The effect of lighting conditions and use of headlights on drivers’ perception and appraisal of approaching vehicles at junctions

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ABSTRACT
Use of Daytime Running Lights (DRL) is mandatory in many countries for motorcycles, and in some for cars. However, in developing countries, DRLs may be optional or compliance low. The effect of car or motorcycle headlights and lighting conditions on Malaysian drivers’ ability to perceive and judge the safety of pulling out was investigated. Stimuli were photographs depicting either daytime or nighttime taken at a T-junction with approaching vehicles with headlights on or off. Headlights improved drivers’ ability to perceive cars and motorcycles in the nighttime photographs but not the daytime photographs, although this could be due to the bright weather in the photographs. Drivers judged it less safe to pull out when approaching motorcycles had headlights on than off, regardless of the lighting conditions, supporting the utility of DRL for motorcycles. Headlights did not affect judgements for cars, questioning the utility of DRL for cars.

Practitioner Summary: The effect of headlights and lighting conditions on drivers’ ability to perceive and make judgements about the safety of pulling out was investigated. Daytime Running Lights influenced drivers’ decision-making about the safety of pulling out in front of motorcycles, illustrating the importance of having automatic headlights equipped.

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1. Introduction
The right-of-way violation is the most common type of collision involving motorcycles. It happens when vehicles fail to give way and pull out at a junction in front of a motorcycle that is approaching on the main carriageway (Clark et al. 2004). Crundall, Humphrey, and Clarke (2008) proposed that there are three key behaviours that drivers need to carry out in order to avoid such collisions at junctions. These include looking in the right direction from where the approaching vehicle is coming, being able to perceive the approaching vehicle, and making the correct judgement about the safety of pulling out. As, typically, real-world driving requires all of these processes to occur near simultaneously, it is not clear to what extent each of these behaviours contributes to the relatively large number of right-of-way violations involving motorcycles.

Crundall, Humphrey, and Clarke (2008); see also Lee, Sheppard, and Crundall (2015) devised a method to separate out the role of failures in perceiving approaching vehicles versus failures to make appropriate judgements about the safety of pulling out. Car drivers were presented with photographs, taken from the point of view of a car that has arrived at a T-junction, the driver of which is looking to the right into the main carriageway to check for oncoming traffic (equivalent to US drivers turning left in the same T junction scenario). Some of the photographs displayed oncoming cars at various distances while others displayed motorcycles, or no vehicle at all. In the first experiment, which isolated the role of perceptual abilities, participants saw each photograph for only 250 ms to simulate a single glance at the junction and were asked to judge whether or not a vehicle was present. In the second experiment, which considered appraisal processes, the same photographs were presented for 5 s (sufficient time for any vehicle to be perceived) and drivers were invited to judge whether or not it was safe to pull out. These studies demonstrated that drivers were better at perceiving approaching cars than motorcycles but there was no vehicle effect when deciding whether or not it was safe to pull out. Based on this, Crundall, Humphrey, and Clarke (2008) argued that the relatively large number of right-of-way violations involving motorcycles is likely to be due to perceptual failures, rather than faulty decision-making about the safety of pulling out.
Using the same methodology, it is possible to investigate how other factors known to affect accident rates for cars and motorcycles influence perceptual and appraisal processes independently. In this paper, we consider two such factors associated with the luminance of the environment itself: whether the photo depicts daytime or nighttime conditions, and the use of vehicle headlights. According to Plainis and Murray (2002), at nighttime there is a decrease in target visibility associated with the low luminance conditions, causing an increase in drivers' reaction times and more accidents. Data from various countries shows that more accidents happen at nighttime as compared to daytime (Abdul Manan and Várhelyi 2012; Clarke et al. 2006; Laapotti and Keskinen 1998; Williams 2003).

While detection may be generally poorer under low luminance conditions, other research suggests that the contrast between the vehicle and background has an important impact on its conspicuity (luminance contrast theory). Hole et al. (1996) found that increasing the luminance contrast (between target object and background) increased motorcycle detection more than solely increasing the luminance itself. If this is true, vehicles with their headlights switched on should be relatively easy to detect and especially when it is dark. Use of vehicle headlights is obligatory in all countries at nighttime and in some during daytime (Daytime Running Lights, DRL). Several countries make it mandatory for motorcyclists to switch on their headlights regardless of time of day, such as Belgium, France, Spain, Germany, Greece, Brazil, Chile and Singapore (Ferraz, Bezerra, and Bastos 2010; Nazïf-Munoz, Quesnel-Vallée, and van den Berg 2015; SWOV 2013; Yuan 2000), and there is support for the notion that this has resulted in significant reductions in the number of accidents (Henderson et al. 1983). Many countries have implemented ‘Automatic Headlamp On’ (AHO) for motorcycles, which is a switch that ensures that the (main or dipped beam) headlight (or the DRL) is always on when the engine is running. For instance, the US, Japan, Europe, Australia and Canada all have mandatory AHO (OECD/ITF 2015; Paine et al. 2005), and India is soon to introduce this (Vijayraghvan 2016). However, AHO is not mandatory across all parts of the world and particularly in low- and middle-income countries (OECD/ITF 2015). Several studies have reported that increasing the conspicuity of motorcycles using DRL increases drivers’ ability to detect their presence using various methods, including interviews (Janoff 1973; Janoff and Cassel 1971; Kirkby and Fulton 1978; Ramsey and Brinkley 1977) and experimental designs (Hole 1996; Hole and Tyrrell 1995). These previous studies have tended to focus on motorcycles and not cars, presumably because motorcyclists are vulnerable and harder to detect, perhaps with the assumption that DRL could not further improve detection of cars.

While previous research supports the notion that day or nighttime conditions and use of headlights influence drivers’ ability to perceive vehicles, less is known about how these factors may influence decision-making about safety independently of perceptual failures. Clarke et al. (2006) argued that the difference in accident rate associated with time of day is not due to low visibility during dark conditions, but a consequence of higher voluntary risk-taking behaviour at nighttime. However, this may not be a consequence of the dark conditions but rather other factors associated with nighttime driving such as lower traffic volume resulting in higher speeds, increased fatigue levels and higher rates of drink-driving. Therefore, it is not clear whether nighttime conditions in the absence of these other factors would foster more risky decision-making.

Malaysia has had the highest road fatality risk (deaths per 100,000 population) in the world since 1996 and a constant increase in road fatalities of 4% in every year in the last 7 years; more than 50% of the fatalities were motorcyclists (Abdul Manan and Várhelyi 2012). Around 28% of these motorcycle accidents involve collisions with cars (Abdul Manan and Várhelyi 2012). As in many countries, the fatality rates vary according to the time of day. For instance, Abdul Manan and Várhelyi (2012) reviewed accident data from years 2000 to 2009 in Malaysia and separated it into 2-h bands starting from 12 to 2 am. They report that fatalities were highest between 4 and 10 pm (10.2% from 4 to 6 pm; 12.4% from 6 to 8 pm and 12.7% from 8 to 10 pm, respectively), which are dusk and dark hours, although overall more motorcycle fatalities occurred during the daytime than the nighttime (55.6%). In September 1992, Malaysia introduced the use of DRL in motorcycles as a compulsory regulation in the country. Radin Umar, Mackay, and Hills (1996) reviewed accident data before and after 1992 and concluded that the accident rate for motorcyclists in Malaysia significantly decreased by 29% after the DRL implementation.

Motorcycle manufacturers in Malaysia have implemented Automatic Headlamp On since the regulation was implemented. However, despite this being the case, in a recent on-road observational study it was reported that among 1850 motorcycles, about 20.27% failed to have their headlights switched on during off peak daytime hours and clear weather (Abdul Manan and Várhelyi 2015). Given that motorcycle manufacturers have included AHO for many years now, it seems likely that most of these motorcyclists that were observed with the headlights off either had not maintained the headlights in working order or were too old to have headlights wired in – raising the possibility that these riders are also not using headlights at nighttime. Assuming that DRL has decreased accidents involving motorcycles, the question remains whether this
improvement is due to an increase in their being perceived by other drivers or a tendency for other drivers to be more cautious when making judgements about safety in relation to them.

This study aimed to investigate the interaction between the effect of headlights and lighting conditions depicted in the photographs on Malaysian drivers’ ability to perceive approaching vehicles, and on the judgements they make about the safety of pulling out in front of them. The same methodology developed by Crundall, Humphrey, and Clarke (2008) was used where drivers viewed images of approaching cars or motorcycles, which were located at three different distances. These images were edited so that they either appeared to be shot under daytime (light) conditions or nighttime (dark) conditions, and so that the approaching vehicles’ headlights were either on or off. As in Crundall, Humphrey, and Clarke (2008), in the first experiment, images were presented briefly and participants were asked to detect the presence of an approaching vehicle while in the second experiment, the images were presented for much longer and participants were asked to judge whether or not it was safe to pull out. Our first hypothesis predicted that drivers would generally find it easier to perceive vehicles in the daytime than nighttime photographs. According to luminance contrast theory, there should be an advantage for perceiving vehicles with headlights on rather than off (second hypothesis), but this should be greater for the nighttime than daytime photographs (third hypothesis). Given that cars are more conspicuous than motorcycles, DRL for approaching cars may have less impact than for motorcycles, which would be demonstrated by a three-way interaction between use of headlights, lighting conditions and vehicle type (fourth hypothesis).

In relation to making judgements about the safety of pulling out, based on Clarke et al. (2006), it is possible that drivers will make more risky decisions for the nighttime photographs, i.e. they might be more likely to say they would pull out in front of vehicles when it is dark. On the other hand, drivers might find the vehicles’ distance harder to judge within the nighttime stimuli and as a consequence be more cautious in their decisions than for the daytime stimuli, i.e. be less likely to say they would pull out. Therefore, the first hypothesis, which was two-tailed, stated that there will be a significant difference in judgements of safety of pulling out for daytime and nighttime photographs. The second hypothesis stated that if drivers are more cautious in their decisions for the nighttime stimuli, we would also expect drivers to make more conservative judgements (be less likely to judge it safe to pull out) when the headlights are off than on.

2. Experiment 1: how lighting conditions depicted in the photographs and the use of headlights affect drivers’ ability to perceive approaching vehicles at junctions

2.1. Methods

2.1.1. Participants

Nineteen drivers (10 females and 9 males) were recruited in this experiment. Their average age was 21.37 years (SD = 2.01 years) ranging from 19 to 27 years old and they reported an average of 3.25 years of active driving experience since getting their driving license in Malaysia (SD = 2.35 years). All reported normal or corrected-to-normal vision and were not colour blind. All participants reported no experience of riding a motorcycle.

2.1.2. Design

A 2 × 3 × 2 × 2 within-subjects design was used. There were four independent variables: type of approaching vehicle (car or motorcycle; ‘no vehicle’ trials were used as controls but do not contribute to the analysis); distance of approaching vehicle (near, intermediate or far); lighting conditions depicted in the photographs (daytime or nighttime); vehicle headlights (on or off). See Table 1 for an illustration of all independent variables. The dependent variable was the accuracy in perceiving an approaching vehicle.

| Distances/vehicle type/time of day/headlights | Near Car Day On | Near Motorcycle Day On | Intermediate Car Day On | Intermediate Motorcycle Day On | Far Car Day On | Far Motorcycle Day On |
|--------------------------------------------|-----------------|------------------------|--------------------------|-----------------------------|----------------|-----------------------|
| Day Headlights on                           | Near Car Day On | Near Motorcycle Day On | Intermediate Car Day On | Intermediate Motorcycle Day On | Far Car Day On | Far Motorcycle Day On |
| Headlights off                              | Near Car Day Off| Near Motorcycle Day Off| Intermediate Car Day Off| Intermediate Motorcycle Day Off| Far Car Day Off| Far Motorcycle Day Off|
| Night                                      | Near Car Night On| Near Motorcycle Night On| Intermediate Car Night On| Intermediate Motorcycle Night On| Far Car Night On| Far Motorcycle Night On|
| Heads lights off                            | Near Car Night Off| Near Motorcycle Night Off| Intermediate Car Night Off| Intermediate Motorcycle Night Off| Far Car Night Off| Far Motorcycle Night Off|

Table 1. An illustration of 16 different conditions.
vehicle. Three hundred and twenty trials were presented across two different blocks (daytime and nighttime). The trials were blocked to simulate real life, where it does not suddenly change from day to night and vice versa. In addition to this reason, it was also taken into account that participants might have to adapt their pupil size while looking at brighter vs. darker pictures, which could have interfered with performance if the trial types were interlaced (Konstantopoulos, Chapman, and Crundall 2010). Therefore, we separated the stimuli into two blocks.

Each 160-trial block (daytime or nighttime) included 30 trials without approaching vehicles (3 repetitions for each stimulus) and 120 trials with approaching vehicles (car or motorcycle) which consisted of 60 trials where cars had headlights on and 60 with headlights off. These approaching vehicles trials were presented at ‘near’, ‘intermediate’ and ‘far’ distances for each condition. The remaining 10 trials were ‘catch trials’ which were used to make sure that drivers’ eyes were focused on the left edge of the screen ensuring a realistic starting location (Crundall, Humphrey, and Clarke 2008; Lee, Sheppard, and Crundall 2015). Following previous studies, data of participants who scored lower than 40% in the catch trials were to be excluded. However, no participant scored less than 40% in this experiment and therefore no data were excluded.

### 2.1.3. Stimuli

The day versions of photograph stimuli were taken from the viewpoint of a driver who was looking towards the right while approaching various T-junctions in Malaysia (University of Nottingham roads, Broga roads and Serdang roads). The same cars and motorcycles used in Crundall, Humphrey, and Clarke (2008) were edited onto these roads at locations of near, intermediate and far. The same 70 photograph stimuli (10 roadways × 2 vehicle types × 3 distances + 10 empty versions of each road as control pictures) were edited to create nighttime versions using Photoshop CS6 by decreasing the brightness and exposure of the pictures, thus creating another 70 photograph stimuli for the nighttime versions. These 120 photograph stimuli with approaching vehicles (60 daytime and 60 nighttime) were then edited to create a set of stimuli where the approaching vehicles had the headlights on. In order to do this, the daytime stimuli with headlights on were created by increasing the brightness of the headlights (with the Dolge tool using settings of midtones for range, 100% exposure with 10 clicks applied to each headlight), to ensure a difference between headlights on and off for daytime stimuli. These set of headlights were then copy pasted to replace the headlights of vehicles in the nighttime stimuli to create the headlights in the nighttime versions. This was also to ensure that the brightness of headlights was controlled in all pictures. All stimuli were edited by the researcher and were 720 × 540 pixels (see examples in Figure 1).

### 2.1.4. Procedure

The procedure of this experiment was similar to Crundall, Humphrey, and Clarke (2008) and Lee, Sheppard, and Crundall (2015). Participants were first asked to fixate on a fixation cross of variable duration (500, 1000, 1500 ms) that appeared at the left of the screen prior to the presentation of each picture. Upon picture onset, participants were asked to identify whether there was an oncoming vehicle approaching them from the right, and to respond as quickly as possible by pressing 0 on the numerical keypad of a computer keyboard if the road was empty, or 2 if a vehicle was approaching. They were also required to abort catch trials where the fixation cross changed shape prior to picture presentation (from a ‘+’ to a ‘×’). Catch trials were correctly aborted by pressing the space bar on the keyboard.

The picture stimuli were each presented for 250 ms, following the variable-duration fixation cross, to simulate a single fixation on the picture. Following offset of each picture, participants were presented with a prompt screen detailing the appropriate buttons to press in order to make correct responses. Consistent with previous studies using similar methodology (e.g. Crundall, Humphrey, and Clarke 2008; Lee, Sheppard, and Crundall 2015), they were presented with visual feedback of the response accuracy before the fixation cross appeared signalling the start of the next trial.

Two blocks of trials were presented (daytime photographs and nighttime photographs). Counterbalancing was used such that half of the participants completed the daytime block first and the other half completed the nighttime block first. Participants were given a practice block of 10 trials (mixture of daytime and nighttime stimuli) before the two blocks of the experiment started, and a self-paced break was allowed between the two experimental blocks. The experiment was carried out for all participants during daytime and in the same room with the same lighting conditions.

### 2.2. Results

The data for all 19 participants were subjected to a 2 × 3 × 2 × 2 analysis of variance (ANOVA) comprising percentage accuracy for spotting an approaching vehicle for different vehicle types (car or motorcycle) at different distances (near, intermediate or far), for daytime or nighttime photographs with the headlights on or off. A normality test revealed that the data are not normally distributed, Kolmogorov-Smirnov, p < .05, however, ANOVA was performed due to the multifactorial nature of the design and
Interactions were subsumed by a three-way interaction between vehicle type, vehicle distance and lighting conditions, $F(2, 36) = 4.77, p < .05, \eta_p^2 = .209$ (see Figure 2). To further investigate the three-way interaction, two $3 \times 2$ ANOVAs were carried out to investigate the effect of vehicle type and vehicle distance for daytime and nighttime photographs separately. For daytime photographs, a main effect of vehicle type was found, whereby cars were easier to perceive than motorcycles, $F(1, 18) = 32.70, p < .001, \eta_p^2 = .645$. There was also a main effect of distance, $F(2, 36) = 54.54, p < .001, \eta_p^2 = .752$, where bonferroni pairwise comparisons revealed that approaching vehicles were easier to perceive at intermediate than far ($p < .001$), and near than far ($p < .001$) but there was no difference.
between near and intermediate locations ($p > .05$). An interaction between vehicle type and vehicle distance was also found for daytime photographs, $F(2, 36) = 14.77$, $p = .001$, $\eta^2_p = .451$. Paired-samples t-tests revealed that cars were easier to perceive than motorcycles but only at the far distance, $t(18) = 4.69$, $p < .001$, $d = .966$. For nighttime photographs, only a main effect of vehicle distance was found, $F(2, 36) = 38.88$, $p < .001$, $\eta^2_p = .684$. Bonferroni pairwise comparisons revealed that approaching vehicles located at near distances were easier to perceive than at intermediate ($p < .05$), intermediate were easier to perceive than far ($p < .001$), and near were easier to perceive than far ($p < .001$).

There was also a two-way interaction between vehicle distance and use of headlights, $F(2, 36) = 40.72$, $p < .001$, $\eta^2_p = .003$; and another interaction was found between the lighting conditions depicted in the photographs and use of headlights, $F(1, 18) = 122.88$, $p < .001$, $\eta^2_p = .872$. These interactions were also subsumed by a three-way interaction between vehicle distance, headlights and the lighting conditions depicted in the photographs, $F(2, 36) = 24.69$, $p < .001$, $\eta^2_p = .578$ (see Figure 3). For both the daytime and the nighttime photographs there was a main effect of vehicle distance, $F(2, 36) = 54.54$, $p < .001$, $\eta^2_p = .752$ for daytime and $F(2, 36) = 39.01$, $p < .001$, $\eta^2_p = .684$ for nighttime. For daytime stimuli, there was a trend towards it being easier to detect vehicles with the headlights on than off, $F(1, 18) = 3.42$, $p = .08$, $\eta^2_p = .159$ whereas for nighttime stimuli there was a much stronger main effect of headlights, $F(1, 18) = 119.75$, $p < .001$, $\eta^2_p = .869$, whereby vehicles with the headlights on were easier to perceive than those with headlights off at all three distances. For nighttime photographs, there was also an interaction between vehicle distance and headlights, $F(2, 36) = 42.20$, $p < .001$, $\eta^2_p = .701$. One-way ANOVAs revealed that for nighttime photographs, there was a main effect of vehicle distance only when the headlights were off, $F(2, 36) = 41.72$, $p < .001$, $\eta^2_p = .699$, while there was no effect of vehicle distance when the headlights were on. A summary of the full analyses shown in Table 3.

### 2.3. Discussion

As in Crundall, Humphrey, and Clarke (2008) and Lee, Sheppard, and Crundall (2015), for the daytime photographs, drivers were more likely to perceive approaching cars than motorcycles (Walton, Buchanan, and Murray 2013) and nearer approaching vehicles than further. However, for the nighttime photographs there was no effect of vehicle type, regardless of the usage of headlights. Crundall, Humphrey, and Clarke (2008) previously suggested that cars have lower spatial frequency, so are easier to perceive in peripheral vision than motorcycles...
which have higher spatial frequency. This difference in spatial frequency may not matter when the objects in question are very easy to perceive (nighttime with headlights on) or difficult (nighttime with headlights off). Moreover, although vehicle distance influenced perception for nighttime photos when the vehicle had the headlights off, it did not affect performance for nighttime photographs with headlights on. In this latter context, it is not clear whether drivers were able to perceive the approaching vehicles or whether their judgements were only based on the presence of lights. However, in real driving conditions, the presence of lights would almost always indicate the presence of approaching vehicles so reliance on lights as a cue to a vehicle’s presence should be sufficient to avert an accident.

The first hypothesis was only partially supported in that approaching vehicles were easier to perceive in the daytime photographs than in nighttime photographs when the headlights were off, but not when the headlights were on. Likewise, headlights improved the perception of approaching vehicles in nighttime stimuli but only showed a non-significant trend towards improving perception in the daytime stimuli, offering only partial support for hypothesis 2, but consistent with the prediction that headlights would have greater effect at nighttime (hypothesis 3). This might be explained by the luminance contrast theory (Shapley and Enroth-Cugell 1984), which suggests that the difference in brightness of the headlights and the dark background images will maximise vehicle conspicuity. Our final prediction was that the effect of DRL on detection of approaching cars may be less than for motorcycles. However, in this study, headlights had no significant effect on detection during the daytime for either vehicle type – therefore the fourth hypothesis was not supported.

The findings of the current study emphasise the importance of switching on headlights while driving at night, as if there is a failure to do so, drivers will be less able to perceive them. However, for daytime stimuli, where the luminance contrast is less, participants’ perception was not significantly affected by the headlights. This could be due to the brightness of the stimuli (as all photos depicted sunny days and clear weather), so switching on

### Table 3. Summary of full analyses for Experiment 1.

| **Main effects** | Day | Night |
|------------------|-----|-------|
| Vehicle distance | F(2, 36) = 99.79, p < .001, η² = .847 | |
| Vehicle type | F(1, 18) = 11.46, p < .005, η² = .389 | |
| Time of day | F(1, 18) = 64.57, p < .001, η² = .782 | |
| Headlights | F(1, 18) = 102.73, p < .001, η² = .851 | |
| **Two-way interactions** | Day | Night |
| Vehicle distance × headlights | F(2, 36) = 4.83, p < .05, η² = .212 | |
| Vehicle type × time of day | F(2, 36) = 4.96, p < .05, η² = .322 | |
| Vehicle distance × headlights | F(2, 36) = 40.72, p < .001, η² = .003 | |
| Time of day × headlights | F(1, 18) = 122.88, p < .001, η² = .872 | |
| Time of day × vehicle distance | NS | |
| Vehicle type × headlights | NS | |
| **Three-way interactions** | Day | Night |
| Vehicle type × vehicle distance × time of day | F(2, 36) = 4.77, p < .05, η² = .209 | |
| Vehicle type | F(2, 36) = 32.70, p < .001, η² = .645 | |
| Vehicle distance | F(2, 36) = 54.54, p < .001, η² = .752 | |
| Vehicle type × vehicle distance | F(2, 36) = 14.77, p < .001, η² = .451 | |
| Vehicle type only at far | t(18) = 4.69, p < .001, d = .966 | |
| Vehicle distance × headlights | F(2, 36) = 24.69, p < .001, η² = .578 | |
| **Four-way interaction** | Day | Night |
| Vehicle type × vehicle distance × headlights | NS | F(2, 36) = 39.01, p < .001, η² = .684 |
| Vehicle type × headlights × time of day | NS | F(1, 18) = 119.75, p < .001, η² = .869 |
| Vehicle type × vehicle distance × time of day | NS | F(2, 36) = 42.20, p < .001, η² = .701 |
| Vehicle type × vehicle distance × time of day × headlights | NS | F(2, 36) = 41.72, p < .001, η² = .699 |
headlights might still increase drivers’ ability to perceive during duller and rainy days. On the other hand, it is possible that there were ceiling effects for the daytime photographs, masking any advantage conferred by headlights. The fact that there was a non-significant trend towards performance being better in the daytime with headlights on suggests that there is some perceptual advantage conferred by DRL which might become more apparent if the detection task was sufficiently difficult. As recent research suggests relatively high rates of non-compliance with DRL for motorcyclists in Malaysia, despite AHO being in place for many years, the current study highlights the importance of encouraging motorcyclists to maintain their headlights in a good state of repair. Even if a driver accurately perceives an approaching vehicle, an accident could still occur if he or she makes the wrong decision about the safety of pulling out (Crundall, Humphrey, and Clarke 2008). Therefore, the next study investigated how conspicuity influences safety judgements. Using the same stimuli, a modified version of the second experiment of Crundall, Humphrey, and Clarke (2008) was conducted to investigate how lighting conditions depicted in the photographs and use of headlights interact with vehicle types and distances in affecting drivers’ judgements about the safety of pulling out at junctions. A two-tailed hypothesis was made in relation to the effect of lighting conditions shown in the photographs. Drivers might be more likely to say they would pull out in front of vehicles in nighttime than daytime photographs due to more risk-taking behaviour (Clarke et al. 2006). Alternatively, drivers might find it harder to judge the distance of approaching vehicles in the nighttime photographs and hence be more cautious in their decisions than for daytime, and say it is less safe to pull out (first hypothesis). The second hypothesis was that if drivers are using a more cautious approach for the nighttime stimuli, they would also be more conservative in their judgements (be less likely to judge it safe to pull out) when the headlights are off than on.

3. Experiment 2: how lighting conditions depicted in the photographs and use of headlights affect drivers’ judgements about the safety of pulling out at junctions

3.1. Methods

3.1.1. Participants

Nineteen drivers (10 females and 9 males) were recruited in this experiment. Their average age was 21.68 years (SD = 3.2 years) ranging from 17 to 28 years old and they reported an average of 3.07 years of active driving experience since getting their driving license in Malaysia (SD = 3.43 years). All reported normal or corrected-to-normal vision and were not colour blind. All participants reported no experience of riding a motorcycle and they did not take part in Experiment 1.

3.1.2. Design

The design of this experiment was similar to Experiment 1. A 2 × 3 × 2 × 2 within-subjects design was used. There were four independent variables: type of approaching vehicle (car or motorcycle); distance of approaching vehicle (near, intermediate or far); the lighting conditions depicted in the photographs (daytime or nighttime); and headlights (on or off). The dependent variable was participants’ judgements about whether it was safe to pull out from the junction.

A total of 300 trials (150 trials in day block and 150 trials in night block) were presented. Two hundred and forty trials were presented with an approaching vehicle included and 60 trials were presented without any approaching vehicles, with three repetitions for each image (10 daytime stimuli and 10 nighttime stimuli). Counterbalancing was used whereby participants either completed the 150 trials for the daytime first, followed by the 150 trials for the nighttime or vice versa. Just like Crundall, Humphrey, and Clarke (2008) and Lee, Sheppard, and Crundall (2015), the fixation cross was located in the middle of the screen.

3.1.3. Stimuli and procedure

The same stimuli from Experiment 1 were presented without catch trials. As in Crundall, Humphrey, and Clarke (2008) and Lee, Sheppard, and Crundall (2015), participants were asked to press 0 for ‘safe’ to pull out and 2 for ‘not safe’ to pull out. Picture stimuli were presented in random sequence for 5000 ms each. This presentation time was used to ensure that any differences in judgements were not due to a failure to perceive the approaching vehicles and all participants made a response within the time frame. Visual feedback of the decision they made was given to the participants for each trial (e.g. ‘You said pull out’ or ‘You said do not pull out’). Participants were given a practice block of 10 trials before the experiment started.

3.2. Results

The data for all 19 participants were subjected to a 2 × 3 × 2 × 2 ANOVA comprising percentage of judgements that it was safe to pull out in front of an approaching vehicle for different vehicle types (car or motorcycle) at different distances (near, intermediate or far), for daytime or nighttime photographs with headlights on or off. Normality test revealed that the data is not normally distributed, Kolmogorov-Smirnov, \( p < .05 \). As in Experiment 1, ANOVA was conducted due to the multifactorial design and its robustness in handling data which is not normally distributed (Ziegler, Danay, and Bühner 2010). Mean
percentage of judgements that it was safe to pull out in front of an approaching vehicle and standard deviations are shown in Table 4.

The ANOVA identified three main effects. First, there was a main effect of vehicle distance, $F(2, 36) = 204.07$, $p < .001$, $\eta^2_p = .919$. Secondly, there was a main effect of vehicle type, $F(1, 18) = 6.27$, $p < .05$, $\eta^2_p = .258$. Thirdly, there was a main effect of the use of headlights, $F(1, 18) = 6.97$, $p < .05$, $\eta^2_p = .279$.

Two two-way interactions and a three-way interaction were found. One two-way interaction was between vehicle type and vehicle distance, $F(2, 36) = 3.72$, $p < .05$, $\eta^2_p = .154$; and the other was between vehicle type and headlights, $F(1, 18) = 5.04$, $p < .05$, $\eta^2_p = .219$. These were subsumed by a three-way interaction between vehicle type, vehicle distance and headlights, $F(2, 36) = 4.11$, $p < .05$, $\eta^2_p = .186$ (see Figure 4). This interaction appears to arise from the fact that drivers were more likely to judge it was safe to pull out in front of an approaching motorcycle with headlights off than on specifically at the intermediate distance, $t(18) = 5.64$, $p < .001$, $d = .712$ while no such effect was observed at the other distances or for cars at any distance. A summary of all analyses is shown in Table 5.

3.3. Discussion

Drivers were more likely to judge it was safe to pull out in front of further approaching vehicles than nearer, consistent with previous research (Crundall, Humphrey, and Clarke 2008; Lee, Sheppard, and Crundall 2015). However, contrary to our first hypothesis, there was no difference in judgements made for daytime and nighttime photographs. This suggests that the more risky behaviour observed in drivers at nighttime (Clarke et al. 2006) is not because of the low luminance conditions themselves, but due to other associated factors such as higher levels of fatigue or drink-driving at this time of day. However, as the judgements were the same for nighttime and daytime photos, it also suggests that people do not adopt a more cautious approach for the stimuli with poorer lighting conditions.

Our second hypothesis was that drivers would judge it safer to pull out in front of vehicles with headlights on than off. This hypothesis was not supported and in fact, further analysis indicated that the reverse was true for motorcycles at an intermediate distance. Judgements that it is safe to pull out in front of an intermediate motorcycle decreased by about 10% when the headlights were on compared with when off, regardless of time of day. Given that there was no right or wrong answer in terms of judgement in this particular study, it is not possible to know whether switching on headlights provided drivers with a more accurate cue to a vehicle’s distance. However, it does seem that drivers were more cautious about saying they would pull out in front of motorcycles with the headlights on, at least at an intermediate distance, which is the distance at which drivers showed lowest levels of agreement about whether it is safe or not. One possible explanation for this finding is that motorcycles with headlights switched on are more salient and so appear to be nearer (despite actually being at the same distance), resulting in more cautious judgements. If this is the case, then one might expect a similar effect in relation to cars with headlights on, which was not observed. However, it is still possible that the larger size of the car offers a clearer basis for judgements and so the headlights are not used as a cue to the same extent in this condition. Another possibility is that headlights are perceived as a warning, and so drivers assume that the motorcycle with headlights on is moving more quickly. However, this does not seem particularly plausible given that the effect was found with the nighttime photographs as well as daytime photographs where the use of headlights is unlikely to be interpreted as a warning.

4. General discussion

In terms of perception, this study failed to demonstrate an increase in perceptual ability associated with DRL, which could be due to the brightness of photographs and/or ceiling effects in the current study, in which case headlights might make a difference in daytime when it is cloudy, foggy or rainy. However, headlights were found to be useful in increasing drivers’ ability to perceive approaching vehicles for nighttime photographs regardless of vehicle type. This finding is in line with the luminance contrast theory, which proposes that object detection is aided by

Table 4. Mean and standard deviation of the percentage of judgements it was safe to pull out in front of an approaching vehicle at different distances.

| Percentages of judgements of safe to pull out (%) | Distances | Vehicles   | Daytime photographs | Nighttime photographs |
|-----------------------------------------------|-----------|------------|---------------------|----------------------|
|                                               |           |            | Headlights on       | Headlights off       | Headlights on       | Headlights off       |
| Near                                          | Car       | 8.42 (12.14) | 10.00 (11.06)      | 4.74 (6.12)          | 7.37 (10.46)        |
|                                               | Motorcycle| 8.42 (14.25) | 10.00 (12.47)      | 4.21 (6.07)          | 7.89 (10.32)        |
| Intermediate                                  | Car       | 17.89 (17.19) | 18.42 (21.15)      | 15.79 (18.05)        | 19.47 (18.40)       |
|                                               | Motorcycle| 18.42 (21.41) | 30.00 (27.29)      | 21.05 (22.58)        | 32.11 (22.99)       |
| Far                                           | Car       | 80.00 (22.36) | 84.21 (17.42)      | 74.74 (21.18)        | 74.21 (21.17)       |
|                                               | Motorcycle| 83.16 (15.29) | 84.74 (13.49)      | 76.32 (24.77)        | 77.89 (22.50)       |
increasing the brightness contrast of the object against the background rather than solely increasing the brightness of the object per se (Hole 1996). In terms of appraisal, drivers were more likely to judge it was safe to pull out in front of motorcycles located at an intermediate position when the headlights were off than when they were on. This is likely to be because the intermediate position is the distance which gives rise to the most indecision, perhaps giving the greatest opportunity for headlights to influence drivers’ judgements. It was similarly recently demonstrated in a driving simulator study that innovative headlight configurations (vertical and combined configurations) increased drivers’ gap acceptance for approaching motorcycles as compared to the standard configuration (Cavallo et al. 2015). The current study suggests that the mere use of headlights influences gap acceptance, even when no motion information is available. No difference was found in participants’ judgements about approaching vehicles for the daytime and nighttime photographs. This suggests that the lighting conditions depicted in the photographs are more likely to be associated with perceptual failure than systematic differences in judgement making.

As it was particularly easy to use headlights as a cue to identify approaching vehicles during nighttime, perhaps even more so than in the daytime, this could result in lower collision rates during nighttime than during daytime. However, according to road accidents reports, this does not seem to be the case in Malaysia, where this study was conducted (Abdul Manan and Várhelyi 2012) as well as in other countries (e.g. UK; Clarke et al. 2006). One reason may be that some road accidents which happened during nighttime were due to vehicles not having the headlights on. It was reported that in Malaysia, among 1850 motorcyclists observed on the road, 20.27% failed to switch on their headlights (Abdul Manan and Várhelyi 2015). Although these observations were made during the daytime (and to our knowledge no similar study has been done at night), given that motorcycles in Malaysia are manufactured with Automatic Headlamp On, this may indicate that some vehicles are used with broken lights. Given the benefits of headlight use both at night and during daytime demonstrated in this study, effort will be needed to further increase motorcyclist compliance with laws on DRL in and ensuring that vehicles have fully functional headlights.

Since February 2011, there is a regulation in effect in Europe which requires automobile manufacturers to equip AHO for all vehicles – not just motorcycles (SWOV 2013). However, there are concerns that car DRL might decrease the visual conspicuity of motorcycles, making them harder to detect (e.g. Knight et al. 2006) and create ‘visual noise’ (Cavallo and Pinto 2012). It was demonstrated in this study that DRL is not particularly beneficial for cars in terms of either increasing others’ ability to perceive them or altering judgements made about them. If DRL on cars decreases drivers’ ability to detect motorcycles, the implementation of DRL on cars should be reconsidered. However, this study revealed that the DRL did decrease drivers’ judgements that it was safe to pull out in front of motorcycles, which suggests that the usefulness of DRL may be related to decision-making for motorcycles. As this study recruited

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**Figure 4.** Percentage of judgements it was safe to pull out in front of approaching (a) cars and (b) motorcycles with the headlights on or off at near, intermediate and far distances (error bars depict between-subjects standard error of the mean).

**Table 5.** Summary of full analyses for Experiment 2.

| Main effects          | F(2, 36)  | p     | ηp² | <.001, ηp² | .919 |
|-----------------------|----------|-------|-----|------------|------|
| Vehicle distance      |          |       |     |            |      |
| Time of day           |          |       |     |            |      |
| Headlights            |          |       |     |            |      |

| Two-way interactions  | F(2, 36) | p     | ηp² | <.05, ηp² | .258 |
|-----------------------|----------|-------|-----|------------|------|
| Vehicle type × vehicle distance |          |       |     |            |      |
| Vehicle type × time of day |          |       |     |            |      |
| Vehicle type × vehicle distance |       |       |     |            |      |
| Vehicle type × time of day |          |       |     |            |      |
| Vehicle type × headlights | F(1, 18) | p     | ηp² | <.05, ηp² | .279 |

| Three-way interactions | F(1, 18) | p     | ηp² | <.05, ηp² | .219 |
|------------------------|----------|-------|-----|------------|------|
| Vehicle type × vehicle distance × time of day |          |       |     |            |      |
| Vehicle type × vehicle distance × time of day |          |       |     |            |      |
| Vehicle type × vehicle distance × time of day | F(1, 18) | p     | ηp² | <.05, ηp² | .186 |

| Headlights effect only for motorcycles at intermediate distance | t(18) | p     | ηp² | <.001, d = .712 |

| Four-way interaction | F(2, 36) | p     | ηp² | <.05, ηp² | .186 |
|----------------------|----------|-------|-----|------------|------|
| Vehicle type × vehicle distance × time of day |          |       |     |            |      |
| Vehicle type × time of day × headlights |          |       |     |            |      |
a fairly homogenous group of young and relatively inexperienced drivers, future work would be needed to determine whether highly experienced drivers are similarly influenced by headlights and lighting conditions.

In summary, this study failed to demonstrate that use of headlights increases drivers’ ability to perceive the approaching vehicles during daytime, but this could be due to ceiling effects and the sunny and clear weather when the photographs were taken. In addition, we found that the use of headlights decreases drivers’ tendency to judge it was safe to pull out in front of approaching motorcycles regardless of time of day, supporting the utility of DRL for motorcycles, suggesting that the DRL might not only play a role in drivers’ perception but also in safety judgement. In terms of application, switching on headlights at night (low luminance conditions) should be encouraged as it increases drivers’ ability to perceive approaching vehicles. This study also shows the importance of DRL in motorcycles and demonstrated that the usage of headlights especially during nighttime driving should be reinforced. This is important in developing countries where motorcyclist fatalities tend to be high and in countries where the compliance rate in switching on headlights at night time is reported anecdotally to be low (e.g. Phillipines, Zimbabwe, China) (https://mmda.gov.ph/18-news/news-news-2011/332-mmda-make-sure-your-lights-are-on; https://factsanddetails.com/China/cat13/sub86/item409.html; https://www.herald.co.zw/let-there-be-headlights-please/). Although most motorcycles are now manufactured with AHO, this does not apply everywhere in the world, and especially not in low- and middle-income countries (OECD/ITF 2015). More advanced technologies such as the ‘high-beam assist’ help to automatically adjust between high and low beam headlights depending on the presence of other vehicles (Reagan et al. 2016). In conclusion, DRL should be implemented especially for motorcycles and the importance of having headlights switched on should be stressed in many countries, especially those countries which have high motorcyclist fatality rates. In addition, new technologies that assist road users to use their headlights appropriately should be applied.

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References

Abdul Manan, M. M., and A. Várhelyi. 2012. “Motorcycle Fatalities in Malaysia.” IATSS Research 36: 30–39.

Abdul Manan, M. M., and A. Várhelyi. 2015. “Motorcyclists’ Road Safety Related Behavior at Access Points on Primary Roads in Malaysia – A Case Study.” Safety Science 77: 80–94.

Cavallero, V., and M. Pinto. 2012. “Are car daytime running lights detrimental to motorcycle conspicuity?” Accid. Anal. Prev. 49: 78–85.

Cavallero, V., M. Ranchet, M. Pinto, S. Espié, F. Vienne, and N.-T. Dang. 2015. “Improving Car Drivers’ Perception of Motorcycle Motion through Innovative Headlight Configurations.” Accident Analysis and Prevention 81: 187–193.

Clark, D. D., P. Ward, C. Bartle, and W. Truman. 2004. In Depth Study of Motorcycle Accidents. Road Safety Research Report, No. 54. London: Department for Transport.

Clarke, D. D., P. Ward, C. Bartle, and W. Truman. 2006. “Young Driver Accidents in the UK: The Influence of Age, Experience, and Time of Day.” Accident Analysis and Prevention 38 (5): 871–878.

Crundall, D., K. Humphrey, and D. Clarke. 2008. “Perception and Appraisal of Approaching Motorcycles at Junctions.” Transportation Research Part F 11: 159–167.

Ferraz, A. C. P., B. S. Bezerra, and J. T. Bastos. 2010. “Road Accidentability in Brazil.” In 12th WCTR, Lisbon, Portugal.

Henderson, R. L., K. Ziedman, W. J. Burger, and K. E. Cavey. 1983. Motor Vehicle Conspicuity (No. 830566). SAE Technical Paper, Detroit, Michigan. doi:10.4271/830566.

Hole, J. 1996. “Some Factors Affecting Motorcyclists’Conspicuity.” Ergonomics 39: 946–965.

Hole, G., and L. Tyrrrell. 1995. “The Influence of Perceptual Set on the Detection of Motorcyclists Using Daytime Headlights.” Ergonomics 38 (7): 1326–1341.

Hole, G. J., L. Tyrrrell, and M. Langham. 1996. “Some Factors Affecting Motorcyclists’ Conspicuity.” Ergonomics 39 (7): 946–965.

Janoff, M. 1973. “Motorcycle Noticeability and Safety during the Daytime.” In Proceedings of the Second International Congress on Automotive Safety, Paper No. 73034: 1–18. California: Recreational Vehicle Safety.

Janoff, M., and A. Cassel. 1971. “Effect of Distance and Motorcycle Headlight Condition on Motorcycle Noticeability.” Highway Research Record 377: 53–63.

Kirkby, C., and J. Fulton. 1978. Daytime Use of High Beam Headlamps on Motorcycles. Loughborough: Department of Transport Technology, University of Technology.

Knight, I., B. Sexton, R. Bartlett, T. Barlow, S. Latham, and I. McCrae. 2006. Daytime Running Lights (DRL): A Review of the Reports from the European Commission. Crowthorne: Transport Research Laboratory.

Konstantopoulos, P., P. Chapman, and D. Crundall. 2010. “Driver’s Visual Attention as a Function of Driving Experience and Visibility. Using a Driving Simulator to Explore Drivers’ Eye Movements in Day, Night and Rain Driving.” Accident Analysis and Prevention 42: 827–834.

Laapotti, S., and E. Keskinen. 1998. “Differences in Fatal Loss-of-Control Accidents between Young Male and Female Drivers.” Accident Analysis and Prevention 30: 435–442.

Lee, Y. M., E. Sheppard, and D. Crundall. 2015. “Cross-cultural Effects on the Perception and Appraisal of Approaching Motorcycles at Junctions.” Transportation Research Part F 31: 77–86.
Nazif-Munoz, J. I., A. Quesnel-Vallée, and A. van den Berg. 2015. “Did Chile’s Traffic Law Reform Push Police Enforcement? Understanding Chile’s Traffic Fatalities and Injuries Reduction.” Injury Prevention 21: 159–165.

OECD/ITF. 2015. Improving Safety for Motorcycle, Scooter and Moped Riders. Paris: OECD Publishing. doi:10.1787/9789282107942-en.

Paine, M., D. Paine, J. Haley, and S. Cockfield. 2005. “Daytime Running Lights for Motorcycles.” In 19th International Technical Conference on the Enhanced Safety Vehicles, Washington DC, USA.

Plainis, S., and I. J. Murray. 2002. “Reaction times as an Index of Visual Conspicuity When Driving at Night.” Ophthalmic and Physiological Optics 22 (5): 409–415.

Radin Umar, R. S., M. G. Mackay, and B. L. Hills. 1996. “Modelling of Conspicuity-related Motorcycle Accidents in Seremban and Shahalam, Malaysia.” Accident Analysis and Prevention 28: 325–332.

Ramsey, J., and W. Brinkley. 1977. “Enhanced Motorcycle Noticeability through Daytime Use of Visual Signal Warning Devices.” Journal of Safety Research 9 (2): 77–84.

Reagan, I. J., M. L. Brumbelow, M. J. Flannagan, and J. M. Sullivan. 2016. “High Beam Headlamp Use Rates: Effects of Rurality, Proximity of Other Traffic, and Roadway Curvature.” Traffic Injury Prevention 18 (7): 716–723.

Shapley, R., and C. Enroth-Cugell. 1984. “Visual Adaptation and Retinal Gain Controls.” Progress in Retinal Research 3: 263–346.

SWOV. 2013. SWOV Factsheet Daytime Running Lights (DRL). Leidschendam: SWOV.

Vijayraghvan, S. (2016). Accessed on June 14, 2017. https://auto.ndtv.com/news/government-to-mandate-automatic-headlamp-on-aho-for-two-wheelers-from-2017-1284054

Walton, D., J. Buchanan, and S. J. Murray. 2013. “Exploring Factors Distinguishing Car-versus-Car from Car-versus-Motorcycle in Intersection Crashes.” Transportation Research Part F 17: 145–153.

Williams, A. F. 2003. “Teenage Drivers: Patterns of Risk.” Journal of Safety Research 34: 5–15.

Yuan, W. 2000. “The Effectiveness of the ‘ride-bright’ Legislation for Motorcycles in Singapore.” Accident Analysis & Prevention 32 (4): 559–563.

Ziegler, M., E. Danay, and M. Bühner. 2010. “Is It Really Robust? Reinvestigating the Robustness of ANOVA against Violations of the Normal Distribution Assumption.” Methodology 6: 147–151. doi:10.1027/1614-2241/a000016.