggest simple strategies to overcome A-frame obscuration (perhaps ‘**look, wait, decide**’, encouraging longer gaze durations so that any obscured vehicle will emerge before the decision to pull out has been made). One problem with this approach is that drivers may theoretically understand the potential for windscreen pillars to obscure the road, yet may fail to heed the advice when it is needed. This is because the situation does not necessarily provide clues to the problem. The windscreen pillar may act in a similar fashion to the retinal blind spot. The retinal blind spot (not to be confused with the over-the-shoulder check) is an area of the retina where the optic nerve joins the eye. At this point there are no receptors and the eye can process no information. Everyone has two such areas in their visual field where there is no visual information, yet the visual system extrapolates from the surrounding visual scene and 'fills in' the gaps such that these areas are not noticeable (though if a visual stimulus appears in the blind spot it will not be seen). Similarly, drivers may be so used to the obscuration posed by windscreen pillars that they are no longer noticed. Instead the perceptual system may fill in this 'external blind spot' and make it difficult for drivers to remember the potential problems of obscuration and to take preventative action to avoid it. Any trained strategy would have to be designed to overcome the driver's propensity to ignore the potential problems that can be caused by pillar obscuration.

Recent work on windscreen pillar obscuration has been conducted by Vargas and Garcia-Perez (2005). They are currently developing a tool involving a mini-camera mounted on a pair of spectacles which can record images from the visual scene with the driver looking in various directions. Using this method they recorded significant obscuration for all drivers in a variety of vehicles, sometimes extending into central vision. Vargas and Garcia-Perez are hopeful that future versions of their device will inform the in-car obscuration debate.

3.1.6 Change blindness

Several features in the visual world that have strong bottom-up properties draw attention to themselves through a localised transient. The sudden movement of a pedestrian stepping into the road, or the abrupt onset of a red traffic light, cause localised and short-lived changes in the visual scene. These local transients are one of the mechanisms by which attention is grabbed. 'Change blindness' describes a phenomenon (e.g. Simons, 2000) where individuals fail to notice such changes in a visual scene. Sometimes these changes can be quite extreme, such as the disappearance of a whole building in the background of a photograph. In order to induce change blindness, the experimenter introduces an unrelated transient in-between the presentation of successive pictures, usually on a computer screen. Any local transient that occurs due to the onset of a change may be swamped by the larger artificial transient, and therefore missed. Artificial transients include 'mud splashes' and global flickers. Mud splashes are blocks of colour which are briefly flashed on the screen in-between picture presentations. Their name comes from their similarity to mud splashes that might occur on car windscreens (though the phrase was coined independently of any research into the application of change blindness to driving research). A global flicker refers to the insertion of a blank screen in-between successively presented pictures. This produces exactly the same results, with participants missing changes made to pictures following the flicker.

It is also possible to note change blindness effects with more realistic interruptions to an individual's visual representation of a scene. For instance, if a change is made to a picture during an eye blink or a saccade, participants are less likely to notice the change than if it occurred during a fixation, especially if the fixation was not on the changed objects (Rensink *et al.*, 1997). It is even theoretically possible that the movement of wipers across a windscreen could induce change blindness.

With regard to driving, however, there are typical areas in the visual scene that drivers tend to look at repeatedly (e.g. Crundall and Underwood, 1998; Crundall *et al.*, 2006). These areas tend to be those that provide information that is highly relevant to the driving task (e.g. the car ahead, the traffic lights, etc.), and excessive sampling of these areas reduces any effects of change blindness. In one study we conducted (Crundall *et al.*, 2001), participants had to spot a change (such as the disappearance of road markings) between two otherwise identical road scenes. Each image was available for a second before the alternate image was presented. In order to hide the transient created by the abrupt offset and onset of the road markings as the cycle repeated, a short-duration blue screen (a global flicker) was inserted after every image. This made it very difficult for participants to identify the change, though they often found changes to driving-relevant stimuli more quickly. Although this finding is heartening, **any** delay in missing a change to a driving relevant object, such as an oncoming motorcycle, could increase the risk of a collision.

3.2 Top-down influences upon whether drivers look at the motorcycle

Bottom-up influences are rarely the sole determinant of visual search (Underwood *et al.*, 2006), and may override, modify or exaggerate the effects of simple saliency. For instance, Bundesen's (1990) Theory of Visual Attention (TVA) takes bottom-up information from a saliency map (see Logan, 1996) and then calculates where to look next by combining this information with measures of perceptual bias and attentional weight. Perceptual bias refers to a predisposition to classify a certain object into a certain category (just as the dehydrated man crawling through the desert is likely to perceive every rock as a potential oasis), while attentional weight refers to those areas of the visual scene that we prefer to sample according to task demands, etc. (e.g. on a foggy day, a driver may concentrate especially hard on the immediate road ahead for vehicles in front that might not have their lights on). Simply put, these two factors combine top-down influences on where an individual looks, and whether that individual processes what they look at correctly. These equate with the first of the two behaviours detailed in our framework (see Figure 2.1). We have added the third behaviour of appraisal which goes beyond Bundesen's model, and considers whether the correct decision is made subsequent to identification of the motorcycle. Sections 3.2.1–3.2.5 will consider what top-down factors influence the first of these behaviours, whether a driver looks at an oncoming motorcycle, before considering influences on perceiving and appraising in the two following sections (Sections 3.3 and 3.4).

3.2.1 Experience affects where drivers look

Experience, either in terms of years since passing the driving test or in annual mileage, is generally used as a surrogate variable for skill. While some driver groups have quantifiable skill levels (e.g. driving instructors, police drivers), the majority of drivers do not. Most researchers assume that increased experience leads to improved skill, and this has been backed up by many studies that have shown experienced drivers to be faster and more accurate at a variety of driving-related tasks. While the assumption that experienced drivers are better drivers may not be true in all instances, it has been widely reported in order to distinguish between drivers’ patterns of eye movements. For this reason it forms the basis of this section.

The very first fixation in a visual scene can be influenced by experience and exposure to similar scenes. We know that drivers’ eye movement strategies change as they progress from learner drivers to novice drivers who have just passed the driving test, through to more experienced drivers (e.g Mourant and Rockwell, 1972; Falkmer and Gregersen, 2005). Crundall and Underwood (1998) conducted an on-road study of drivers’ eye movements and noted that inexperienced drivers failed to search as widely as their more experienced counterparts on a dual-carriageway containing slip roads from both the left and the right. A follow-up study demonstrated that this could not simply be explained in terms of increased levels of anxiety or due to poor motor skills demanding extra attention (Underwood *et al.*, 2002b). Instead it appears that, at least in part, the poor visual scanning was due to an inappropriate mental model, or schema, for that particular driving situation. The inexperienced drivers did not realise that a wider visual search was necessary for safe navigation. They did perform comparably with the more experienced drivers on rural and suburban roads however.

When the data for the on-road study were first collected, learner drivers were not required to drive on a dual-carriageway as part of their test, and many of the novice drivers in the 1998 study (who were within six months of passing their test) had limited experience of driving on such roads compared with rural and, in particular, suburban roads. These results demonstrated the effects of driving experience on the development of visual search strategies, with the most experienced drivers favouring a wide search strategy that was focused predominantly along the midpoint of the visual scene. Relatively few fixations were found below or above this horizontal inspection window. It was suggested that the experienced drivers had developed their general driving schema through repeated exposure to driving situations and this, in turn, provided guidelines for a general visual search strategy.

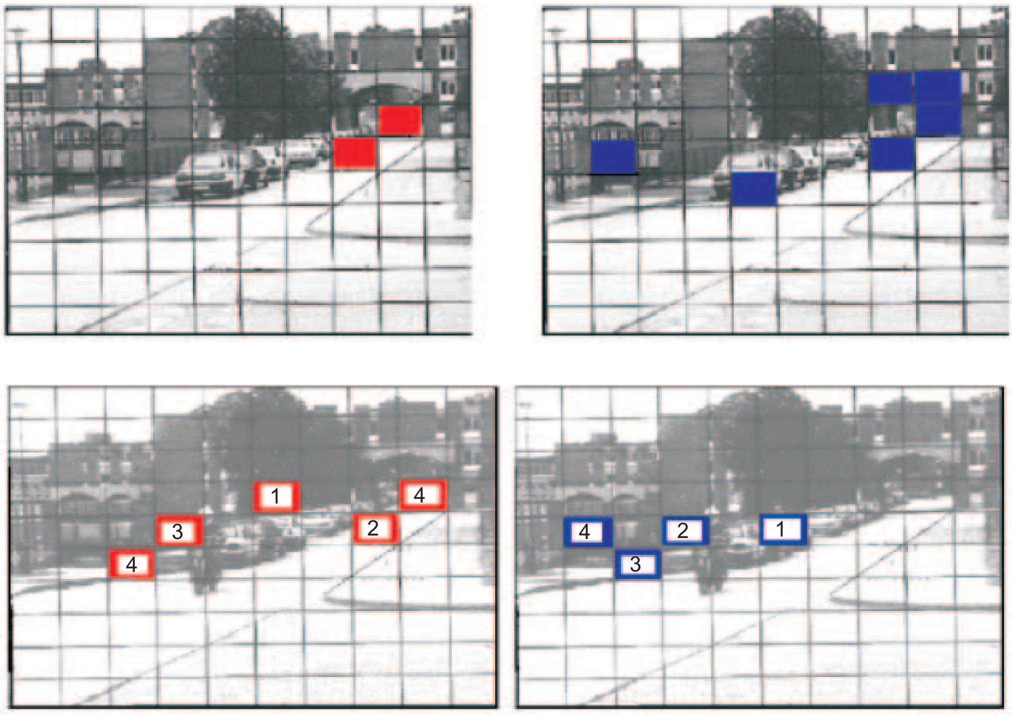
Evidence for repetitive scanning patterns in more specific driving situations, reflecting the development of specialised sub-schemata, has also been noted in experienced drivers. Salvucci and Liu (2002) found that drivers' eye movements move to the adjacent lane before they announce any intention to overtake the vehicle ahead. Liu (1998) has also used Markov matrices to identify significant scan paths of fixation transitions from one area of the scene to another in a driving simulator. Two particular patterns revealed themselves on straight roads: a preview pattern (where drivers would tend to look straight ahead, varying the distance of fixation from the car) and a horizontal scanning pattern (where drivers tend to look from side to side). On curved roads, the preview pattern disappeared, though the horizontal pattern remained.

In all such experiments that record eye movements, it is usually found that the focus of expansion (FoE; essentially the furthest point that one can see down the road) accrues the majority of fixations (e.g. Underwood *et al.,* 2003b). This location provides the earliest warning of potential hazards ahead. When given one opportunity to glance at a road, fixations will tend toward the FoE. This may be due, in part, to bottom-up influences, such as the orientation of lane markings guiding attention to the vanishing point (recent research has demonstrated that attention tends to spread or move along straight lines inadvertently, see Crundall *et al*. (2007)), though it is also highly probable that relatively little experience of driving quickly teaches one that the FoE is a valuable location to monitor. This can present a problem for spotting motorcycles at junctions if the motorcycle is relatively close to the car waiting to pull out, if the driver makes only one fixation at the FoE much further down the road. As mentioned earlier, the further an object is into the extra-foveal regions of vision, the harder it will be to spot due to the decreasing acuity of the retina away from the fovea.

One recently reported experiment has demonstrated exactly this with regard to the visual search for motorcycles. Labbett and Langham (2006) showed participants eight video clips, each lasting two seconds, while monitoring their eye movements. Six of the clips involved T-junctions, with either approaching traffic, traffic moving in the opposite direction or no traffic. Although this gives a very limited number of stimuli to extrapolate any results from, the experiment is crucial in demonstrating the potential for where drivers look in a scene and for this to be related to the possibility of missing a motorcycle. In Figure 3.1 (taken from Labbett and Langham), the top two panels show a road scene with shaded segments representing where an experienced driver (left) and a novice driver (right) look. It can easily be noted that the experienced driver prioritises the FoE more than the novice. The bottom two panels represent the fixations of the experienced and novice driver when confronted by a motorcyclist. It appears that the novice driver locates the motorcycle first.

We cannot conclude too much from this initial pilot study due to low numbers of stimuli, however the experiment provides an excellent basis for developing a series of highly controlled yet ecologically valid studies that can systematically vary a wide variety of factors, and assess their impact on where drivers look.

Figure 3.1: **Fixations upon an empty road (top) and a road containing an approaching motorcycle. The left panels are produced by an experienced driver and the right panels are from a novice driver (Labbett and Langham, 2006)**



Although Labbett and Langham's initial study suggests an advantage for novice drivers, this may occur because they are viewing the scenes without reference to driving a car. The experienced drivers, however, may use strategies that have been developed from real driving, which are automatically transferred to this non-driving situation.

If novices were placed in a similar situation in the real world, their eye movements may be more greatly influenced by the increased demands created by driving the car. For instance, Land and Horwood (1995) demonstrated that experienced drivers take in information from lane markers through peripheral vision. Many analyses of drivers' eye movements note, however, that novices tend to fixate lane markers quite often (e.g. Mourant and Rockwell, 1972; Underwood *et al*., 2003b), suggesting that they are not as efficient at using peripheral vision as the experienced drivers and have to fixate the lane markers instead. This can pose a problem for car–motorcycle interactions if fixations necessary for basic car handling (such as checking road markers to maintain lane position) have greater priority than checking for other vehicles. This could easily occur in car–motorcycle interactions where a novice driver is changing lanes, and devotes so much attention to the lane markers, that they limit their visual checks for other vehicles, such as filtering motorcycles.

One particularly innovative study of top-down influences upon attentional capture was conducted by Shinoda *et al.* (2001). Participants were asked to drive through a series of city blocks in a driving simulator. During the drive a number of road signs would change from a parking sign to a stop sign. In order to mask the transient nature of the road signs changing in the middle of a drive, they inserted a blank screen just before the change. This screen acted like a global flicker in change blindness studies, and prevented the local transient created by the changing sign from attracting attention. Other flickers were inserted randomly into the drive, so that the participants did not associate the flicker with a changed sign. Participants were instructed to either follow a lead vehicle while obeying all instructional road signs (i.e. stopping when then saw a stop sign), or they were simply told to follow the lead vehicle without any reference to the traffic signs. The additional instructions affected the probability that the drivers would fixate the changed road signs, with drivers who received the instructions to obey the road signs increasing the amount of time they spent looking to the side of the road (where the signs were located) from 1% of the time to 6%. Thus, drivers' information needs promoted a specific search strategy that increased the likelihood of the traffic signs catching their attention. The more interesting manipulation was, however, the location of the road sign which could either occur at an intersection (highly predictable on the basis of the context), or while driving along a straight road without a junction (unpredictable on the basis of location). Drivers who were instructed to heed traffic signs spotted the changed sign 100% of the time if it was located at a junction, but only 33% if the change occurred during a straight road. Shinoda *et al.* suggest that these effects occur because drivers employ specific search strategies on the basis of 'learned regularities in the environment'. In other words, experienced drivers develop a variety of schemata with guidelines for specific search strategies through repeated exposure to similar situations. They can then select a particular schema to guide their search strategy according to the current situation.

Fisher *et al*. (2003) found similar benefits of driving experience in fixating specific sources of potential hazards in a number of simulated scenarios. For instance, one particular scenario involved the participant driving through a junction that had a crossing marked on the road (and also indicated by a traffic sign). As they approached the crossing, a large hedge obscured the pavement near to the crossing, potentially hiding a pedestrian who could have stepped into the road at any point. Fisher *et al*. found that, as experience increased across the drivers, so the likelihood of the participants fixating these potential sources of hazards increased. They reported their findings in terms of schemata built up from exposure to previous hazardous events. These may be the most difficult schemas to develop because hazardous events are relatively rare. Even though one study of near accidents (Chapman and Underwood, 2000) found drivers to report up to 26 near accidents over a two-week period (using a Dictaphone diary method after every journey), they still make up a fraction of overall driving. Considering that motorcycle traffic, in terms of total vehicle kilometres travelled, formed only 1.3% of total car and motorcycle traffic in 2006 (Department for Transport, 2007a), a driver will only encounter bikes on an infrequent basis. If we assume that only a fraction of these car–motorcycle interactions will result in a hazardous situation, then this further reduces the opportunity for drivers to develop relevant schemata.

One final problem that may hinder the development of car–motorcycle schemata is whether drivers even remember the near accidents that form the building blocks of new schemata. Chapman and Underwood (2000) found that, on average, drivers forgot 20% of actual accidents, many of which resulted in injury to one of the people involved. A diary study by Joshi *et al.* (2001) of the risk perceptions of road users revealed that when incident reporting was compared with accident figures, car drivers were found to have paid more attention to near misses with less vulnerable road users (i.e. those who could harm them) than they did to more vulnerable road users (i.e. those whom they could harm). This suggests that even when near accidents occur with motorcycles, they are the least likely hazardous events to have an impact on the driver.

3.2.2 Peripheral vision affects where drivers look

Though the field of view encompasses almost 180 degrees, the functional field of view (FFoV) is considerably less. The FFoV refers to the area of the visual field within which a bottom-up feature might grab attention. The FFoV is much smaller than the actual visual field and is in a constant state of flux due to the changing allocation of attentional resources. The most straightforward conception of the FFoV is similar to Eriksen and Murphy's (1987) zoom lens model of attention (though there is some debate over the true nature of the spatial decrement in attention, the zoom lens metaphor will suffice for the current examples; but see Crundall *et al.*, 1999, 2002, and Williams, 1982, 1985, for more detailed arguments).

The zoom lens metaphor suggests that attention moves around the visual scene as a spotlight or a beam of variable width. This spotlight (which is normally coincident with the focus of the eyes) can contract or expand according to the attentional demands of the task. When the task at the point of fixation is especially difficult or demanding (such as reading a complex traffic sign), the spotlight contracts, increasing the concentration of attention at that point. With less demanding tasks the spotlight can widen and spread resources over a larger area. This latter strategy is very good for non-complex vigilance tasks. The contraction or expansion of the spotlight modifies the ability of bottom-up features to capture attention. If a sudden bright flash occurs within the FFoV, then attention may be captured. If, however, the flash occurs outside the FFoV, then it should be completely missed. This has been noted with driving stimuli. Crundall *et al*. (1999, 2002) presented participants with a hazard perception test requiring a foot pedal response. Participants were also required to a make a hand-button response if they saw a brief flash of light during the hazard perception test that could appear in one of four placeholders around the screen. The results revealed that, when a hazard appeared (such as a pedestrian stepping out from between parked cars), participants fixated the hazard for longer than other objects (indicating increased processing) and peripheral target accuracy declined considerably suggesting that the zoom lens had contracted around the point of fixation. In this instance, however, one might be tempted to argue that this can only be a good thing: if the driver spots the hazard they devote all available resources to it, ensuring that it is fully processed as soon as possible. However, there are two factors that prevent us from drawing such a positive conclusion from this 'perceptual narrowing' effect. First, the amount of peripheral degradation that drivers suffer when tightly focusing on a hazard is dependent upon experience. More experienced drivers can process the hazard faster and reallocate attention back to the peripheral field much sooner than inexperienced drivers (Crundall *et al*., 2002). Secondly, the stimulus that causes perceptual narrowing does not need to be a hazard, it merely needs to be demanding. Unfortunately for inexperienced drivers, most events in driving are relatively novel and demand greater attention and longer fixations (e.g. Chapman and Underwood, 1998). Asking a novice driver to simply follow a lead vehicle within a simulated cityscape can lead to increased fixations on the car ahead, and potentially degraded peripheral attention (Crundall *et al.*, 2004). In that particular study the excessive focusing on the lead vehicle reduced drivers' awareness of pedestrians and also increased their number of give-way violations, which is especially pertinent to car–motorcycle collisions.

Thus there is the potential that an inexperienced driver may fail to see a potential hazard, such as an oncoming motorcycle, because a different object (such as a novel road sign or road layout) attracts so much attention that the motorcycle falls outside of the function field of view.

3.2.3 Attitudinal influences on where drivers look

Attitudes are considered to be a predisposition to behave positively or negatively towards an individual, group, event or even an object (Forward, 2006). In relation to driving, attitudes could relate to other road users (e.g. 'motorcyclists deserve what they get') or to one's own behaviour (e.g. 'speeding is okay if you're a good enough driver'). But can attitudes explain why drivers might not look at a motorcycle?

We do not suggest that some drivers might have a specific attitude against making appropriate visual checks while driving, though certain attitudes could have an indirect effect.

Much research has been conducted into the intention to commit violations (Forward, 2006), and specifically into the intention to speed (e.g. Wallén Warner and Åberg, 2006; Lawton *et al.*, 1997). Speed has a U-shaped relationship with accidents, with either extremes being linked with increased accident liability (e.g. Finch *et al.*, 1994). Lawton *et al.* (1997) noted that intention to speed varied across different road types and that this was related to the perceived negative consequences. For instance, the perceived negative consequences of speeding in a busy shopping street mirrored the low intention to speed on such a road. They found, however, that younger respondents and those respondents with less regard for the negative consequences reported greater intentions to speed. Higher speeds can, in turn, have an effect upon visual search. Rogers *et al*. (2005) noted that increased speed greatly constrained eye movements. The most obvious influence of speed upon eye movements is that either the sampling rate must increase or the number of fixations must decrease for any given portion of road. Either of these compensatory mechanisms may cause problems, either by reducing the amount of processing time that each fixation is allowed (which is especially problematic for inexperienced drivers who usually need relatively long fixations to process driving stimuli) or by cutting out certain fixations altogether. For instance, a speeding driver approaching a T-junction may not want to stop if at all possible. By approaching the junction at a faster than average speed however, they reduce the amount of time that they have to make the required visual checks before making this decision. They could then carry on through the give-way line without adequately sampling the main carriageway for traffic, risking a collision.

Attitudes towards general violations (tailgating, undertaking, etc.) have also been related to accident rates (e.g. Parker *et al.*, 1995a, Özkan *et al.*, 2006). The direct link with failures to complete all necessary visual checks however is limited. One possible influence of violation propensity upon visual search might manifest in such drivers being less likely to consciously practice explicit routines (such as ‘look right, look left, look right again’). As the impact of these taught strategies (requiring conscious effort on the driver’s part) is unknown, it is impossible to estimate how important a disregard for such strategies might be.

Typically, males who drive frequently produce the highest violation scores (e.g. Özkan *et al*., 2006). This demonstrates one area in which greater experience is not necessarily reflected in better behaviour. Whereas novice drivers may have increased accident liability due to a lack of skills, the more experienced drivers are actually more likely to break the rules. This does not mean that young inexperienced drivers will not perform stupid behaviours on the road, just that these behaviours are more likely to arise from misperceived levels of control and perceived norms (especially when other young people are in the car).

3.2.4 Errors and lapses

Together with violations, errors and lapses make up the three traditional factors of the Driver Behaviour Questionnaire (DBQ). Based on Reason’s (1990) taxonomy of aberrant driving behaviour, the DBQ structure has been replicated (with varying degrees of modification) in many countries (see Özkan *et al*. (2006) for a concise review). While lapses refer to relatively low risk slips of attention (e.g. switching on the windscreen wipers instead of the indicators), errors represent more serious events that could lead to an accident (e.g. failing to notice that pedestrians are crossing when turning into a side street from a main road). Errors are more obviously linked to those dangerous car–motorcycle interactions than violations (e.g. forgetting to check a mirror before making a u-turn, or failing to make an adequate visual check for approaching vehicles before pulling out at a junction), and tend to be reported more by women (Özkan *et al.*, 2006). However, errors tend to produce a less clear relationship with accidents than violations (e.g. Parker *et al.*, 1995b). This does not necessarily mean that errors (failures to look) cannot explain specific accident types, as these studies typically collapse across many error types. It may be the case that certain drivers, who do not make many typical errors, may still have a problem with a particular visual error (such as mirror checks). Such a link between errors and car–motorcycle accidents may well be hidden in the amalgamation of events that often occurs in such studies.

3.2.5 Environmental knowledge

An in-depth study of bicycle–car accidents conducted in Finland (Rasanen and Summala, 1998) found that only 11% of drivers involved in an accident where the car pulled out of a junction saw the cyclist. The remainder reported looking down the road before pulling out but, as they did not expect a cycle lane to run parallel to the road, they did not check for bicycles. While this does not directly map on to motorcycle accidents, it does point out that different environments require different eye movement strategies. If a driver has never been through a particular junction before, he or she may apply an inappropriate visual search schema.

This can also occur when the layout of familiar junctions is changed. While studies have demonstrated that changing road layout can positively influence driver behaviour (e.g. De Waard *et al.*, 1995; Horberry *et al.*, 2005), the period following a change in layout may be dangerous for drivers who are so familiar with the previous road layout that they may drive through it without realising that traffic priorities may have changed. To the authors' knowledge there have been no studies that have directly assessed the level of prior junction familiarity with behaviour at a junction following a change to traffic priorities.

3.3 Top-down influences upon whether drivers perceive the motorcycle

The previous sections were concerned with whether a driver looked at a motorcycle, either through the attraction of bottom-up factors or the development of schemata that guide the eyes in a certain direction. If we assume, as many drivers involved in car–motorcycle accidents claim, that most drivers at least look in the general direction of an oncoming motorcycle, then we must ask why they fail to perceive them. This would represent a 'Looked but Failed to See' (LBFTS) error in its truest form.

Does the fact that the driver has looked at the motorcycle mean that the brain automatically processes it? The hypothesis that whatever the eyes are fixating is automatically processed is known as the *eye-mind assumption*. Researchers such as Underwood (1992) and Reichle *et al*. (2003) have described how, in many situations, the eye–mind assumption does not necessarily hold true. Internal thoughts may take precedence over external stimuli without individuals having to close their eyes to shut out all distraction. Alternatively, information from the parafovea, beyond the point of fixation, may be processed instead. Thus the fixation position of the eyes is neither necessary nor sufficient to explain the exact content of the mind, and can only be used as a guide to current processing.

3.3.1 Expectations of what is task-relevant

Even if the driver makes an effort to process whatever the eye lands upon, this does not guarantee that the correct information will be processed. A commonsense argument was once made that if you process an object, then you process all the features of that object (colour, size, orientation, etc.) regardless of whether they are crucial to the task (O'Craven *et al.*, 1999). There is, however, increasing evidence to suggest that some task-irrelevant features may not be processed in all cases. Scholl *et al*. (1999) asked participants to track multiple dynamic objects moving among distracters. Masked changes occasionally occurred to either a distracter or one of the targets. When the change affected a target's colour or shape there was no improvement for change detection in targets compared with distracters. However, when the change affected a target's location or heading (both features that were more directly related to the tracking task than shape or colour), change detection was found to be superior in targets.

This suggests that filters may be set in terms of processing. We have already noted that drivers may not be attracted to motorcycles because of their high spatial frequency. In conjunction with this evidence, it is possible that even if a driver was lucky enough to fixate the motorcycle in the first fixation, he or she may still not process it as his/her schema may suggest that only low spatial frequencies need be processed to determine whether the way is clear.

A recent study clearly demonstrated how expectancies, even for specific colours, can influence the likelihood of a collision. Most and Astur (2007) asked participants to drive through a simulated series of junctions, following arrows (presented as signposts) that showed which way to turn at every junction. These arrows were either blue or yellow. At a critical junction a motorcycle would turn in front of the participant's vehicle. The motorcycle was also coloured either blue or yellow. They found that drivers were significantly more likely to crash into the motorcycle if its colour was different to that of the arrow they were searching for.

3.3.2 *Priming the processing of information*

Expectations not only influence whether one looks in a specific location (see Section 3.2.1) and influence what features are processed (Section 3.3.1), but they can also reduce the actual processing time. Experimental studies of repetitive priming and semantic priming have demonstrated faster response times to targets if they are preceded by a brief irrelevant stimulus that is either identical to the target (repetitive) or semantically related to it (such as **butter** preceding **bread**; Meyer and Schvaneveldt, 1971). This unconscious effect demonstrates that if participants are mentally prepared for a potential stimulus they will process it much faster. Semantic priming has been reported with regard to the relationship between red triangle warning signs and subsequent roadways (e.g. a right-hand bend warning sign decreases response times to classify a subsequent picture of a right-hand bend in the road ahead; Crundall and Underwood, 2001), and could even play a role in the perception of motorcycles. The 'Think Bike' signs may not only encourage drivers to look for motorcycles, but may also speed up their processing.

Although these laboratory priming effects are highly context specific and restricted to certain time windows of presentation, the underlying cause, that mental preparation can reduce processing time, is extremely relevant to car–motorcycle interactions. Those drivers who have had greater exposure to motorcycles, and will have a more developed schema, are likely to be more prepared to see a motorcycle at a junction or in a wing mirror. Not only will this encourage them to look for an approaching motorcycle, it may also allow them to perceive the motorcycle more quickly.

Though, to the knowledge of the authors, no studies have been undertaken to directly assess the processing time and fixation durations required to perceive a motorcycle, a similar study has been conducted on the perception of pedestrians. Shinar (1985) reported that drivers were better able to recognise a pedestrian when they were primed with the knowledge of when the pedestrian would appear. Thus expectations (albeit very short term in this study) influence the processing time of the stimulus.

3.3.3 *The competition between fixation and movement of the eyes*

One of the most basic explanations for LBFTS errors could simply be that the fixation made by the driver was too short. Processing any localised item in the visual field takes time and effort (Labbett and Langham (2006) observed that drivers at real junctions on a university campus spent 0.5 seconds on average checking that the way is clear). Some items may require very little effort, though some unexpected, novel or complex objects may take considerably more effort. This is reflected in the length of time that the eyes need to focus on an object, with increased fixation durations usually representing increased processing requirements. We know, for instance, that novice and learner drivers tend to have longer fixation durations on driving stimuli (e.g. Crundall and Underwood, 1998; Crundall *et al*., 1999, 2002) and that the need to fixate for longer is magnified even more when they encounter hazardous situations that they have previously had little exposure to (e.g. Chapman and Underwood, 1998).

If drivers had no other demands upon their attentional resources, then the length of any individual fixation would be of little relevance as they could take all the time they need to extract the information, before moving the eyes. However, driving is a dynamic task which requires multiple sources of information to be monitored. The introduction to Section 3 briefly mentioned the model of saccade generation suggested by Findlay and Walker (1999) and how it argues for a competitive relationship between the need to fixate and the desire to move the eyes. This section further explores the implications of this model with regard to whether drivers may adequately process a fixated stimulus, such as an approaching motorcycle.

Findlay and Walker's model is built around two distinct pathways that control eye movements: the WHEN and WHERE pathway. Activation in the WHEN pathway increases activation in the fixate centre, encouraging the eyes to remain in one place and continue processing the currently fixated stimulus. Activation in the WHERE pathway relates to a salience map and, in turn, increases activation in the move centre, encouraging the eyes to move to a new area of the visual scene. There is a competitive push-pull relationship between these two centres. Typically, as one continues to fixate a stimulus and process it, the level of new information still contained in that stimulus decreases. This is reflected by a decline in activity in the fixate centre, and a corresponding increase in activity in the move centre. Once a specific threshold of decreasing activation has been reached, the greater activity in the move centre wins the battle and a saccade is made. This theory is supported by neurophysiologic evidence that suggests a competitive relationship between cells in the rostral pole of the superior colliculus (representing the fovea) and other cells in the colliculus that code saccade metrics (Munoz and Wurtz, 1993).

Though there are many more subtleties to Findlay and Walker's model than we can do justice to here, this basic push-pull relationship is crucial to understanding whether a driver has had sufficient time to perceive an approaching motorcycle.

In Section 3.1 we considered bottom-up factors that could increase activation in the move centre and thus try to drag the eyes away from their current focus before processing has finished. There are also several top-down reasons why increased activation in the move centre might occur. Not least of these is heading. Underwood *et al*. (2003b) noted a predominance of visual patterns of two and three fixations in length that always return to the road ahead. On the basis of saliency calculations (e.g. using Itti and Koch's (2000) model) the direction of heading will always be underestimated as an area of interest, though for obvious top-down reasons (e.g. collision avoidance) the road ahead is extremely important. Fixations away from the direction of heading must be limited when driving, and the further away from the road ahead that one must fixate, the worse the consequences may be (Summala *et al.*, 1996; Wittmann *et al.*, 2006). The activity generated in the move centre by the direction of heading will change according to many variables, a primary one being speed. As noted in Section 3.2.3, increased speed may cut down the number of fixations one can make (affecting where the driver **looks**), but can also cut down the length of individual fixations (affecting whether the driver **perceives**). Thus higher speeds (linked with attitudes and intentions to speed) increase the need to fixate the heading and may therefore reduce the fixation durations on other items such as mirrors or cross traffic. Tailgating may produce the same effect, with reduced headway increasing the importance of checking the vehicle ahead on a frequent basis. This suggests yet another possible causal link that could explain why drivers who report a high number of violations are more likely to be involved in an accident. Conversely, reduced speed should decrease the activity in the move centre caused by the direction of heading, and increase opportunities for longer fixations on other potential hazards. This is a distinct advantage that stop junctions have over give-way junctions, as they forcibly reduce the need to fixate heading. Drivers who travel through give-way junctions at relatively high speeds may perform the appropriate check, but the need to fixate the direction of heading may reduce the fixation to a cursory glance that is unlikely to pick up a high spatial frequency motorcycle.

3.3.4 Attention on autopilot

An automated behaviour is defined as an effortless process that is no longer under direct control and is symptomatic of expert performance (Schneider *et al.*, 1984). The resultant behaviours are stereotypical and are often unavailable to conscious awareness. In a review of automaticity in relation to driving, Groeger and Clegg (1997) argue that only lower-order components of the driving task may become automatic. For instance, the relatively constant mapping between stimulus and response with regard to changing gear from second to third suggests that this motor action could become automatic. When learning to drive, a lot of thought and practice goes into changing gears, but soon this becomes a smooth action that requires no further monitoring. Decisions that involve the processing of visual information, such as whether to go through a traffic light or turn through a gap in traffic, are, however, less likely to become automatic because of the wide variation in such situations.

Despite this, it has been found that demanding visual search tasks in the laboratory can become automatic with enough practice (Sireteanu and Rettenbach, 2000), so the possibility remains that some aspects of drivers' visual search could become automatic also. The most likely visual strategies susceptible to automation are the repetitive search patterns that rarely reveal any unexpected events that would otherwise cancel an automatic process. For instance, the **mirror, signal, manoeuvre** process is very similar to gear changing in the sense that it combines a number of task units, which initially require much thought and attention, into a single fluid unit of behaviour. It is possible that experienced drivers could make all appropriate visual checks, but that some of them have become so embedded in a well-rehearsed behavioural pattern that it may be hard for them to break the sequence. Highly salient stimuli might break the automated control (e.g. seeing a large vehicle in your blind-spot may make you rethink the overtaking manoeuvre you had planned), but the saliency threshold for interrupting an automated process will be higher than usual, and less salient motorcycles may be even less likely to capture attention than under normal controlled processing.

Support for 'over-learned' visual strategies in driving was reported by Van Elsande and Faucher-Alberton (1997). They undertook a case study of a number of accidents where drivers reported high familiarity with the road, and high driving experience in general. In the analysis of accidents where the driver crossed an intersection without giving way, one of the key factors they reported was a reliance on a rigid series of visual checks. These inflexible search strategies were employed regardless of deterioration in the context (e.g. poorer visibility, perhaps due to weather or failing light), which would normally require a modified search strategy. Unfortunately, the typical quick glances that these drivers had used on previous journeys through the junction were not sufficient and led to a collision. It should be noted, however, that this case analysis involved accident reports and interviews, rather than eye tracking or direct observation. Conclusions about search strategies were inferred indirectly.

3.4 Top-down influences upon whether drivers correctly appraise the motorcycle

The final action in the chain of behaviour that could lead to a car–motorcycle collision is the appraisal of the approaching motorcycle as a hazard or not. This assumes that, if the driver looks, perceives and correctly appraises an oncoming motorcycle as a hazard, they will then select the appropriate behaviour. One could argue that response selection should be viewed as a potential fourth behaviour in the chain of events, though for simplicity we have subsumed both appraisal and response under one heading.

3.4.1 The size-arrival effect

We have acknowledged that the smaller size of a motorcycle compared with a car may affect whether a driver looks at the motorcycle in the first instance, and can also affect whether the driver perceives the motorcycle even after fixating it. A further hypothesised influence of the size of a motorcycle is that it may affect whether one judges it to be a hazard, by influencing a driver's estimation of its speed and likely arrival time. This has been termed the 'size-arrival effect' (DeLucia, 1991).

Using a simulated driving task, Caird and Hancock (1994) found that drivers often underestimated the arrival time of vehicles approaching a junction. This judgemental bias should actually improve safety margins, with drivers less likely to pull out into short gaps in traffic. They also found that drivers' estimates of arrival times varied with the size of the vehicle, with smaller safety margins given to smaller vehicles. In fact, at relatively close distances (1–3 seconds before arrival), the average estimated arrival time for motorcycles was greater than the actual arrival time. DeLucia (1992) had also argued for this effect two years earlier, suggesting that collision avoidance for small objects can occur later than for large objects, despite both objects being at equal distance and equal speed.

Contradictory evidence is provided by Herstein and Walker (1993). They found that drivers were able to discriminate between two different approach speeds for vehicles (40 km/h and 80 km/h), but found no effect of vehicle size on estimated time to collision (TTC). They suggested that the discrepancy between their results and other data supporting a 'size-arrival effect' was that their vehicles were perceived from a long distance, whereas other studies tended to use relatively near approaching vehicles. As studies of looming have demonstrated, it is only at near distances that motion directly towards the viewer becomes apparent (Edwards, 2005; see Section 3.1.1).

More recently, Horswill *et al*. (2005) replicated the 'size-arrival effect' using video stimuli of various vehicles approaching a junction at 30 and 40 mph. They found that smaller vehicles, such as motorcycles, were perceived to arrive later than larger objects moving at the same speed. They acknowledged, however, that an alternate theory could explain their results. This competing theory uses **tau** to calculate TTC. Tau is the optical size divided by the optical rate of expansion (Lee, 1976). A calculation based on tau does not require the observer to know anything about the size of the object, or its speed, and therefore the width of a motorcycle should have no direct impact upon a TTC estimation compared with a car. However, as noted in the discussion on looming (Section 3.1.1), the expansion rate of the image created by a motorcycle on the retina is very small at large distances. Hoffman and Mortimer (1994) estimated that the minimum expansion of an image required for detection is approximately 0.17 degrees of visual angle. Horswill *et al*. (2005) calculated that the optical expansion created by the small motorcycle stimuli that they used fell beneath the threshold, whereas the expansion of the car fell above the threshold. This meant that the reduced safety margins noted with estimations of TTC with small motorcycles could have been due to the lack of information to calculate tau. They therefore undertook a second experiment, controlling the expansion rate of all stimuli to ensure that they were above the threshold for calculating tau. The pattern of results remained generally the same, with drivers believing that the motorcycles would reach them later than the larger vehicles. This suggests that the size of the vehicle plays an important role in TTC estimations (see also Davies and Swenson, 2004). DeLucia (2004) suggested a number of reasons why perceived size might influence arrival judgements:

1. The image-expansion rate may provide information independently of vehicle speed.
2. Perhaps smaller vehicles appear to be further away, resulting in a belief that they will arrive later.
3. Object size may influence response times, with smaller objects resulting in faster hand movements to press a response button.
4. Perceived negative consequences may have a delaying influence on making a response to a large vehicle (e.g. we have a higher safety margin for interacting with vehicles that are more threatening).

More research is needed to assess which of these potential explanations accounts for the 'size-arrival effect', as the underlying cause will determine what type of intervention could be undertaken. In addition, there are many other factors that interact with the 'size-arrival effect', such as the level of background detail and whether the viewer is moving at the same time (DeLucia and Meyer, 1999). Future research into these factors could suggest alternative strategies for improving safety margins in junction decisions, such as turning some give-way junctions into stop junctions, forcing the driver to extract TTC information without the potential confounds of self-motion.

3.4.2 Distraction during decision making

In-car or external distracters can influence whether one looks at an approaching motorcycle (Section 3.1.4) and whether one has enough time to process and therefore perceive the motorcycle (Section 3.3.3), but distraction can also influence the appraisal of whether it is safe to pull out in front of an oncoming motorcycle.

Cooper and Zheng (2002) demonstrated this by asking drivers to select safe gaps in traffic while in an instrumented car on a closed track. The participants waited at a junction while a continuous stream of traffic passed by. They were required to make a response whenever they thought it was safe to pull out by pressing the accelerator pedal (though their vehicle was in neutral and therefore did not move). For approximately half of the possible gaps the roadway was wet.

The results showed that drivers' decisions were influenced by their age, gap size and the estimated speed of the approaching vehicles. In addition, the drivers also took the roadway conditions into account when making decisions, with greater safety margins in wet weather conditions. When the same drivers were also asked to listen and respond to complex verbal messages while making the same gap decisions, they failed to take into account the road conditions and doubled the number of decisions that could have led to potential collisions compared with the no-distraction condition. These results demonstrate that the correct appraisal of a potentially hazardous situation can depend on the adequate processing of several cues. Such processing requires effort and attention. If resources have to be shared with a secondary task (perhaps interpreting the comments of a satellite navigation system at a complex junction), then some of these cues may be missed.

3.4.3 The influences of age upon judgement

The work of Keskinen *et al*. (1998) revealed that older drivers have particular problems at intersections. Young, middle-aged and older male drivers' habits at T-junctions were examined, the focus of interest being on the attention and interaction between drivers of different age groups. Time differences were noted (i.e. the time passing from the moment the turning driver had completed his/her turn until the opponent driver on the main road reached the centre of the intersection). Two notable conclusions were reached: first, older drivers had a habit of driving and accelerating slowly, which shortened the time difference when entering the main road. Secondly, young drivers/riders tended to travel faster. Situations with an older, turning, driver and an approaching young driver could therefore create some potentially dangerous situations, with an extremely small margin of error. Crucially, time differences were found to be particularly short when the opponent driver was riding a motorcycle.

Most studies of older drivers suggest that they are aware of their deficiencies and employ compensation strategies wherever possible. This often includes limiting the time of day when they drive, and how frequently they drive. Older drivers have even reported avoiding certain junctions because they are aware that they do not necessarily have the resources to cope with the high demands (Ball *et al.*, 1998). There must, however, be a point at which an older driver realises that certain driving demands cannot be met. This point is likely to be some form of near accident (or actual accident) which makes the driver reassess their skill-demand balance. Prior to this point these older drivers may be in a vulnerable position if they have not yet realised that certain aspects of their driving are out of step with their conceptions of their own skill. While slow acceleration could be a problem in several driving contexts, it need not apply to pulling out at a junction, providing the driver is aware of this and adjusts his/her judgement of what constitutes a safe gap accordingly.

4 DISCUSSION

The evidence suggests that variables at all levels of the framework (see Figure 2.1) could influence the probability of a car colliding with a motorcycle. There are times when the bottom-up nature of the visual world will conspire to hide motorcycles from vision, and there are times when drivers' attitudes, knowledge, skills and preconceptions hinder the safe interaction between vehicles. The framework divides the typical car–motorcycle interaction into three behaviours (from the driver's perspective). These were reflected in three questions: whether the driver looked, whether the driver perceived, and whether the driver correctly appraised. Although the majority of such accidents are recorded as 'Looked but Failed to See' (LBFTS) errors, the evidence suggests that there are many factors that could account for a failure of looking or a failure of appraisal. As Brown (2002) pointed out, LBFTS may just be a convenient cause that mitigates the responsibility of the driver. However, we have also reported much evidence that could explain a true LBFTS error.

The problem with the state of the evidence at the moment is that no research has succeeded in sufficiently measuring all three behaviours within a single paradigm. A related problem is that the studies that have tackled these three behaviours independently have done so with a variety of methodologies. Some researchers have focused on accident statistics and interviews (e.g. Van Elslande and Faucher-Alberton, 1997), observation in natural (Labbett and Langham, 2006) or simulated environments (e.g. Caird and Hancock, 1994) or video-based stimuli (e.g. Horswill *et al*., 2005). Future research needs a systematic approach to all three behaviours in order to identify which of them contribute most to potential accidents. Furthermore, the potential causes behind the errors that accompany each behaviour need to be assessed. This review of the literature has offered many potential causes which most likely will need to be combined to provide the best model to account for accidents involving cars and motorcycles.

Though the list of these potential influences is considerable (making any subsequent systematic test quite daunting), there is hope for future interventions due to the large role played by experience and expectations. Some of the influences of experience and expectations are negative (e.g. Van Elslande and Faucher-Alberton, 1997), though, providing the experience and expectancies are appropriate, they will tend to reduce the risk of accident. For instance, we know that motorcyclists have better hazard perception abilities than car drivers (Horswill and Helman, 2003; Haworth *et al*., 2005), and there is evidence that drivers who also ride motorcycles are less likely to cause motorcycle crashes while driving a car (Magazzù et al., 2006). Brooks and Guppy (1990) have even found that drivers who have family members or close friends who ride motorcycles are less likely to collide with motorcycles, and showed better observation of motorcycles than drivers who did not. These results suggest that the safety of car drivers in relation to motorcycles can be improved.

But what of the bottom-up influences? There is even evidence that global-to-local processing (the prioritisation of low spatial frequencies in a visual scene) is susceptible to task demands and experience. Schyns and Oliva (1999) found evidence that participants prioritised high spatial frequencies for certain face categorisation tasks, dependent upon the dimension along which the faces had to be judged. This suggests that, even if the prioritisation of low spatial frequencies is the default, those drivers who are more aware of the need to look for motorcycles may adjust the priority bandwidth of spatial frequencies in order to ensure that motorcycles are more easily detected.

Obviously car drivers cannot be forced to undertake several years of motorcycle riding in order to gain the improvements that such experience brings, and neither can we force their loved ones onto a motorcycle, but if we can extract the underlying factors that reduce the accident liability of these **dual drivers** (who use both cars and motorcycles) then we can apply it to all drivers. This should be the aim for future research in this area.

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