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Comparing drivers' gap acceptance for cars and motorcycles at junctions using an adaptive staircase methodology

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ABSTRACT

A disproportionate number of road deaths occur at intersections where one vehicle is a motorcycle. Previous research has not systematically varied the type of vehicles presented in a controlled environment.

We compared drivers' (n = 54) gap acceptance when either a car or motorcycle was approaching a junction. We used a QUEST adaptive staircase to estimate gap acceptance thresholds for cars and motorcycles separately. On each trial, drivers saw a car approaching from the left and a vehicle (car or motorcycle) approaching from the right. The driver had to stop for the car from the left, but could choose whether to pull out in front of the vehicle from the right, or to wait for it to pass. Participants completed the task in either a medium-fidelity simulator (steering wheel and pedals, 180-degree screen) or a high-fidelity simulator (fully instrumented car, 360-degree screen).

Participants accepted significantly smaller (riskier) gaps in front of motorcycles than in front of cars, particularly in the high-fidelity simulator. The speed of crossing the junction did not differ between vehicle types, meaning that drivers were closer to the motorcycle than the car during the manoeuvre. There was one instance that appeared to replicate a 'Look But Fail To See' error, where a participant pulled out in front of an oncoming motorcycle resulting in a crash. This suggests that drivers accept riskier gaps around motorcycles than cars, which may be due to a difference in attitude towards different vehicles or differences in optic flow properties. These results help to explain the disproportionate involvement of motorcycles in real junction crashes.

1. Introduction

1.1. The problem

Intersection safety is a major problem worldwide, with crash data suggesting that there are higher risks in these segments of the road compared with other road segments. Many accidents at intersections can be attributed to inappropriate gap selection by drivers who are pulling out of a side road and entering a carriageway with approaching vehicles (Hoareau, Candappa, & Corben, 2011). This suggests that there is a need to better understand drivers' gap acceptance behaviour to develop strategies that can support drivers' decision making at intersections.

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When inspecting intersection crash data, a large number of intersection crashes involve motorcycles. Data from the UK show that motorcycles are involved in a disproportionate amount of road crashes given the distance travelled, with 122.3 motorcycle fatalities compared with 1.8 car driver fatalities per billion miles (DfT, 2015). In many road crashes involving motorcyclists, car drivers are solely at fault, with the main cause of motorcycle crashes in the UK consisting of right of way violations (ACEM, 2009). These crashes occur when another road user, usually a car, pulls out of a side junction into the path of a motorcycle on a main carriageway (Clarke, Ward, Bartle, & Truman, 2007). These crashes in the previous literature are commonly known as 'Look But Fail To See' errors, with it being typical in these accidents that a driver reports being careful and attentive with their visual checks but nonetheless fails to see an oncoming motorcyclist (Brown, 2002). However, there are many reasons why a driver may report afterwards that they failed to see an oncoming motorcycle. The driver may not want to admit to a driving error, for example, accepting a risky gap between traffic.

1.2. Gap acceptance literature

There is a growing literature investigating drivers' behaviour at intersections in regards to their response to different gaps in traffic. Gap acceptance tasks ask the driver to decide between acceptable and unacceptable gaps to move into. These methods produce rich sources of data, compare gaps which are accepted or rejected by drivers, and estimate the 'critical gap'. This 'critical gap' has been defined as 'the minimum time gap a driver is ready to accept' (Brilon, Koenig, & Troutbeck, 1999, p. 2).

Previous research has used both naturalistic observations and experimental studies (Beanland, Lenné, Candappa, & Corben, 2013; Keskinen, Ota, & Katila, 1998; Scott, Hall, Litchfield, & Westwood, 2013; Yan, Radwan, & Guo, 2007). In most experimental studies the researchers have presented approaching vehicles at a limited and predetermined set of distances. This method allows for vehicles at selected distances to be repeatedly presented to participants. For example, Scott et al. (2013) investigated the effect of driving experience on visual attention at junctions, using a gap acceptance design which included a series of gaps between vehicles which increased in 1.5 s increments. It was found that young experienced drivers distribute their gaze more evenly across the junction, whereas older and novice drivers made sweeping transitions. However, due to the time constrained nature of the task, the study was only able to complete a single manoeuvre with each participant, with the authors concluding that future studies need to investigate drivers' gap acceptance using a larger sample so more gaze sequences can be analysed.

In addition, Beanland et al. (2013) used time gaps which varied from 3 to 11 s to measure a driver's gap acceptance (whether the driver accepted or rejected a given gap), accepted lag (the time of arrival of the target vehicle when participants have accepted the gap in front of it) and turn time, for two different manoeuvres (turning across traffic and merging with traffic). Drivers appear to vary their gap acceptance strategy depending on the intended manoeuvre, with drivers accepting smaller gaps when turning across traffic compared to merging with traffic. As drivers can vary their behaviour dependent on manoeuvre type, this would suggest that it is possible for drivers to vary their behaviour dependent on approaching vehicle type, for example, motorcycles.

Despite the pressing need, few studies of gap acceptance have systematically varied the type of vehicles presented. A review of published articles examining drivers' gap acceptance behaviour found that there are substantial experimental research studies investigating drivers' gap acceptance when intersecting with cars however, relatively fewer research efforts have been made to investigate gap acceptance behaviour when intersecting with motorcycles, despite the high number of crashes occurring with this type of vehicle (Pai, 2011).

Gap acceptance studies when intersecting with motorcycles are also extremely important in developing countries, where the number of motorcycles can be very high (Lee & Sheppard, 2017). Serag (2015) focussed on drivers' gap acceptance in developing countries, conducting a field study in Egypt. It was found that when estimating drivers' gap acceptance (where the driver was 50% likely to accept the gap), these gaps were less than those in developed countries, suggesting riskier behaviour from drivers' in developing countries. Many of these countries have a different traffic composition which needs to be taken into account, especially the characteristics of motorcycles. Ibrahim and Sanik (2007) conducted a field study in Malaysia at T-junctions, investigating drivers' gap acceptance behaviour as a function of approaching vehicle type. The results indicated that there were significant differences in drivers' gap acceptance for cars and motorcycles, demonstrating smaller gaps for motorcycles compared to cars. These results suggest that there may be a specific problem associated with gaps accepted around motorcycles, however, without experimentally controlling the behaviour of different vehicles it is not possible to decide whether it is the vehicle type, or its behaviour that brings about the differences in gap acceptance (motorcycles may be approaching with different speeds and directions than other traffic).

One of the few simulator studies investigating gap acceptance towards motorcycles and cars was conducted by Mitsopoulos-Rubens and Lenné (2012). Three time gaps of 5.0, 7.0 and 9.0 s were used, which were associated with a 20% (i.e. low), 50% (i.e. medium) and 80% (i.e. high) rate of gap acceptance, respectively. It was found that when the time gap was short and long, participants were more likely to accept fewer trials with an approaching motorcycle than car, however, this effect was reversed with the medium time gap.

Although the method of constant stimuli used in previous studies (Beanland et al., 2013; Mitsopoulos-Rubens & Lenné, 2012; Scott et al., 2013) can be argued to be satisfactory in some circumstances (e.g. Crundall, Humphrey, & Clarke, 2008), it may lead to participants being repeatedly exposed to stimuli that may be a long way from their personal threshold. Previous gap acceptance literature highlights that drivers are neither wholly consistent (e.g. always rejecting gaps lower than the critical gap and accepting gaps higher than the critical gap) or homogeneous, with some drivers accepting smaller gaps than others (Amin & Maurya, 2015). This suggests that there is variability within and between drivers. Presenting pre-determined stimuli may lead to participants behaving unrealistically, particularly in simulator studies. Trials in a simulator are longer so participants may simply become bored, or, they may begin to be able to predict the structure of each trial. In the current study, we take advantage of the flexible nature of a driving simulator to introduce an adaptive staircase procedure for measuring critical gaps. This has the considerable advantage that the gaps used are rapidly and efficiently altered to approach the individual driver's personal critical gap so that most of the experimental trials actually require a difficult decision to be made by the driver.

The current study measures drivers' gap acceptance for cars and motorcycles at junctions, using the QUEST Bayesian adaptive staircase procedure (Watson & Pelli, 1983), which works on the basis that the stimulus values presented to participants depend critically on the preceding responses, with the posterior distributions of the psychometric-function parameters being updated on a trial-by-trial basis. We used a separate QUEST function for each driver and for cars and motorcycles separately. The QUEST adaptive staircase method for measuring drivers' gap acceptance estimates the distance where the driver was 50% likely to accept the gap. This is similar to previous studies investigating developing (Serag, 2015) and developed countries (Mitsopoulos-Rubens & Lenné, 2012) however, this method increases the efficiency of the testing procedure, by adjusting the distance of the target vehicle for each trial based on the individual's previous responses to vehicles of that type. This minimises the number of trials needed to reach each critical threshold, measuring tightly around the threshold region, therefore reducing the time and tediousness of the testing process (Kingdom & Prins, 2010).

Multiple methods have been used to assess gap acceptance. A naturalistic observation study was conducted in Japan, videoing drivers' on-road behaviour at T-junctions (Keskinen et al., 1998). Various measures of gap acceptance were measured including time gap (the time from the moment the driver entered the junction until the nearest vehicle reached the centre line of the intersection), time difference (the time from the moment the driver had completed their turn until the nearest approaching vehicle reached the centre line) and turning time (the time it took the driver to make the turning operation). Results indicated that the time margin left for motorcycles was shorter than cars. As this experiment was naturalistic, the speed of the vehicles varied when approaching the junction, which makes it difficult to draw conclusions as to the mechanisms underlying the decision.

Many previous studies specifically investigating right of way accidents at junctions have important limitations because they use static images or video clips of junctions as stimuli (Crundall, Crundall, Clarke, & Shahar, 2012; Langham & Labbett, 2006; Lee & Sheppard, 2017). These methods fail to provide drivers with any vehicle control element – this may free more resources for a gap acceptance judgment, while additionally encouraging unrealistic assumptions about the efficiency with which they would be able to pull out and clear the gaps they are looking at. In the current experiment, we felt that it was important to allow participants to complete the full manoeuvre, both controlling the vehicle while approaching the junction, and actually pulling out into accepted gaps.

Some of the most relevant previous gap acceptance studies have studied drivers' behaviour using a fixed based, medium-fidelity simulator which includes a steering wheel, pedals and gear box for vehicle control. Mitsopoulos-Rubens and Lenné (2012) presented visual stimuli on three 19-inch LCD screens which covered 120-degrees. Beanland et al. (2013) projected the visual environment on a curved projection screen subtending 180-degrees, with a rear projection screen subtending 60-degrees. There are two potential problems with restricting the field of view available to the driver. One is that visual cues presented near the edge of the screen (as an approaching vehicle at a junction will often be) may be hard to detect or judge accurately because of the lack of realistic surrounding environment. The other is simply that the lower the fidelity of the environment, the less engaged participants may be with the task. This is particularly important in safety critical tasks – if drivers do not feel that they are surrounded by real vehicles in a realistic environment they may be prepared to take greater risks than they would in real life (Al-Shihabi & Mourant, 2003). In the current study, we have chosen to explore this possibility by systematically varying the visual fidelity of the simulator. This study therefore measured drivers' gap acceptance towards cars and motorcycles in a high-fidelity driving simulator with a 360-degree screen, and compared this with their performance in the identical task conducted in a medium-fidelity driving simulator with a 180-degree screen more similar to that which has been employed by previous authors.

1.3. The current study

Firstly, it was predicted that drivers will accept smaller gaps in front of motorcycles than in front of cars, using a more robust staircase procedure to measure individual drivers' gap acceptance thresholds.

Secondly, it is predicted that drivers' gap acceptance behaviour in the high-fidelity simulator will be closer to previous naturalistic results (Keskinen et al., 1998) compared to behaviour in the medium fidelity simulator, due to the increase in reality of the surrounding environment. We use two simulators which differ in fidelity, our medium fidelity simulator is similar to that used in previous research (Beanland et al., 2013; Mitsopoulos-Rubens & Lenné, 2012) however, our high-fidelity simulator has both a full field of view and an instrumented vehicle for full vehicle control.

As previous research has empathised the need to differentiate between gap acceptance and lag (Serag, 2015), the current study had four main dependent variables: Gap Acceptance Thresholds, Gap Accepted Lag, Time Difference and Cross Time. Gap Acceptance Thresholds were created using the QUEST adaptive staircase procedure (Watson & Pelli, 1983), estimating a distance where the driver was 50% likely to accept the gap. Gap Accepted Lag was the time of arrival of the target vehicle, when participants have accepted the gap in front of it. Time Difference was the time of arrival of the target vehicle, when the driver had cleared the junction. Cross Time was the amount of time it took the driver to complete the manoeuvre by crossing the junction.

2. Methods

2.1. Participants

Fifty-four participants took part in the study (27 in the high-fidelity simulator and 27 in the medium-fidelity simulator) based on a power analysis to detect a medium effect size, Cohen's f = 0.25 (This design provides good power to detect within-subjects differences and within-between subjects interactions, $1 - \beta = 0.95$, though it is underpowered to detect purely between subject effects, i.e. overall effects of simulator that apply to all conditions, $1 - \beta = 0.55$).

Twenty-seven participants completed the task in the high-fidelity simulator (Mean age = 22 yrs, SD = 3.49, Range = 18–31; Male = 16, Female = 11), and twenty-seven participants completed the task in the medium-fidelity simulator (Mean age = 22 yrs, SD = 3.12, Range = 18–27; Male = 12, Female = 15).

2.2. Design

The two independent variables of interest were Vehicle Type (car vs. motorcycle) and Driving Simulator (high fidelity vs. medium fidelity).

To allow comparison with previous studies, we calculated four main dependent variables of interest: Gap Acceptance Thresholds, Gap Accepted Lags (Beanland et al., 2013 and previously known as 'Time Gap' in Keskinen et al., 1998), Time Differences (Keskinen et al., 1998) and Cross Times (previously known as 'Turn Time' in Beanland et al., 2013; Keskinen et al., 1998). See Fig. 1.

Gap Acceptance Thresholds were the time (in seconds) that the vehicle from the right was from the junction where the driver was 50% likely to accepting the gap. This was the output of the QUEST adaptive staircase. The other three dependent measures were calculated using data from the 18 staircase trials, with the first 12 constant distances removed. This ensured that performance was only considered for trials where an effortful decision was made.

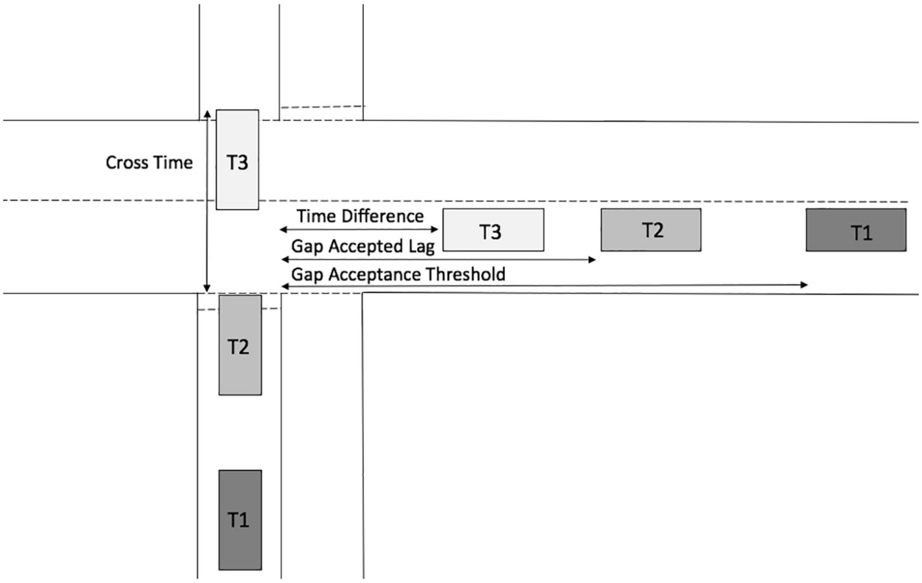

Fig. 1. This shows the approximate layout of the junction with the driver's vehicle and the oncoming vehicle from the right shown at three locations representing three separate time points (T1, T2, and T3) to help illustrate the different dependent variables. The Gap Acceptance Thresholds are a measure of how far the approaching vehicle needs to be from the centre of the junction to produce a 50% chance of the driver pulling out, represented by locations marked T1. The Gap Accepted Lag is how far the oncoming vehicle is from the centre of the junction when the driver subsequently enters the junction, represented by T2, and is only calculated on trials where the driver does accept the gap. On these trials, the Time Difference is how far the oncoming vehicle is from the centre of the junction when the driver reaches the point where the vehicle can pass, represented by locations marked T3. The Cross Time is the time from when the front of the drivers' car enters the junction (T2) to the moment where it has reached the point where the oncoming vehicle can pass without collision, also calculated from the front of the vehicle (T3). Unlike the previous two measures, this can be meaningfully calculated on occasions where the gap is not accepted by measuring the time to cross the equivalent distance when there is no longer any oncoming vehicle present. Note that although all four measures are represented as distances in this figure, the dependent variables are actually the time taken to travel these distances. Because the speed of the oncoming vehicle is constant the Gap Accepted Lag and Gap Acceptance Threshold are simply and linearly related to the distances shown, however the Time Difference and Cross Time will depend on the precise crossing behaviour of the driver on each trial.

The Gap Accepted Lags were calculated only for accepted gaps. The Gap Accepted Lag was the car or motorcycle's time-to-arrive at the centre of the junction at the moment where the front of the drivers' car had entered the junction by crossing the give way line. This depends on the Gap Acceptance Threshold and also the delay between the threshold and the manoeuvre by the driver.

The Time Difference was also only calculated for accepted gaps. The Time Difference is the car or motorcycles' time-to-arrive to the centre of the junction, measured at the point where the rear of the driver's car had cleared the point at the junction where the approaching vehicle would continue on an unimpeded path.

The Cross Time refers to the amount of time it took the driver's car from entering the junction (crossed the give way line) until when the rear of the driver's car had cleared the point at the junction where the approaching vehicle would continue on an unimpeded path. Therefore, Time Difference + Cross Time = Gap Accepted Lag.

The Gap Acceptance Thresholds, Gap Accepted Lag and Time Difference were analysed using a 2×2 mixed design ANOVA with a within factor of Vehicle Type (cars vs. motorcycles) and a between factor of Driving Simulator (high fidelity vs. medium fidelity).

The Cross Time was analysed using a $2 \times 2 \times 2$ mixed ANOVA with the additional factor of Driver Behaviour (before or after), which distinguishes whether the driver pulled out before or after the target vehicle had passed.

An adaptive staircase was used to estimate individual drivers' gap acceptance thresholds by manipulating the distance of the approaching vehicle. The staircase consisted of 12 initial trials (6 car, 6 motorcycle) which covered a range of constant distances to provide an initial estimate of each participants performance. Therefore, all participants completed an initial 12 trials with both a car and motorcycle placed at the following distances: 45 m, 55 m, 65 m, 75 m, 85 m and 95 m. The remaining 18 trials (9 car, 9 motorcycle) were at variable distances presented using a QUEST thresholding function implemented in Matlab (Kingdom & Prins, 2010).

The study used a QUEST adaptive staircase to estimate gap acceptance thresholds for cars and motorcycles separately for each participant. After each trial, the starting position of the vehicle from the right was adjusted. If participants had previously accepted a gap, the starting position was moved closer. If participants had waited for the vehicle to pass, the starting distance was increased. During the adaptive staircase procedure, drivers completed 30 trials in the driving simulator (15 for cars and 15 for motorcycles), estimating the gap acceptance threshold that offers 50% probability of accepting the gap, using the mode of the posterior probability density function. On all occasions, the staircases converged.

2.3. Apparatus

The experiment took place in Nottingham's Integrated Transport and Environment Simulation (NITES) facility, using both the high-fidelity driving simulator (NITES 1) and the medium-fidelity driving simulator (NITES 2). The high-fidelity simulator comprises of a full BMW Mini, housed within a projection dome and mounted on a six-degree motion platform with a 360-degree projection screen. The scenarios were formed on the screens using six projectors.

The medium-fidelity simulator is a fixed based driving simulator, consisting of a five-metre diameter hemicyclindrical screen, subtending 180-degrees, and a rear display screen. The scenarios were formed on the screens using three projectors. The fixed based driving rig consists of a car unit with adjustable seat, and a dashboard that included a steering wheel and speedometer. There was also a gear lever, brake, clutch and accelerator pedal for vehicle control.

XPI (XPI Simulation, London, UK) driving simulation software was used to create the scenarios. All scenarios were centered around the same intersection. The intersection was in an urban area, which was controlled by a 'Give way' sign. The intersection was a crossroad, therefore traffic could in principle be coming from the left, the right or straight ahead. This junction was chosen as it was flat junction, with houses either side of the road on the approach. The junction had equal visibility to the left and right, with all vehicles visible when the driver stopped at the junction.

On each trial, participants started 100 m from the junction, and the trial ended around 30 m after the participant had cleared the junction. Participants encountered two vehicles at the junction. Participants saw a car approaching from the left and a vehicle (car or motorcycle) approaching from the right. The car from the left was timed such that the driver always had to stop to allow it to pass. Each trial began with the car from the left placed 10 m away from the junction. This approach was introduced after a pilot study in which some volunteers adopted steadily increasing speeds approaching the junction in an attempt to clear predictable oncoming vehicles. After waiting for the vehicle from the left participants could then choose whether to pull out in front of the vehicle from the right, or to wait for it to pass.

On half the trials, the vehicle from the right was a car and on half the trials it was a motorcycle. This vehicle approached from one of 60 possible distances, ranging from 40 m to 100 m from the junction (1 m intervals). The exact distances each participant encountered were dependent on their responses on previous trials. The speed of the oncoming cars and motorcycles were kept constant, with both approaching at 30 mph. This is the average speed of these vehicles on British roads, with cars and motorcycles on average travelling at 30 mph (DfT, 2014).

2.4. Procedure

Participants completed a short 'Driving Experience' questionnaire and the 'The Extended Driver Behaviour Questionnaire' (Lajunen, Parker, & Summala, 2004), which is often used as a measure of self-reported violations, errors and lapses while driving. Following this, the primary task was explained to every participant by the following systematic instructions:

'In this experiment, you will encounter an intersection 30 times. Your task is to drive up to the junction at a speed of 20 mph and perform a manoeuvre at the end when it is deemed to be safe. You will always be going straight on at the junction. Shortly after clearing the junction, the scenario will end and the next scenario will begin. You must try and drive as naturally as possible throughout the experiment.'

Participants first completed the twelve constant distance trials, which also served as practice trials to allow the participants to become familiar with the simulator and the nature of the task. Participants then completed the remaining 18 trials, (9 cars, 9 motorcycles). To determine the next distance for each vehicle, this was calculated using the QUEST thresholding function from the Palamedes Matlab routine toolbox (Kingdom & Prins, 2010). Car and motorcycle trials were randomised. The whole experimental procedure lasted around 45 min.

3. Results

3.1. Driving experience

The twenty-seven participants in the high-fidelity simulator had held a driving licence for between 4 months and 13 years. They had a reported average annual mileage between 0 and 11,000 miles (Mean = 3823), a total mileage between 75 and 60,000 miles (Mean = 19,236) and reported an average of 321 hours travel per year.

The twenty-seven participants in the medium-fidelity simulator had held a driving licence for between 4 months and 10 years. They had a reported average annual mileage between 0 and 10,000 miles (Mean = 2710), a total mileage between 0 and 50,000 miles (Mean = 15,314) and reported an average of 360 hours travel per year.

Our sample thus over-represents relatively inexperienced drivers (those generally at highest risk of crash) but does include a wide range of driving experiences and the samples are well matched between the two simulator conditions.

Drivers' self-reported aggressive violations [t (52 = 1.84, $p = .07$], ordinary violations [t (52 = 1.22, $p = .23$], errors [t (52 = .84, $p = .40$] and lapses [t (52 = −.77, $p = .47$] on The Extended Driver Behaviour Questionnaire did not differ between the high-fidelity and medium-fidelity simulator group. These mean values were typical of previous research (Lajunen & Summala, 2003).

3.2. Gap acceptance thresholds

A main effect of Vehicle Type was found (F (1, 52) = 17.62, MSe = 41.76, $p < .001$), indicating that participants accepted significantly smaller gaps in front of motorcycles than in front of cars. There was no significant main effect of Driving Simulator [F (1, 52) = 1.25, MSe = 3194.58, $p = .16$], but there was a two-way interaction between Vehicle Type and Driving Simulator (F (1, 52) = 10.17, MSe = 41.76, $p < .01$), with the difference between cars and motorcycles being more pronounced in the high-fidelity simulator – see Fig. 2a.

The variance in thresholds was greater in the high-fidelity simulator than in the medium fidelity simulator so a log transformation of gap acceptance threshold data was conducted after which there was no longer a significant difference in variance between groups. There was a main effect of Vehicle Type found (F (1, 52) = 17.702, MSe = .001, $p < .001$). The main effect of Driving Simulator was not significant [F (1, 52) = 2.21, MSe = .031, $p = .14$]. The two-way interaction between Vehicle Type and Driving Simulator was significant (F (1, 52) = 11.55, MSe = .001, $p < .01$). A simple main effects analysis with Sidak correction was conducted. This revealed that the effect of vehicle type was mainly due to the differences found in the high-fidelity simulator. In the high-fidelity simulator, drivers' gap acceptance thresholds were significantly smaller for motorcycles than cars ($p < 0.01$) but that this was not significantly different in the medium fidelity simulator [$p = .57$]. An alternative way of conducting these comparisons would be to say that drivers' gap acceptance thresholds for cars were significantly higher in the high-fidelity simulator compared to the medium-fidelity simulator ($p < .05$), however, gap acceptance thresholds for motorcycles were not significantly different in the high-fidelity-simulator compared to the medium-fidelity simulator [$p = .37$].

3.3. Gap accepted lag

A main effect of Vehicle Type was found (F (1, 52) = 17.78, MSe = 56.49, p < .001), indicating that participants accepted significantly smaller gaps in front of motorcycles than in front of cars, however for this measure there were no significant effects of Driving Simulator or interactions involving this factor, see Fig. 2b.

3.4. Time difference

Again, a main effect of Vehicle Type was found (F (1, 52) = 16.15, MSe = 67.53, p < .001), indicating that the gap between the drivers' vehicle and approaching motorcycles are significantly smaller than approaching cars at the point the junction had been crossed, but there were no significant effects of Driving Simulator or interactions involving this factor, see Fig. 2c.

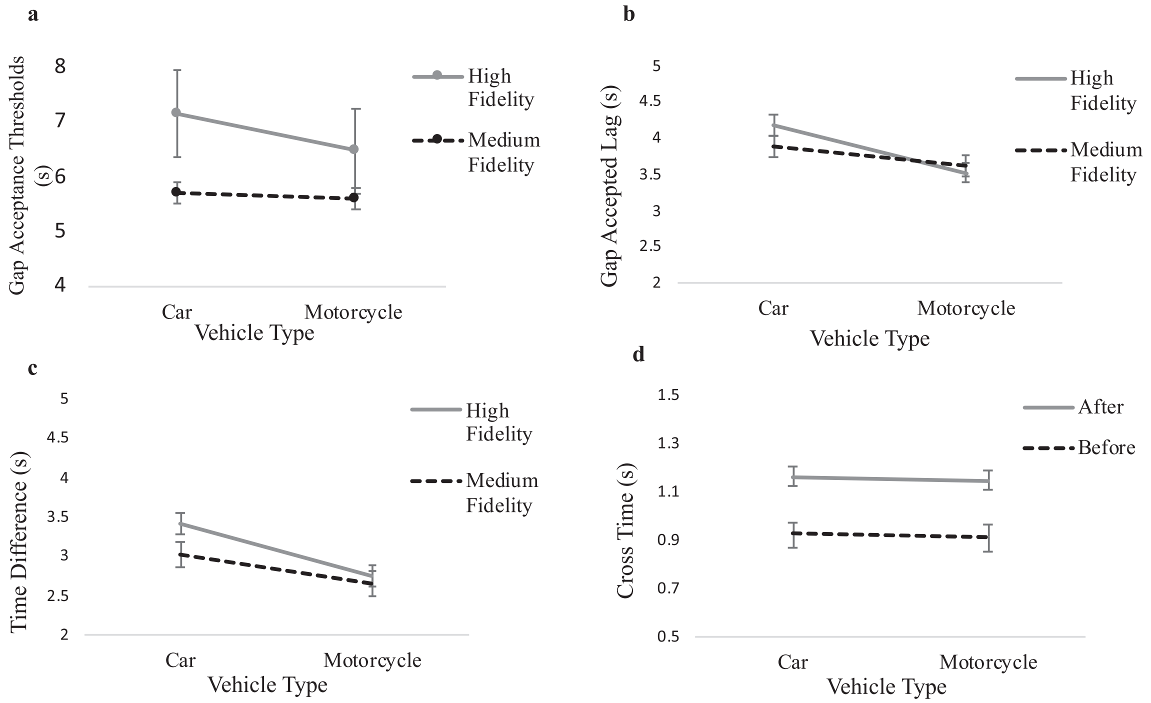

Fig. 2. (a) Shows the main effect of Vehicle Type and the interaction between Vehicle Type and Driving Simulator for Gap Acceptance Thresholds, (b) shows the main effect of Vehicle Type for Gap Acceptance Lag, (c) shows the main effect of Vehicle Type for Time Difference and (d) shows the main effect of Driver Behaviour for Cross Time. Error Bars show one standard error above and below the mean.

3.5. Cross times

A main effect of Driver Behaviour was found (F (1, 52) = 73.73, MSe = .40, p < .001), indicating that drivers cross the junction faster when pulling out before the vehicle than after the vehicle, see Fig. 2d. There were no significant effects of Vehicle Type, Driving Simulator or interactions involving these factors.

Cross Times were all calculated using the same formula irrespective of Vehicle Type. It must be noted that in practice, there is a slight difference in the time needed to physically cross the junction to reach the point where the approaching vehicle could continue on an unimpeded path, depending on the nature of the oncoming vehicle. As the physical width of a motorcycle is smaller than that of a car, it might be possible to safely cross in front of a motorcycle at a slightly smaller gap that that required for a car. This does of course assume that neither type of oncoming vehicle would modify its behaviour in any way, which is true in the simulator, but unlikely to be the case in the real world. Nonetheless, based on the actual size of cars and motorcycles in the simulation and the behaviour of our participants we calculated separate cross times for cars and motorcycles. On average the difference between these two times was 0.096 s, with cross times indeed being slightly lower for motorcycles than cars in all cases. There was no significant difference between this measure when it was calculated based on behaviour in the high-fidelity (.08) simulator compared to behaviour in the medium-fidelity (.11) simulator [t (26.2 = 1.01, p = .32].

3.6. Errors

On one occasion, out of a total of 1620 trials, a crash occurred with an oncoming vehicle. This was a motorcycle trial. Fig. 3 shows the view of the junction that was available to the driver on the particular trial where a crash occurred. The motorcycle was travelling at the standard 30 mph and started at 85 m from the junction. This was trial number 10 out of the 30 trials that were completed by the driver. This individual driver's threshold for motorcycles was calculated to be 83 m.

4. Discussion

The most immediate finding from the analysis is that despite the fact that motorcycles and cars were approaching the junction at identical speeds, participants accepted significantly smaller gaps in front of motorcycles than in front of cars but did not modify their behaviour by clearing the junction faster, leading to them passing motorcycles closer to the junction. This finding demonstrates that drivers in the study reliably leave a smaller safety margin when pulling out of a junction in

Fig. 3. An LBFTS error? This is the view to the right-hand side of the junction that was available to the driver on the particular trial where a crash occurred. This shows the oncoming motorcycle approaching the junction at the point the driver crossed the give way line, which subsequently resulted in a crash. The motorcycle was travelling at the standard 30 mph and there was no possible way in which the driver could have safely cleared the junction at this moment.

front of a motorcycle compared to a car. The finding that drivers adopt smaller safety margins around oncoming motorcycles than oncoming cars even in an environment where the behaviour of both vehicles has been kept identical is important and novel. It could, in part, explain the large number of crashes that occur at real junctions involving cars pulling out into the path of oncoming motorcycles.

In regard to drivers' junction cross times, the fact drivers are crossing the junction significantly faster when a vehicle is approaching compared to when the vehicle had passed the junction is comforting. This finding indicates that drivers are consciously modifying their behaviour in order to clear the junction quicker when they have pulled out before the oncoming vehicle – this shows that drivers are adjusting the dynamics of the behaviour in a way that is appropriate to the circumstances. Nonetheless, drivers' cross times did not differ dependent on what vehicle was approaching the junction. Therefore, although drivers are willing to accept smaller gaps in front of motorcycles than cars, they are not modifying their cross time behaviour to account for this. Even if we allow for a physical difference in crossing times between oncoming cars and motorcycles, this difference is less than 0.1 s. Although this may account for some small part of the difference between drivers' gap accepted lag for cars and motorcycles, it does not allow a difference of around half a second to be thought of as a rational adjustment to the actual vehicle sizes. If drivers do think they can clear oncoming motorcycles sooner than oncoming cars and using this idea to rationalise their behaviour they are clearly massively overestimating the true size of this difference.

The second immediate finding was that the difference between car and motorcycle gap acceptance thresholds was significant in the high-fidelity simulator but not in the medium-fidelity simulator. The significant difference in gap acceptance thresholds for cars and motorcycles in the higher fidelity simulator supports previous naturalistic findings that drivers leave a smaller time margin for motorcycles than cars (Keskinen et al., 1998). In addition, previous naturalistic research in the US, investigating drivers' gap acceptance towards cars have found that the average accepted gap is around 7.6 s (Tupper, 2011) and in simulation studies, a comparable measure of gap acceptance has been found at around 7–9 s for Australian drivers (Beanland et al., 2013). Drivers' gap acceptance in the current study for cars in the high-fidelity simulator was 7.1 s and in the medium-fidelity simulator was 5.6 s. This suggests that the behaviour witnessed in the high-fidelity simulator is more comparable to real world driving behaviour, with the gaps accepted in the medium-fidelity simulator being arguably relatively short.

This finding highlights problems with the previous methods used to investigate drivers' behaviour towards motorcycles at junctions. Static images and video clips may not provide the level of psychological reality, regarding how realistic and immersive the environment and task is, needed to elicit driving behaviour similar to that on real roads. One possibility is that in the medium-fidelity driving simulator, drivers are treating this environment more like a computer game, engaging in riskier behaviour that would not be witnessed in more immersive environments (Alexander, Brunyé, Sidman, & Weil, 2005). If this is indeed the case, then it is possible that the difference between gap acceptance between motorcycles and cars in the high-fidelity simulator is because the drivers feel at greater risk from approaching cars than approaching motorcycles. Where the feelings of risk are lower, in a medium fidelity simulator, the differences between vehicle types becomes less pronounced.

An alternative approach to thinking about the differences between the two simulators would relate to the visual field in which the drivers have access to. As the high-fidelity simulator has a visual field covering 360-degrees, all relevant background information surrounding the oncoming vehicle was available. However, as the medium-fidelity simulator only covers

180-degrees, in some instances the vehicles were near the edge of the display screen on the approach to the junction, therefore not all surrounding context was available. When judging the optic flow (pattern of apparent motion of objects in a visual scene), motion is easier to judge when there is relevant background information available. Research studies have found that drivers preferentially use optic flow information in time-to-collision estimates (McLeod & Ross, 1983).

However, it could be possible that if drivers' perception of optic flow is wrong, this will directly impact their sense of risk. Slater and Wilbur (1997) suggests that the immersiveness of the driving environment is dependent on factors such as the extent to which the visual display shuts physical reality out, the size of the field of view, and vividness of the display (resolution, richness, and quality) and levels of control. Therefore, if the optic flow was harder to judge in the medium-fidelity simulator, this may have caused risker behaviour compared to the high-fidelity simulator and real roads, with drivers accepting smaller gaps. Previous research also concerned with varying the visual components of the approaching motorcycle (e.g. headlights) has found that this changes the behaviour of the participants in terms of risk (Mitsopoulos-Rubens & Lenné, 2012). Although it is hard to see why this would change the size of the car-motorcycle difference in the two simulators, the present data do not allow for an unequivocal distinction to be made between these possible explanations. In future research, it would be interesting to take direct or indirect (e.g. skin conductance) measures of risk perception to see whether this does change as a function of vehicle type or simulator type.

In regards to previous naturalistic observation studies (Keskinen et al., 1998), drivers' gap accepted lags in the current study are shorter than those witnessed in naturalistic settings. For example, the gap accepted lag for cars in the high-fidelity simulator was around 4.1 s compared to 6.1 s (Keskinen et al., 1998). This however, seems to be due to the different manoeuvres taking place in these studies. The current study requires drivers to continue straight on at the junction however, in previous research the driver is required to make a right turn, therefore a full manoeuvre takes more time to complete in these instances. This can be reflected in the difference in cross times, with an average of 0.92 s in the current study and an average of 3.3 s in the naturalistic study (Keskinen et al., 1998).

In addition, the measures taken of gap accepted lag in naturalistic studies may be subtly different to specific measures taken in a driving simulator. In the driving simulation environment, the moment at which a driver's car has crossed the give way line can be exactly calculated however, in a naturalistic setting, video validation measures need to be in place to make sure the visually coded data accurately captures the driver's behaviour at the junction. Keskinen et al. (1998) used a single person for their final coding and stated that the observational data, in particular the visual attention measures, could only be estimated roughly. A more substantial reason for the difference may be our adaptive staircasing procedure. The current study's gap accepted lag was of course calculated only on trials which were around the drivers' gap acceptance threshold region, therefore it is likely that these times would be shorter than ones witnessed in everyday driving which will include large numbers of completely safe gaps.

When comparing the current findings to field studies conducted in developing countries, Ibrahim and Sanik (2007) found that drivers' gap acceptance was around 3.7 s for cars and 3.2 s for motorcycles, whereas Serag (2015) differentiated between gap acceptance and gap accepted lag, witnessing drivers' average gap acceptance around 4.8 s, and gap accepted lag around 3.9 s. These findings support the conclusions made by Serag (2015), suggesting that drivers from developing countries demonstrate risker behaviour at intersections than those witnessed in the current simulation study.

Regarding actual motorcycle accidents at junctions, the current study investigated drivers' gap acceptance behaviour as a function of approaching vehicle type. It was not expected that any of these scenarios would cause crashes, especially instances of 'Look But Fail To See' errors. While 'Look But Fail to See' errors might relate to specific occasions where the driver makes a clear and disastrous error, general differences in gap acceptance are more likely to have a small but continuous effect in increasing the risks faced by motorcyclists as opposed to cars approaching junctions. The current experiment involved multiple trials where the driver would quickly learn to expect two oncoming vehicles at every junction. We would thus expect that the drivers in our study would always look carefully at each approaching vehicle and make an informed decision about whether to accept or reject a given gap. However, one accident occurred with an oncoming motorcycle during the experiment. Given the shock and disbelief from the participant after the crash had occurred, is it possible that this could be an instance of a real LBFTS error. Fig. 3 is from a simulator replay of this trial, and shows the view that was available at the moment the driver pulled out into the junction. Although this was only one instance and should not be over-interpreted with respect to LBFTS errors, it is nonetheless surprising given the current task. The driver seemed to be attentive and behaving normally in all other ways, but still pulled out in front of a motorcycle that should have been fully visible to them.

In order to develop strategies that can support drivers' decision making at intersections, future research may need to further investigate whether this inherent difference in gap acceptance towards cars and motorcycles is due to an attitude bias or a perceptual bias. An attitude bias suggests that drivers perceive motorcycles to be less threatening compared to cars, displaying a basic human instinct of self-preservation, as a crash with a car may cause more harm to the driver compared to a crash with a motorcycle (Simmel, 1944). This could also explain the significantly larger gap acceptance for cars in the high-fidelity simulator compared to the medium-fidelity simulator, as an oncoming car in a more immersive environment may be seen as potentially more threatening. The perceptual bias explanation may suggest that drivers have a difficulty in judging the distance or speed of the motorcycle compared to the car. This effect is commonly known as the size-arrival effect, referring to the illusion of a smaller vehicle seeming further away than it actually is (Horswill, Helman, Ardiles, & Wann, 2005). A literature review focusing on gap acceptance studies (Pai, 2011), found that a speed/distance judgement error is likely to be attributable to larger vehicles being perceived as more threatening than motorcycles.

However, it should be pointed out that many of the included studies were not experimental studies, used static or intermittent stimuli and used varied tasks to investigate gap acceptance. To fully explore this possibility, it would be necessary to systematically vary the sizes of vehicle, the speeds they are travelling at, and the distances they start at to unconfound the various effects.

5. Conclusions

In summary, this study has provided evidence to suggest that drivers accept smaller gaps at junctions in front of motorcycles compared to cars. This noted difference suggests that the disproportionate number of accidents involving motorcycles at junctions may be partly attributed to inappropriate gap selection by drivers. The significant difference in drivers' gap acceptance thresholds for car and motorcycles in the high-fidelity simulator but not the medium-fidelity simulator suggests that future research investigating drivers' behaviour at junctions needs to be conducted in a realistic and immersive driving environment in order to generalise to real on-road driving.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.trf.2018.07.023.

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