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A simulator study investigating how motorcyclists approach side-road hazards

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ABSTRACT

The most common form of motorcycle collision in the UK occurs when another road user fails to give way and pulls out from a side road in front of an oncoming motorcyclist. While research has considered these collisions from the car driver's perspective, no research to date has addressed how motorcyclists approach these potential hazards. This study conducted a detailed analysis of motorcyclist speed and road position on approach to side-roads in a simulated suburban setting. Novice, Experienced and Advanced riders rode two laps of a simulated route, encountering five side-roads on each lap. On the second lap, a car emerged from the first side-road in a typical 'looked but failed to see' accident scenario. Three Experienced riders and one Novice rider collided with the hazard. The Advanced rider group adopted the safest strategy when approaching side-roads, with a lane position closer to the centre of the road and slower speeds. In contrast, Experienced riders chose faster speeds, often over the speed limit, especially when approaching junctions with good visibility. Rider behaviour at non-hazard junctions was compared between laps, to investigate if riders modified their behaviour after experiencing the hazard. Whilst all riders were generally more cautious after the hazard, the Advanced riders modified their behaviour more than the other groups after the hazard vehicle had pulled out. The results suggest that advanced training can lead to safer riding styles that are not acquired by experience alone.

1. Introduction

Motorcycles account for a disproportionate number of road traffic accidents. As of June 2010, motorcycles constituted less than 1% of the total vehicle miles on UK roads, but accounted for 21% of all UK road fatalities (DfT, 2010 a,b,c). Research has shown that car driver failures to give way at T-junctions are one of the three main causes of accidents involving motorcycles in the UK (Clarke et al., 2007). In a recent report, 54.3% of motorcycle accidents took place at an intersection and in 60% of these cases, the motorcyclist collided with a passenger car (MAIDS, 2009). These accidents are characterized by other road users emerging from a side-road onto a main carriageway into the path of an approaching motorcycle. In such cases drivers often report failing to see the motorcycle, despite looking in the appropriate direction. This has been termed a 'look but fail to see' (LBFTS) error (Brown, 2002).

There has been much debate as to the cause of LBFTS errors (see Crundall et al., 2008b, for a review of potential causes). Crundall et al. (2008a) proposed three stages to a LBFTS error, with a failure in anyone of these stages potentially leading to a collision. First the driver must *look* at the approaching motorcycle, then process and *perceive* the motorcycle, before *appraising* the risk it poses and selecting an appropriate action. A mixture of bottom-up factors (e.g. luminance, contrast, spatial frequency, etc.) and top-down factors (expectancy, experience, perceptual biases, etc.) are likely to be responsible for any errors. Interestingly, while novice drivers are typically at greater risk of collision than more experienced drivers (e.g. Underwood, 2007), experienced drivers may actually have a more deep-seated expectancy to see an oncoming car rather than a motorcycle while waiting to exit a side-road and therefore be more prone to LBFTS errors. Indeed Crundall et al. (2012a) eye-tracked participants watching videos clips from the perspective of a driver waiting to pull out from a side road and found that experienced car drivers had inappropriately short gaze durations on approaching motorcycles. Such short gaze durations (compared to those on approaching cars) are linked with limited or inadequate processing, and are therefore symptomatic of a LBFTS error. More specific experience can be beneficial however, with some researchers reporting that car drivers who also ride motorcycles (or have at least ridden pillion) are less likely to collide with motorcycles while driving a car (Brooks and Guppy, 1990; Magazzù et al., 2006).

While the car-drivers' perspective has received considerable focus, it would appear that no research has looked at side-road collisions from the rider's perspective. Given the prevalence of accidents at these junctions, it is likely that many motorcyclists recognise

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them as a potential source of danger, therefore one might expect riders to slow down on approach to these junctions and to select a road position that improves their safety. Furthermore, one would expect that Experienced riders, who have probably witnessed more accidents or near-misses, should be more aware of potential side-road hazards than inexperienced riders, and may therefore display more pronounced precautionary behaviour when approaching side roads, especially when they contain another vehicle waiting to pull out.

Many studies have indicated that the hazard perception skill of car drivers is positively related to experience and training (e.g. Chapman et al., 2002; Crundall et al., 2010; Groeger and Chapman, 1996; Quimby et al., 1986; McKenna et al., 2006; McKenna and Crick, 1994; Pollatsek et al., 2006; Wallis and Horswill, 2007), thus one might also expect motorcycling experience and training to improve motorcycle-perspective hazard perception skills, such as identifying vehicles in side roads who may pose a threat.

More recently, simulator studies have begun to confirm that the positive effects of experience on hazard perception are also evident for motorcyclists (Liu et al., 2009; Hosking et al., 2010; Shahar et al., 2010; Vidotto et al., 2011). Generally, experienced motorcyclists are better at detecting hazards than novices and motorcycling experience appears to improve hazard perception over and above car driving experience (Hosking et al., 2010).

If experience of hazards improves a motorcyclist's ability to spot them in the future, one might question what mechanism may be used to achieve this. Shinoda et al. (2001) suggest that car drivers perform an active search of the environment, influenced by a learnt probabilistic structure. Extrapolated to motorcyclists one can imagine that experience of a side-road hazard is likely to increase the perceived probability of future cars emerging from side-roads, resulting in a change in behaviour when the rider approaches subsequent side-roads. If riders are guided by a learned probabilistic structure, then experiencing a hazard could modify this via one of at least two ways.

First, one might expect that riders could assign a probability to the hazard occurring in subsequent situations on the basis of *similarity*. The higher the degree of similarity between the original hazard scenario and subsequent situations, the higher the perceived probability will be of the hazard recurring in the subsequent situation. This means that riders who have experienced a car emerging from a side-road will assign a higher probability to that hazard arising again at a subsequent side-road if they can see a car approaching or if the surroundings are similar to the original scenario.

Alternatively, riders could assign a probability of the hazard occurring in subsequent situations on the basis of *uncertainty*. In this case, riders who have experienced a car emerging from a side-road will still assign a higher probability to that hazard arising again at a subsequent side-road if they can see a car approaching, but also if they are uncertain that junction is empty (i.e. if their view of the junction is obscured).

Since similarity and uncertainty are both subjective, the probabilities assigned by different riders are likely to depend on what aspects of the situation the rider pays attention to.

1.1. Rationale

The primary aim of this study was to demonstrate whether riders of differing experience and training approach side roads differently, and whether this can be identified in a motorcycle simulator. On the basis of previous research suggesting experience leads to greater hazard awareness (Liu et al., 2009; Hosking et al., 2010; Shahar et al., 2010; Vidotto et al., 2011), more Experienced riders might be expected to approach side-roads at slower speeds than Novice riders and adopt a road position that is further from the potential source of danger. While this common-sense hypothesis appears well founded (i.e. if one notices a hazard then speed and position should be altered accordingly to reduce the possibility of collision), it is also possible that Experienced riders may choose to increase speed to pass the junction before the vehicle in the side road can pose a threat. Either way, one might predict a change in speed if Experienced riders predict a hazard ahead.

At least one study has however demonstrated that experienced car drivers do not necessarily outperform their novice counterparts on every measure. Duncan et al. (1991) found experienced drivers were outperformed by both novice and advanced drivers (the latter having had advanced driver training) in certain measures such as mirror checks. Duncan et al. suggested that this was because some poor behaviours are rarely punished (e.g. poor blind-spot checking) resulting in experienced drivers developing 'bad habits' that are only corrected when the driver has a collision (or near collision), or possibly through the advanced training that Duncan et al.'s third group had undertaken. Thus while a naïve view of the role of experience might argue for a linear improvement in behaviour related to a potential side-road hazard across novice to Experienced to Advanced riders, it is also possible that Experienced riders may show a dip in performance compared to the other two groups. The following study aims to establish whether the benefits of experience and advanced training are cumulative or different.

In addition to assessing differences between rider groups on approach to side roads, this study can assess how these riders respond when an actual hazard occurs (on one side road a vehicle fails to give way, causing a hazard). Riding measures can also be investigated to assess how exposure to the hazard influences approach behaviour to subsequent side-roads. Can a one-shot exposure change approach behaviour, and if so, does it work through scenario similarity or through uncertainty?

2. Method

2.1. Participants

Sixty-two participants were reimbursed for their time. Participants were filtered for excessive driving experience so that anyone with a typical annual mileage over 17,000 miles per annum or who held any other type of driving licence (e.g. large goods vehicle) was excluded from the study. One rider withdrew due to simulator sickness leaving 20 Novice riders, 21 Experienced riders and 20 Advanced riders. Novice riders (mean age = 26.5 years; SD = 8.2 years) were post-compulsory basic training (CBT; which allows them to ride with Learner plates) and either preparing to take the standard Driving Standards Agency (DSA) motorcycle test, or had passed it within the last 12 months. They averaged 7.7 h riding per week (SD = 5.3) and 3711 miles per year (SD = 2997). Experienced riders (mean age = 40.6 years; SD = 9.3 years) had over three years' riding experience since passing the standard DSA motorcycle test, but had no further training (7.3 h riding per week, SD = 5.8, and 4318 miles per year, SD = 3319). Advanced riders (mean age = 47.4 years; SD = 9.2 years) had passed their Institute for Advanced Motorists (IAM) advanced riding test in the last three years. Experienced and Advanced riders were matched on overall riding experience (mean = 16.1 years), although Advanced riders rode more (8.8 h per week, SD = 6.2), and had greater mileage (7400 miles per year, SD = 4357).

2.2. Apparatus

The MotorcycleSim facility consists of a full size Triumph Daytona 675 with standard user input controls. 'STISIM-Drive' simulation software takes throttle, gears and braking input along with

Fig. 1. Rider view of side-road hazard.

steering data to allow interaction with the simulated virtual environment. The scenario was projected (1280 × 1024 pixels) onto a large flat-screen (285 cm × 228 cm) in front of the rider at a distance of 190 cm. A speedometer, tachometer, current gear selection, and a rear view mirror were presented at the bottom of the screen. Auditory feedback of engine noise (based on current rpm) was provided using surround-sound speakers. Speed data and lateral position of the rider were recorded every 0.1 s. For a detailed description of MotorcycleSim please refer to Stedmon et al. (2009).

2.3. Side-road scenario design

A virtual route was developed, which integrated a number of different experimental sub-scenarios across two laps (Stedmon et al., 2011). The current study used a suburban section which included five side-roads on the left hand side of the main carriageway, a minimum of 628 ft apart. A crossroad intersection was placed 526 ft before the first side-road with traffic lights that turned red as the rider approached, ensuring all participants entered the suburban section from a stationary position at a pre-defined point. A 40 mph speed limit sign was placed 687 ft before the crossroads.

Each side-road represented a give way junction onto the main carriageway with standard road markings indicating priority for the rider. On Lap 1, the first side road was empty and excluded from analyses. However, on Lap 2, this side road contained a hazard (a car approached the give way line and then pulled out of the junction into the path of the motorcyclist, as in a typical LBFTS situation; Fig. 1).

The car hazard was triggered when the rider was 5 s from the junction. The car then travelled at a speed of 10 mph from a distance of 68 ft from the junction (i.e. initially beyond the rider's view). The car then continued at the same speed and finally stopped with the centre of the vehicle 1.8 ft over the give-way line. The car came into view approximately 218 ft before the junction if the rider was travelling down the centre line at 40 mph.

On the nearest corners of the second and fourth side-roads, buildings were positioned 38 ft from the carriageway, obscuring the rider's view down the side roads. These side roads are referred to as 'obscured junctions' (Fig. 2a and b). On the near corners of the third and fifth side-roads, buildings were positioned 58 ft from the carriageway, allowing the rider to see further down the side-roads. These side roads are referred to as 'open junctions' (Fig. 2c and d). The hazard junction was also open.

During Lap 1, the second and fifth side roads contained a car, which approached and stopped at the give way line (a potential hazard that does not subsequently materialize). As with the hazard vehicle, each car was triggered when the rider was 5 s away and travelled at 10 mph from a distance of 68 ft from the junction (i.e. initially out of the rider's view). During Lap 2, the third and fourth side-roads contained cars, which pulled up to the junctions in the same way as the cars in Lap 1. Therefore, excluding the hazard side road, there were 2 obscured junctions (one with a car pulling up and one without a car) and 2 open junctions (one with a car pulling

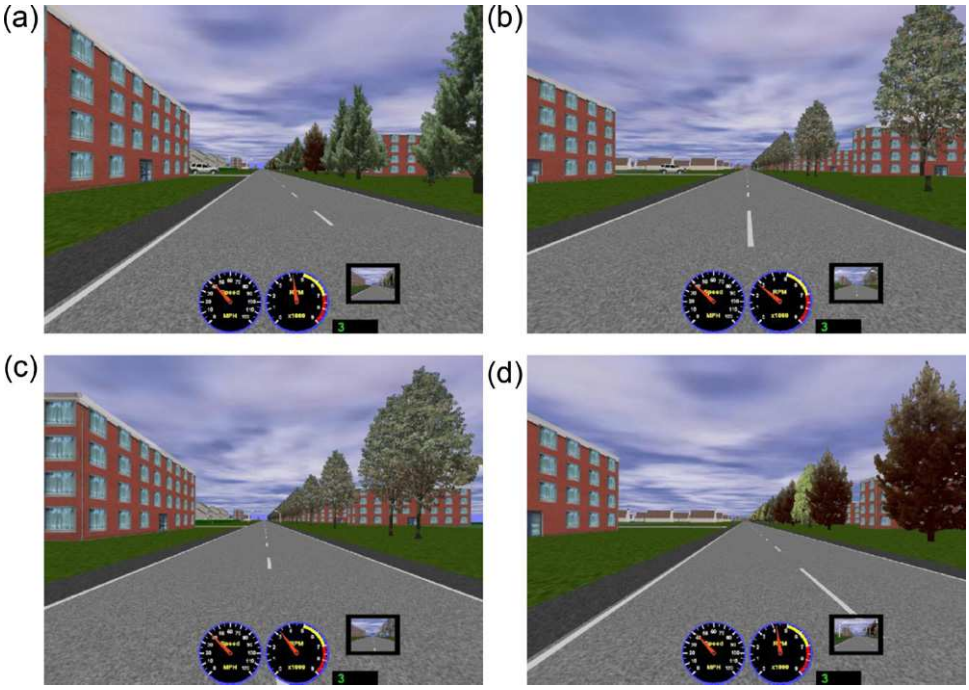

Fig. 2. Side-road conditions as observed by riders: obscured side-roads with approaching car (a) and without approaching car (b); open side-roads with approaching car (c) and without approaching car (d).

up and one without a car) on each lap. If the rider travelled down the centre line at 40 mph, the cars pulling up to open junctions were visible approximately 120 ft earlier than cars that pulled up to obscured junctions. There was no other traffic in the suburban section, although traffic did appear in other parts of the scenario.

2.4. Design

This study contained two sub-experiments that were analysed separately. The first analysis employed a 3 × 5 mixed design to assess riders' responses to the side-road hazard (Lap 2, side road 1, where the car in the open side road fails to give way). The between-groups independent variable was rider group with three levels (Novices vs. Experienced vs. Advanced riders). The within-group independent variable was distance from the hazard junction. This refers to the longitudinal distance between the rider and the position where the hazard car subsequently emerged, and was categorised as one of five distance bins: 500–400 ft; 400–300 ft; 300–200 ft; 200–100 ft; and 100–0 ft. Thus each rider contributes behavioural measures to each of these 5 distance bins as they approach the hazard junction. Average speed (mph), lateral position (ft) and variance of lateral position (ft^2) were recorded for each distance bin to find out how the different groups responded as they approached the junction and spotted the hazard. The hazard became visible in the third bin (200–300 ft), providing approach data before, during, and after detection of the hazard.

Lateral position was measured in feet from the centre of the road, with zero representing the centre line and increasingly negative numbers reflecting positions further to the left of the lane (a score of −12 represented the left edge of the road).

The second analysis was concerned with junctions 2–5 on both Laps 1 and 2. A 3 × 2 × 2 × 2 mixed design was used with rider group as the between-groups variable and junction type (obscured vs. open), car presence (car pulling up vs. no car), and lap (Lap 1 vs. Lap 2) as repeated measures variables. The independent variable 'junction type' refers to whether the buildings in the foreground obscured the majority of the side road, or whether the buildings were set back allowing good visibility of the side road. Two side roads were obscured and two were open. The independent variable of 'car presence' refers to whether or not a car would approach the main carriageway from the side road while the rider was approaching. Each junction was presented twice (across two laps), once with an approaching car and once without. Unlike the hazard car in the first analysis, all of these cars stopped at the give way line. The final repeated measures variable was 'lap' (1 or 2). Pre-hazard behaviour on Lap 1 was compared with post-hazard behaviour in Lap 2, to investigate if riders modified their behaviour after experiencing the hazard.

The same dependent variables were included in this analysis, but mean data were calculated from 300 ft before the start of each junction up to when the rider reached the start of the junction.

2.5. Procedure

Participants conducted two practice sessions on MotorcycleSim to familiarise themselves with the simulator controls (e.g. steering, throttle response, gears, and braking inputs), an emergency stop (to assess the braking potential of the simulator) and overtaking manoeuvres around slow moving vehicles. These practice sessions lasted between 8 and 10 min in total and were immediately prior to the experimental session.

Participants then completed the two laps of the main riding scenario (20–25 min). Participants were instructed to ride as they would in the real world. If participants left the road (by more than 1 ft on either side of the road) an accident was recorded and they were placed back on the road to continue the simulated route from that point. Finally, participants were fully debriefed on the purpose of the study and reimbursed for their time.

3. Results

Prior to analysis the data from one Novice rider was removed due to a technical fault with the simulator at the time of testing.

3.1. Responses to the side-road hazard

A series of 3 × 5 mixed ANOVAs were conducted on mean speed, mean lateral position and variance of lateral position data, with rider group (Novices vs. Experienced vs. Advanced) as a between-groups factor and distance from hazard (500–400 ft; 400–300 ft; 300–200 ft; 200–100 ft; 100–0 ft) as a repeated-measures factor. Data recorded while the motorcycle was stationary (i.e. if the rider stopped before the junction) were excluded from the analyses, though all participants still contributed to all levels of the analysis. One Novice rider and three Experienced riders collided with the hazard vehicle.

3.1.1. Mean speed

Analysis of mean speed revealed a main effect of distance from hazard [$F(4,228) = 187.488$; $MSE = 34.933$; $p < 0.001$], shown in Fig. 3. Riders increased speed across the first three distance bins ($p < 0.01$), then significantly decreased their speed between 200–100 ft and 100–0 ft from the hazard ($p < 0.001$).

3.1.2. Mean lateral position

Analysis of lateral position revealed a main effect of rider group [$F(2,57) = 3.616$; $MSE = 1.269$; $p < 0.05$]. Scheffé tests illustrated that Advanced riders (mean = −4.08 ft) rode significantly closer to the centre line than Novice riders (mean = −5.05 ft; $p < 0.05$). Experienced riders (mean = −4.58 ft) were not significantly different from either of the other groups. There was also a main effect of distance [$F(4,228) = 56.465$; $MSE = 0.952$; $p < 0.001$; Fig. 4]. Repeated contrasts revealed that riders moved towards the centre line across all 5 bins ($p < 0.05$ between 500–400 ft and 400–300 ft; $p < 0.001$ for all other comparisons).

3.1.3. Variance in lateral position

The same analysis was conducted on the variance of lateral position. There was a significant main effect of distance [$F(4,228) = 36.880$; $MSE = 1.041$; $p < 0.001$; Fig. 5]. Repeated contrasts revealed increases in lateral variance between the 200–100 ft (mean = 0.11 ft^2) and 100–0 ft distance bins (mean = 1.86 ft^2; $p < 0.001$).

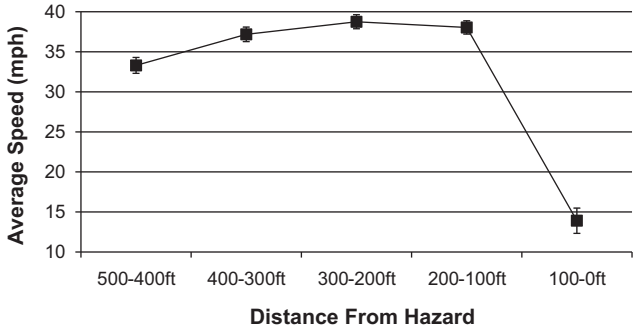

Fig. 3. Average speed across the five distance bins (with standard error bars). The hazard is first visible in the 300–200 ft bin.

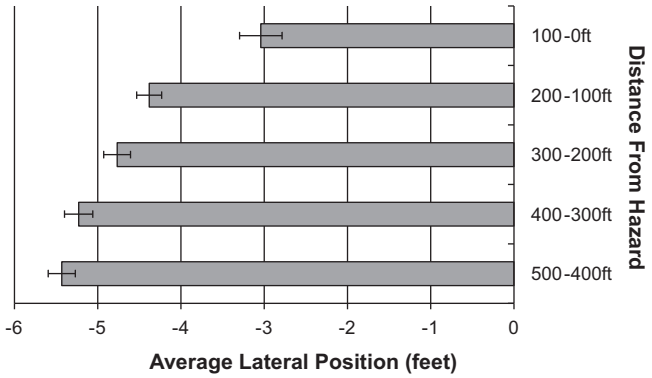

Fig. 4. Average lateral position across the five distance bins (with standard error bars). The hazard is first visible in the 300–200 ft bin.

3.2. Responses to non-hazard junctions

A series of 3 × 2 × 2 × 2 mixed ANOVAs were conducted on mean speed, mean lateral position and variance of lateral position data, with rider group as a between-groups factor and lap (Lap 1 vs. Lap 2), junction type (obscured vs. open), and presence of car (car pulling up vs. no car) as repeated-measures factors.

3.2.1. Mean speed

Analysis of mean speed illustrated a significant main effect of rider group [$F(2,57) = 3.283$, $MSE = 321.320$, $p < 0.05$]. Scheffé tests revealed that Advanced riders (mean = 36.8 mph) were slower than Experienced riders (mean = 41.8 mph). Novices (mean = 40.0 mph) did not differ from either of the other groups ($p > 0.05$). There was also a main effect of junction type [$F(1,57) = 10.928$; $MSE = 22.110$; $p < 0.01$], with riders approaching obscured junctions (mean = 38.8 mph) more slowly than open junctions (mean = 40.2 mph). However, an interaction between junction type and rider group [$F(2,57) = 4.339$, $MSE = 22.110$, $p < 0.05$] suggested that this was due to Experienced riders' faster speeds at open junctions (Fig. 6). Simple main effects confirmed this, revealing that only the Experienced riders were affected by junction type [$F(1,20) = 22.626$; $MSE = 4.661$; $p < 0.001$], riding significantly faster when they approached open junctions than when they were approaching obscured junctions. Simple main effects also revealed an effect of rider group only for open junctions [$F(2,57) = 4.153$; $MSE = 47.290$; $p < 0.05$], with Experienced riders approaching open junctions faster than Advanced riders.

There was also a main effect of car presence [$F(1,57) = 51.271$; $MSE = 33.353$; $p < 0.001$], with slower speeds when approaching side-roads with a car present (mean = 37.6 mph) than empty side-roads (mean = 41.4 mph). However, car presence interacted with group [$F(2,57) = 6.158$; $MSE = 33.353$; $p < 0.01$]. Fig. 7 illustrates that this interaction was primarily driven by Experienced riders' faster speeds past empty side-roads. Simple main effects analysis confirmed that, although all three groups were faster when no car was present, this effect was more exaggerated for Experienced riders [$F(1,20) = 38.381$; $MSE = 11.047$; $p < 0.001$] than for Novice [$F(1,18) = 10.101$; $MSE = 4.786$; $p < 0.01$] or Advanced riders [$F(1,19) = 8.382$; $MSE = 8.852$; $p < 0.01$].

The presence or absence of a car pulling up also interacted with lap [$F(1,57) = 37.158$; $MSE = 29.495$; $p < 0.001$], and junction type [$F(1,57) = 18.854$; $MSE = 17.548$; $p < 0.001$], which resulted in a 3-way interaction between car × lap × junction type [$F(1,57) = 15.492$; $MSE = 30.513$; $p < 0.001$], shown in Fig. 8.

Simple main effects found that slower speeds to junctions where a car pulls up, were only found on Lap 2. This was significant for both obscured ($p < 0.01$) and open junctions ($p < 0.001$), although the difference was much greater for open junctions. On Lap 1, riders were slower at obscured junctions than open junctions, regardless of whether or not a car was pulling up ($p < 0.05$). On Lap 2, riders were only slower at the obscured junction than the open junction when there was no car pulling up ($p < 0.001$). At junctions where a car pulled up on Lap 2, riders were slower when approaching the open junction ($p < 0.001$). It is worth noting at this point that since the approaching car was visible earlier at open junctions, the results are likely to be a reflection of riders reducing their speed earlier when riding past these junctions. Simple main effects analysis revealed that, when approaching open junctions where a car pulled up, riders were slower on Lap 2 than on Lap 1 ($p < 0.001$).

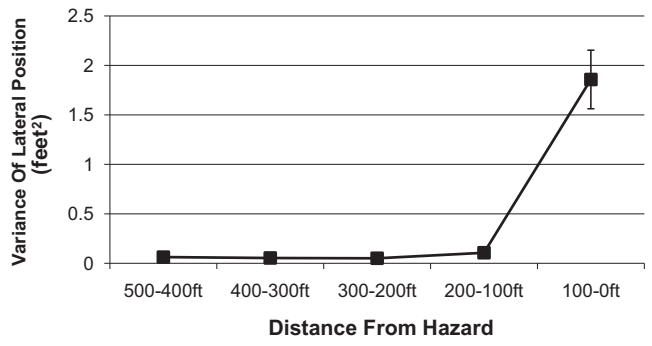

Fig. 5. Variance of lateral position across the five distance bins (with standard error bars). The hazard is first visible in the 300–200 ft bin.

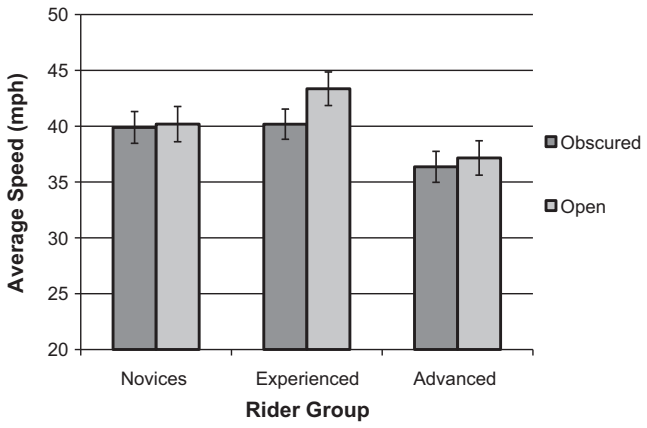

Fig. 6. Average speed of Novices, Experienced and Advanced riders approaching obscured and open junctions (with standard error bars).

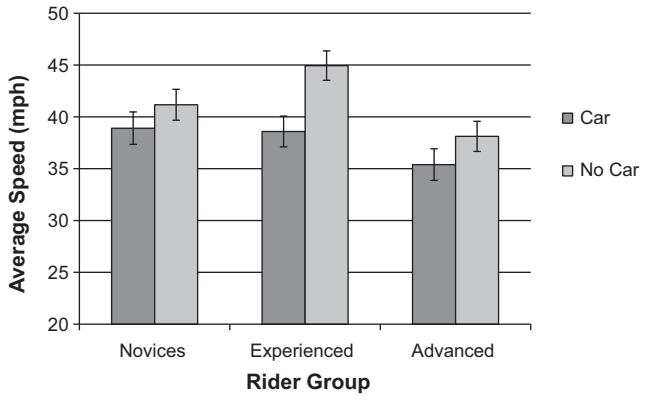

Fig. 7. Average speed of Novice, Experienced and Advanced riders approaching junctions with and without an approaching car (with standard error bars).

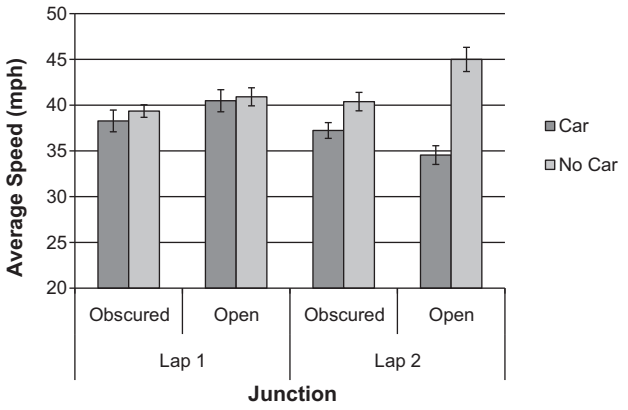

Fig. 8. Average speed when approaching obscured and open junctions, with and without an approaching car during Lap 1 and during Lap 2 (with standard error bars).

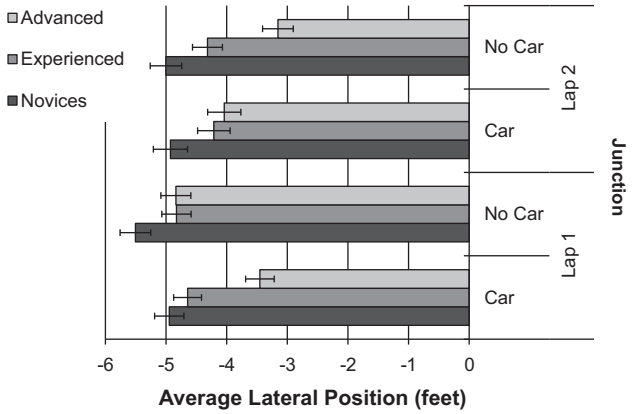

Fig. 10. Average lateral position of Novice, Experienced and Advanced riders when approaching junctions with and without approaching cars during Laps 1 and 2 (with standard error bars).

However, when approaching open junctions where a car did not pull up, riders were faster on Lap 2 than on Lap 1 ($p < 0.01$).

3.2.2. Mean lateral position

Analysis of mean lateral position revealed a group effect [$F(2,57) = 8.898$; $MSE = 6.573$; $p < 0.001$], with Advanced riders significantly closer to the centre line (mean = −3.87 ft) than Novices (mean = −5.10 ft; $p < 0.001$). Experienced riders (mean = −4.50 ft) did not significantly differ from either of the other groups. A main effect of lap [$F(1,57) = 13.760$; $MSE = 1.589$; $p < 0.001$], revealed that riders were closer to the centre line in Lap 2 (mean = −4.28 ft) than in Lap 1 (mean = −4.70 ft), while an effect of junction [$F(1,57) = 40.775$; $MSE = 1.253$; $p < 0.001$] suggested that riders were closer to the centre line when approaching open junctions (mean = −4.16 ft) rather than obscured junctions (mean = −4.82 ft). However, an interaction between junction type and rider group [$F(2,57) = 3.583$; $MSE = 1.253$; $p < 0.05$] revealed that it was primarily the Advanced riders [$F(1,19) = 39.786$; $MSE = 0.256$; $p < 0.001$] and, to a lesser extent, the Novice riders [$F(1,18) = 20.471$; $MSE = 0.167$; $p < 0.001$] who behaved in this way (Fig. 9). Furthermore, when junctions were obscured, the Advanced riders were positioned closer to the centre line than the Novices ($p < 0.01$), but were not significantly different from the Experienced riders ($p > 0.05$). However, at open junctions, the Advanced riders were positioned closer to the centre line than both the Novices ($p < 0.001$) and the Experienced riders ($p < 0.05$).

There was also a main effect of car presence [$F(1,57) = 7.078$; $MSE = 0.952$; $p < 0.05$], with participants riding closer to the centre line when approaching with cars (mean = −4.37 ft) compared to side roads without cars (mean = −4.61 ft). A three-way interaction between car x lap x rider group complicated matters [$F(2,57) = 12.283$; $MSE = 1.119$; $p < 0.001$; Fig. 10]. Simple main effects analysis revealed that on Lap 1, Advanced riders rode closer to the centre line than both the Novices ($p < 0.001$) and the Experienced riders ($p < 0.01$), but only when approaching junctions where a car pulled up. On Lap 2, Advanced riders rode closer to the centre line than both Novice riders ($p < 0.001$) and Experienced riders ($p < 0.01$), but only when approaching junctions with no car.

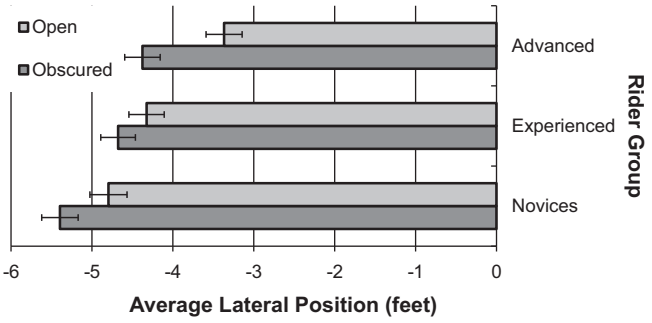

Fig. 9. Average lateral position of Novice, Experienced and Advanced riders when approaching open and obscured junctions (with standard error bars).

Novice riders also showed an interesting sensitivity to the presence of cars in the side-roads [$F(1,18) = 7.817$; $MSE = 0.380$; $p < 0.05$]. On Lap 1 they were positioned closer to the centre line when a car appeared in the side-road, than when passing an empty side-road. In Lap 2, however, they were equally close to the centre, regardless of whether a car was present or not. This suggests that on Lap 2 they approached empty side roads with increased caution compared to Lap 1. It is possible that this sensitization to side roads was evoked by the hazard (a car pulling out from a side road) which occurred between Laps 1 and 2.

There was no effect of car presence for Experienced riders, but as with Novice riders, the Experienced riders also rode closer to the centre line on Lap 2 than on Lap 1 when approaching junctions with no car [$F(1,20) = 5.221$; $MSE = 0.527$; $p < 0.05$]. Advanced riders rode closer to the centre line when a car pulled up in Lap 1 [$F(1,19) = 37.714$; $MSE = 0.510$; $p < 0.001$], but on Lap 2 they rode closer to the centre line when there was no car present [$F(1,19) = 13.382$; $MSE = 0.585$; $p < 0.01$]. Furthermore, at junctions with no car, Advanced riders rode closer to the centre line on Lap 2 than on Lap 1 [$F(1,19) = 24.783$; $MSE = 1.143$; $p < 0.001$], but at junctions where a car pulled up, Advanced riders rode further from the centre line on Lap 2 than on Lap 1 [$F(1,19) = 5.073$; $MSE = 0.683$; $p < 0.05$].

The analysis of mean lateral position also revealed an interaction between car × junction type × lap [$F(1,57) = 37.988$; $MSE = 1.505$; $p < 0.001$]. As Fig. 11 shows, riders generally rode just over 4 ft to the left of the centre line. However, in Lap 1, riders adopted a less cautious road position when approaching obscured junctions without a car. In this condition, riders were significantly further from the centre line than both open junctions without a car [$F(1,59) = 44.436$; $MSE = 1.068$; $p < 0.001$] and obscured junctions with a car [$F(1,59) = 44.817$; $MSE = 1.114$; $p < 0.001$]. In Lap 2, riders were more cautious when approaching open junctions with a car, riding significantly closer to the centre line than open junctions without a car [$F(1,59) = 6.385$; 1.528; $p < 0.05$]. However, on the second lap, riders were also less cautious when approaching obscured junctions with a car, riding further from the centre line than when approaching obscured junctions without a car

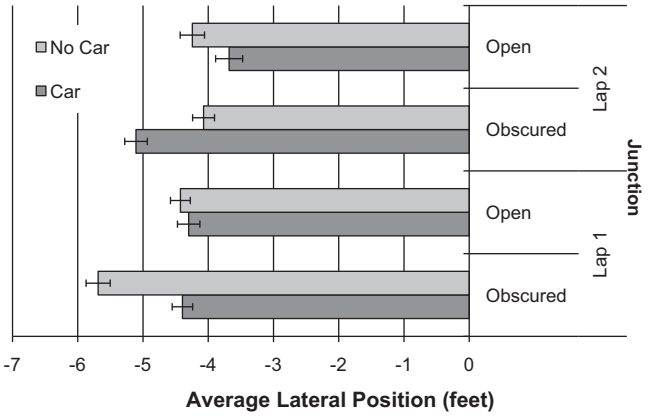

Fig. 11. Average lateral position of riders during Laps 1 and 2 at obscured and open junctions with and without cars (with standard error bars).

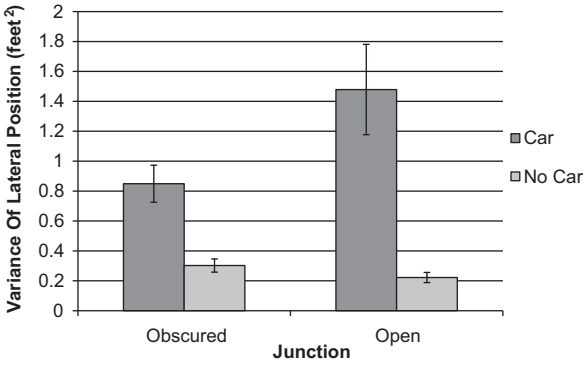

Fig. 12. Variance of lateral position of riders at obscured and open junctions with and without cars (with standard error bars).

[$F(1,59) = 25.981$; $MSE = 1.250$; $p < 0.001$] or open junctions containing a car [$F(1,59) = 45.598$; $MSE = 1.349$; $p < 0.001$].

On the second lap, riders approached open junctions containing a car significantly closer to the centre line than in Lap 1 [$F(1,59) = 8.259$; $MSE = 1.464$; $p < 0.01$]. There was a similar lap effect for obscured junctions without a car [$F(1,59) = 52.155$; $MSE = 1.507$; $p < 0.001$]. However, when approaching obscured junctions with a car pulling up, riders were further from the centre line in the second lap [$F(1,59) = 13.612$; $MSE = 1.117$; $p < 0.001$].

3.2.3. Variance in lateral position

A significant main effect was observed for car presence [$F(1,57) = 25.880$; $MSE = 3.769$; $p < 0.001$] which illustrated that riders varied their lateral position more when a car pulled up (mean = 1.16 ft^2) than when there was no car (mean = 0.26 ft^2).

There was an interaction between car presence and junction type [$F(1,57) = 5.994$; $MSE = 2.519$; $p < 0.05$], shown in Fig. 12. Riders varied their lateral position more when a car pulled up than when there was no car when approaching both open [$F(1,59) = 17.588$; $MSE = 2.670$; $p < 0.001$] and obscured junctions [$F(1,59) = 17.306$; $MSE = 0.518$; $p < 0.001$]. Riders also varied their lateral position more when approaching open junctions rather than obscured junctions, but only when a car pulled up [$F(1,59) = 4.766$; $MSE = 2.431$; $p < 0.05$].

4. Discussion

This experiment was designed to investigate how different groups of riders approached side-roads, how they responded to a car pulling out of a side-road in a typical LBFTS scenario, and whether riders modified their approach to subsequent side-roads after experiencing this hazard.

4.1. Riders' general approach to side-roads

The results indicate that Advanced riders tended to approach junctions more slowly than the other two rider groups, while Experienced riders travelled exceptionally fast (approximately 4 mph over the speed limit) when approaching open junctions. A similar pattern was found regarding the presence or absence of cars pulling up to the side-road junctions. Experienced riders again travelled at the fastest speeds in the ostensibly safest condition (when the side roads are empty). While all three groups travelled at faster speeds when passing empty junctions compared to junctions with a car pulling up, this difference is greater for Experienced riders. Therefore, it appears that Advanced riders exercised caution regardless of whether they could see a potential hazard, whereas Experienced riders only reduced their speed when a potential hazard was visible, or in conditions where they could not be certain that there was no hazard (i.e. at obscured junctions).

Comparing results from Laps 1 and 2, it appears that while rider speed was sensitive to junction type (with riders generally approaching obscured junctions more slowly than open junctions) it was not sensitive to the presence of cars until after the hazard. Only lateral position appeared to be affected by the presence of cars in Lap 1, with both Advanced and Novice participants riding closer to the centre line when a car approached the junction.

In general, riders approached open junctions by riding closer to the centre line than obscured junctions. It is unlikely that this was due to riders exercising more caution on open junctions than obscured junctions, since the former were generally approached at a higher speed. Rather, it is possible that riders noticed the open junctions earlier, since more of the side-road was visible, and positioned themselves accordingly. In contrast riders reduce speed on approach to obscured junctions rather than change lane position, perhaps because, if the side road is perceived relatively late on the approach, it would be unsafe to make a sudden shift in lane position. This suggests that riders are choosing their avoidance strategies on the basis of a rapid assessment of the potential negative outcomes.

Whereas the Novice riders did not differ from the Advanced riders in terms of speed, the Advanced riders rode closer to the centre line than the Novices. The Advanced riders also rode closer to the centre line than the Experienced riders but only when junctions were open. Furthermore, the Advanced riders tended to ride closer to the centre line on approach to open junctions compared with obscured junctions. Again, this might be because the Advanced riders took advantage of the higher visibility of open junctions, and moved out to the centre line earlier than the other two rider groups. This lends support for training programmes that encourage road users to look as far down the road as possible in order to prepare early for what is ahead.

4.2. Responding to the side-road junction hazard

Three of the Experienced riders crashed into the hazard car while only one Novice rider was involved in a collision. While there were too few crashes to analyse statistically, it raises the possibility that riders might adopt bad habits with increasing experience, perhaps relating to overconfidence in their observation or braking skills. None of the Advanced riders collided with the hazard. While we cannot conclude (on the basis of collision data) that advanced training can overcome the bad habits that accrue with experience, we can look to surrogate measures of crash liability, such as measures of rider behaviour on approach, and in response, to the hazard.

In general, riders increased their speed on approach to the junction before the hazard appeared. This finding is likely to reflect

riders accelerating to the speed limit after having stopped at a red traffic light. When the hazard became visible (approximately 218 ft before the junction) riders responded by decreasing their speed, slightly at first, but then with a significant decrease in speed 100 ft before the junction.

While initially increasing speed on approach to the hazard junction, the riders also started to move towards the centre line between 500–400 ft and 400–300 ft before the hazard. This suggests that, before the hazard became visible, the riders were exercising caution on approach to the side-road by moving towards the centre line rather than by decreasing speed. Although the lateral movement of riders towards the centre line was initially more gradual, they made greater lateral movements in the last 100 ft in an attempt to avoid a collision with the car. The gradual early shifts in position compared with the more urgent braking in the last 100 ft, fits with the earlier suggestion that changing lane position is an early avoidance strategy that must be selected well in advance, and is therefore dependent on the early detection of potentially hazardous scenarios.

Since there were no interactions with rider group, the results suggest that all three groups responded to the hazard in a similar way by adjusting lateral position then braking. However, while the Advanced riders adopted a relatively safe, central position, the Novices were much closer to the nearside of the road which meant that they were more vulnerable to a collision. The Experienced riders did not differ from the other two groups in their approach to the hazard junction in terms of speed or lateral position, despite having more accidents. Furthermore, the Experienced riders did not require more evasive action than the other rider groups, despite their relatively incautious approach to open and apparently empty junctions in Lap 1. A closer examination of the data seemed to suggest that those participants who were involved in accidents with the hazard car were riding at particularly high speed. While their lateral position was comparable with that of other members of their rider group, the four riders who crashed were still riding over the speed limit 200–100 ft before the hazard (each with mean speeds of 44.1 mph, 44.1 mph, 41.3 mph and 40.2 mph) and failed to decelerate to avoid hitting the vehicle hazard.

4.3. Modifying subsequent behaviour

Before the hazard, rider speed was not affected by the presence of a car in a side-road. However, after the hazard vehicle had emerged from the side-road on Lap 2, riders approached subsequent junctions containing cars at more cautious speeds than empty junctions. This effect was greater for the open junctions, where the approaching car could be seen earlier. Since the open side-road with an approaching car closely resembled the hazard junction, this might suggest that riders were basing the probability of the hazard recurring on similarity between the original hazard event and subsequent scenarios. However, if riders were basing their behaviour on scenario similarity alone, then it would be reasonable to expect that riders would approach the empty open junction with more caution than the empty obscured junction, since the former was more similar to the hazard junction. This was not the case, as the empty open junction was approached at a higher speed than the empty obscured junction. More interestingly, the empty open junction was approached at a higher speed after the hazard compared with Lap 1. It appears that riders are basing hazard predictions on the uncertainty of the situation: riders treated all obscured junctions with the same level of caution since they could not be certain about what might be hidden from view, but approached empty open junctions at a higher speed because they could be more certain that there were no approaching vehicles.

While rider speed became more sensitive to cars at the junction after the hazard had occurred, riders tended to modify their lateral position at empty junctions. In Lap 1, Novices adopted a more cautious road position when approaching junctions containing cars than empty junctions. However, after experiencing the hazard, they adopted the same position as in Lap 1 when a car was present, regardless of whether a car was actually there or not. Furthermore, when approaching empty junctions, all three groups of riders positioned themselves closer to the centre line after experiencing the hazard compared with Lap 1, suggesting that the occurrence of the hazard caused riders to exercise more caution when they could not see a car. Again, this provides further evidence that riders were predicting potential hazards on the basis of uncertainty rather than similarity with the original hazard scenario. Interestingly, the Advanced riders modified their lateral position after the hazard more than the other two rider groups, despite having already adopted a safer road position than the Novice riders and having had no collisions with the hazard car. However, while they positioned themselves nearer to the centre line on Lap 2 junctions without cars, they were actually closer to the road edge on Lap 2 junctions with side-road cars. We should note however that Advanced riders were still only 4 ft from the centre line and still in a safer position (i.e. further from the left hand side of the road) than the other two rider groups. Although this did not interact further with junction type, an observation of the mean lateral positions revealed that the effect was isolated to the obscured junction containing a car. For the open junction containing a car, Advanced riders still rode closer to the centre line on Lap 2 compared with Lap 1. This is further supported by the separate interaction between lap, junction type and car, which shows that when the junction contained a car, riders adopted a road position closer to the left hand side of the road after experiencing the hazard, but only when the junction was also obscured. The relatively slow speeds adopted by Advanced riders suggest that their positioning at the obscured junction with the approaching car was not due to a lack of caution. Rather, after seeing the previous hazard car pull out into the road it is likely that the Advanced riders decided to respond to the car at the obscured junction by moving towards the nearside of the road. At the open junction, the car was visible earlier so there was more opportunity to move out to avoid a collision should the car pull out further, and more time to check that there was no oncoming traffic or vehicles in the rear view mirror. However, at the obscured junction the car was visible later, so pulling in towards the left (perhaps with the intention of stopping, or even going behind the back of the car if it were to pull out) was perhaps preferable to swerving across the centre line.

5. Conclusion

To summarise, this study has demonstrated that detailed simulator measures of performance can discriminate between rider groups on the approach to side road junctions. The Advanced group mainly adopted a strategy which most riding instructors would consider to reflect safe practice when approaching junctions, riding closer to the centre line than the Novices. We suggest that this is due to their advanced training, though we cannot rule out the possibility of self-selection effects in the Advanced group. The Experienced riders chose faster speeds, often above the legal speed limit, especially when approaching open junctions or when the junction apparently did not contain another vehicle. It is perhaps a consequence of this lack of caution that more Experienced riders collided with the hazard vehicle. On the basis of these results, while the current research focus on car driver skills in avoiding collisions with motorcycles should not be reduced, it does raise the possibility that motorcyclists can also be trained to approach these junctions in a manner that may reduce their crash liability.

In addition, it has been noted that Experienced riders may show sub-optimal performance on some measures compared to Novice and Advanced riders (cf. Duncan et al., 1991). This negative impact of experience on some rider measures has also been recently reported in a simulator study of curve negotiation (Crundall et al., 2012b). While Duncan et al. (1991) reported several measures that experienced car drivers fared worse on compared to novice and advanced drivers (due to a lack of negative feedback across the driving career), there is the possibility that motorcycling may be even more prone to the failings of experience than car driving due to the nature of the vehicle and the reasons for riding.

Furthermore, the study has provided evidence for a two-tier response to potential hazards, with changes in lane position only being chosen as the initial response if the potential hazard is spotted in time (cf. Crundall et al., 2012b), while braking acts as the default emergency procedure with late notice. There is some evidence that exposing riders to a simulated hazard emerging from a side road can affect approach behaviour to subsequent simulated side roads, and that this might be achieved by highlighting potentially hazard events on the basis of uncertainty. However, there is also some evidence to suggest that riders can use the hazard to calibrate their risk taking upwards in scenarios that they subsequently deem to be less likely to evoke a hazard.

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