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Title: Differences in gap acceptance for approaching cars and motorcycles at junctions: What causes the size-arrival effect?

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Abstract

This study investigated whether the size-arrival effect for approaching vehicles, whereby people judge that approaching motorcycles will arrive later than approaching cars, is more likely to be due to overestimating the distance available in front of motorcycles or underestimating the speed of approaching motorcycles relative to cars. Approaching vehicles at junctions (cars and motorcycles) were shown in a series of video clips (speed and distance information was provided) and photographs (only distance information was provided). Drivers' judgments about whether it was safe to pull out was investigated. The vehicle effect arose only in the video condition when vehicles were presented at a far distance. It was concluded that drivers' error in judgment is likely to be due either to the miss-estimation of the speed of approaching motorcycles or drivers making judgments based on the rate of optical expansion, rather than direct misperceptions of distance.

Keywords gap-acceptance, motion, motorcycles, size-arrival effect

1. Introduction

Motorcycles are vulnerable road users and over-represented in road accidents and fatalities in many countries. For instance, although in the UK motorcycles constitute less than 1% of road users, in 2015 motorcyclists accounted for 8.1%% of accidents and 13.7% of deaths on the roads (DfT, 2015). In Malaysia 29.0% of accidents and 52.6% of road fatalities involved motorcycles (Sarani, Roslan & Saniran, 2010), although Abdul Manan and Várhelyi (2012) state that only fatalities can be accurately measured in Malaysia due to underreporting and unreliable records of accidents without fatal injury. Similarly high levels of road injuries and fatalities involving motorcycles were also reported in other countries such as New Zealand (Reeder et al., 1999), Norway (Kopjar, 1999) and many more. Car drivers' failures to give way to approaching motorcycles at junctions (known as right-of-way violations, ROWVs) are one of the most common types of car-motorcycle collision (Clarke et al., 2004; Abdul Manan & Várhelyi, 2012). One explanation for this failure is that drivers simply do not see the approaching vehicle. The smaller frontal size of motorcycles than cars leads to conspicuity problems resulting in difficulties in motorcycle detection (Crundall et al., 2008; Pai, 2009; Lee et al., 2015). However, another factor which may contribute to the high number of ROWVs involving motorcyclists is drivers making incorrect gap acceptance judgments (Pai, 2009), whereby they decide it is safe to pull out from the junction when there is in fact insufficient room to do so safely.

A number of previous studies have demonstrated that car drivers typically allow smaller gaps when pulling out in front of motorcycles than cars (Hancock et al., 1991; Hancock & Caird, 1993; Nagayama et al., 1980). In gap acceptance studies participants are typically asked to press a button at the last moment when they felt they could safely pull out from a junction while watching short videos of approaching vehicles (cars, motorcycles and trucks) travelling from a pre-specified distance from the junction at a constant speed. Previous studies using this method have revealed that drivers were more likely to accept a smaller gap size in front of motorcycles than trucks and cars, and this was true especially when the velocity of approaching motorcycle was high rather than low (Hancock et al., 1991; in line with Nagayama et al., 1980).

A widely cited explanation for this characteristic pattern in gap acceptance behaviour is the size-arrival effect, a perceptual illusion whereby people perceive smaller objects to arrive later than larger objects travelling at the same speed (DeLucia, 1991). The size-arrival effect has been demonstrated more directly in time-to-arrival studies, which present an observer with a video showing an approaching object (such as another vehicle) which is then occluded and the observer is asked to judge the time at which the approaching object would have reached them. Several such studies have found that cars were estimated as arriving earlier at junctions than motorcyclists (Caird & Hancock, 1994; Horswill et al., 2005), consistent with the suggestion that the acceptance of smaller gaps for approaching motorcycles may be due to an error in judging the arrival time of the approaching vehicle.

While these previous studies suggest that drivers may have more difficulty judging the arrival time of approaching motorcycles than cars, resulting in gap acceptance errors (see Pai, 2011 for a review; Olson, 1989) the exact explanation remains uncertain. First, the appraisal error could be due to errors in judging the distance of the approaching vehicle. Frontal size may be used as a cue to distance (smaller objects usually are further away) and drivers might have overestimated the distance of approaching motorcycles compared with cars, resulting in drivers accepting a gap which is actually too small for them to pull out (Olson, 1989). Second, the appraisal error could be due to errors in judging the speed of the approaching vehicle (Thomson, 1980). The smaller size of the motorcycle could make drivers underestimate its speed due to the difficulties in perceiving movements of motorcycles in comparison with cars (Lee & Sheppard, 2016), resulting in their accepting a gap which is too small.

These previously mentioned gap acceptance studies were conducted using only videos, which contain both speed and distance information. Therefore, it is not possible to tell whether drivers are underestimating the speed or overestimating the distance, or both.

This question can be answered by comparing gap acceptance for cars and motorcycles in videos (speed and distance information provided) and photographs (only distance information provided). The current study investigated drivers' judgment about the safety of pulling out at junctions in photos and video stimuli using the occlusion method. Drivers were presented with videos or photos depicting a vehicle approaching a T-junction viewed from the point of view of a driver who has stopped at the junction and is looking to the right in the roadway ahead. The approaching vehicle was either a car or a motorcycle and when occlusion took place the vehicle was located at one of three different distances from the junction (near – 14 m, intermediate – 30 m, far – 46 m). Drivers were required to decide whether or not they felt it was safe to pull out after each stimulus was presented.

If errors in gap acceptance judgments for motorcycles are due to drivers underestimating speed, drivers will be more likely to judge safe to pull out in front of approaching motorcycles than cars in the video stimuli but not photo stimuli. However, if the differences are due to drivers overestimating the distances of the approaching vehicles, the vehicle effect in gap acceptance should be present in both videos and photograph stimuli. Given that Crundall et al. (2008) and Lee et al. (2015) did not find any effects of vehicle type on drivers' judgments about the safety of pulling out using photograph stimuli only, we predict that the judgment errors made by drivers are more likely to be due to underestimating the speed of motorcycles in comparison to cars, and to a lesser extent in overestimating the distance/gap.

2. Methods

2.1. Participants

In total 17 drivers were recruited in the experiment (9 males and 8 females). Their average age was 22.12 years (S.D. = 3.16) ranging from 17 to 29 years old and they reported an average of 2.99 years (S.D. = 3.33 years) of active driving experience since getting their driving license in Malaysia, ranging from 0.17 to 12.42 years. All reported normal or corrected-to-normal vision and were not colour blind. All participants reported no experience of riding a motorcycle.

2.2. Design

A 2 x 3 x 2 within-subjects design was used. There were three independent variables: type of approaching vehicle (car or motorcycle); distance of approaching vehicle (near, intermediate or far); type of stimuli (photographs or videos). In addition, the approaching vehicles were recorded at three different travelling speeds (30 km/h, 40 km/h, and 50 km/h). Speed was not included as an independent variable in the current study but was included to provide speed variability and make the video stimuli less predictable. The dependent variable was the participants' judgments about whether it was safe to pull out from the junction.

Two hundred and eighty-eight trials were presented to each participant across four blocks (2 blocks of photographs and 2 blocks of videos). The two blocks of photographs were identical, as were the two blocks of videos. In each trial of the 72-trial video block, an approaching vehicle was presented. Videos were recorded on two different junctions and each of the stimuli was repeated twice in each block, resulting in four presentations per block for each vehicle type/speed/distance combination. The approaching vehicle was a car or a motorcycle (30 km/h, 40 km/h, 50 km/h), which was located at 'near', 'intermediate' or 'far' distances. Counterbalancing was used, whereby participants either completed the two blocks of videos first followed by two blocks of photographs or vice versa.

2.3. Stimuli

2.3.1. Road measuring phase

A Trumeter Measuremeter® 5500 (Mechanical Metric Distance Measuring Wheel) was used for road measuring. Road measuring started from the point where the video recorder was standing which was located at the junction. Three distances from the junction were measured and they were 14 m, 30 m and 46 m. These three distances were used as the near, intermediate and far distances in this experiment. While measuring the road, photographs were taken as a note to mark the location of 14 m, 30 m and 46 m. Static objects (i.e. lamp post, bushes, edge of the roads, tree etc.) that were located at the side of the roads in those photographs were used as the road markers for guidance while doing the video editing.

2.3.2. Video Recording Phase

Two junctions near University of Nottingham Malaysia campus (Semenyih and Broga) were used for video recordings. They were selected due to being relatively quiet resulting in little disruption to the filming process. Videos of approaching vehicles were recorded from the viewpoint of a driver (refer to Figure 1: position C) who was looking towards the right while approaching the T-junctions. A Panasonic HDC-SD900 video camera was used for the filming. The approaching vehicles (a silver Toyota Vios and a black Honda PCX 150 motorcycle) drove straight (refer to Figure 1: from position A to B) and travelled at a constant speed from the end of the road towards the junction and passed by the video camera. Each recording consisted of only one approaching vehicle which either travelled at the speed of 30 km/h, 40 km/h or 50 km/h.

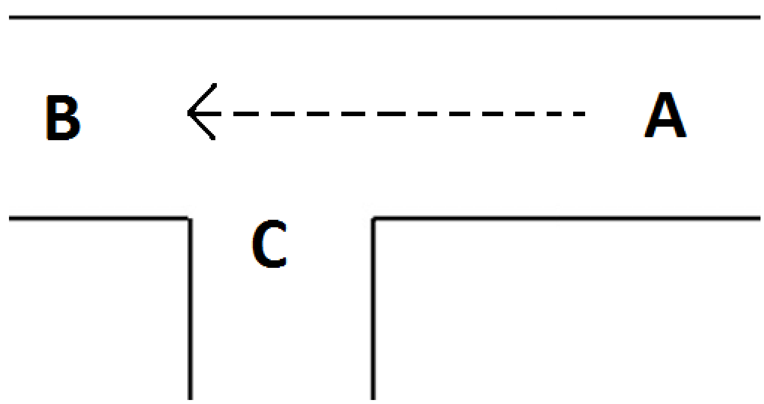

Figure 1. Location of approaching vehicle and video camera. A represents the initial location of the approaching vehicle which travelled straight to B. C represents the location of the video camera

2.3.3. Stimuli editing phase

Windows Live Movie Maker was used as the video editor. Each video stimulus lasted for 1500ms. Videos were cut when the approaching vehicle was at the distance of 14 m, 30 m or 46 m from the junction such that in the final frame the vehicle was either near, intermediate or far from the junction. The last frame of each video was used as the picture stimulus in the static version of the experiment. All the stimuli were presented at a resolution of 1280 x 720 pixels.

2.4. Procedure

Participants were seated approximately 70 cm from the computer screen with stimuli presented at a visual angle of approximately 28 x 21°. Instructions were presented on the screen which explained to participants that they were about to see a series of stimuli (photographs or videos depending on the block) depicting the view of a vehicle positioned in a side-road, looking right along the main carriageway, which has the intention to turn right and cross the contraflow lane. They were first asked to fixate on a fixation cross that appeared in the middle of the screen (1000ms) before the presentation of each stimulus (1500ms). The stimulus was then replaced by a prompt screen reminding participants about the appropriate keys to press in order to make the correct responses. They were asked to press 0 for "safe" to pull out and 2 for "not safe" to pull out. The fixation cross appeared again in the middle of the screen before the next trial began. All stimuli were presented in random sequence within the block. They participated in all four blocks (two blocks of videos and two blocks of photographs), the order of which was counterbalanced. There was a short break between the blocks. The experiment was carried out using the PsychoPy program (Peirce, 2007) and took approximately 30 minutes to complete.

3. Results

The data for all 17 participants were subjected to a 2 x 3 x 2 repeated measured Analysis of Variance (ANOVA) comparing percentage of judgments 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), which were presented in either photographs or videos (see Figure 2).

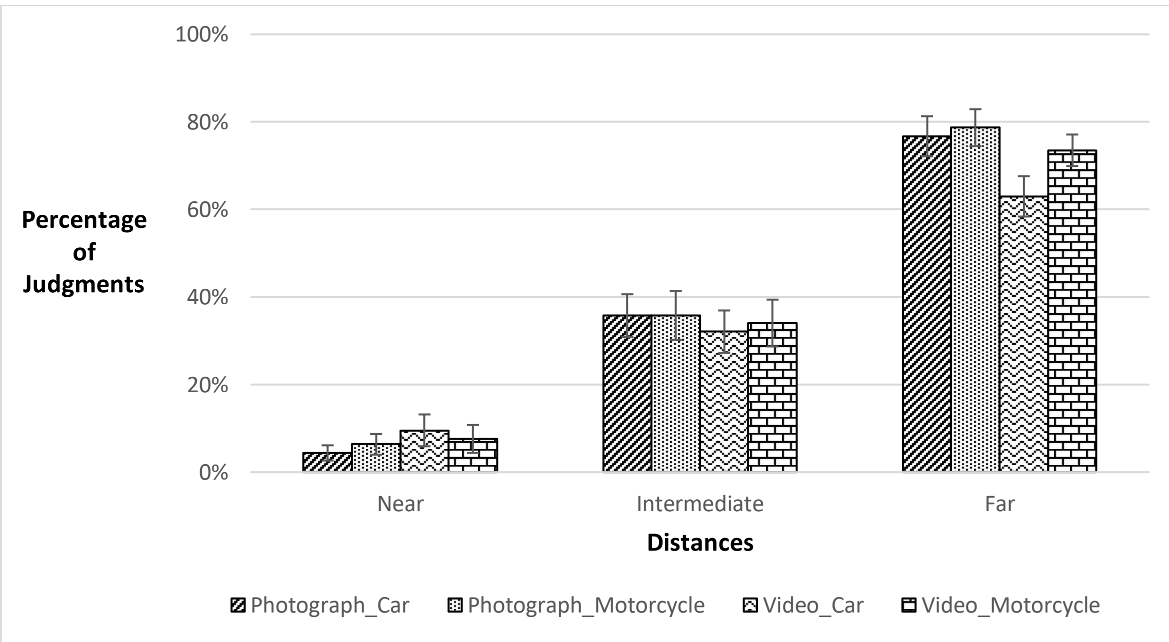

Figure 2. Percentage of judgments it was safe to pull out in front of cars and motorcycles at different distances for photograph and video stimuli (error bars depict standard error of the mean)

The ANOVA identified a main effect of distance, $F(2,32) = 213.24$, $p < .001$. Bonferroni pairwise comparisons showed that it was judged safer to pull out in front of intermediate (34.44%) as compared to near (6.99%) approaching vehicles, $p < .001$; in front of far (72.98%) than intermediate approaching vehicles, $p < .001$; and in front of far than near vehicles, $p < .001$. There was a two-way interaction between stimulus type and vehicle distance, $F(2,32) = 5.53$, $p < .01$. Paired-samples t-tests found that it was judged safer to pull out in front of approaching vehicles in photographs (77.82%) than videos (68.45%) but only at the far distance, $t(16) = 3.00$, $p < .01$.

There was also a three-way interaction between stimulus type, vehicle distance, and vehicle type, $F(2,32) = 5.97$, $p < .01$. To investigate the basis of this interaction, two further 3 x 2 ANOVAs were conducted separately for each stimulus type (photographs and videos). For photographs, there were no effects other than the previously mentioned main effect of distance, $F(2,32) = 192.28$, $p < .001$. For videos, in addition to the main effect of distance, $F(2,32) = 127.47$, $p < .001$; the effect of vehicle type was approaching significance, $F(1,16) = 4.26$, $p = .056$, and interacted with vehicle distance, $F(2,32) = 7.69$, $p = .005$. Paired-samples t-tests revealed that it was judged safer to pull out in front of motorcycles (73.53%) than cars (63%) at a far distance, $t(16) = 2.84$, $p < .05$; but not at intermediate, $t(16) = 1.14$, $p > .05$, and near distances, $t(16) = 1.22$, $p > .05$. To express this interaction another way, there was a main effect of stimulus type, $F(1,16) = 9.17$, $p < .01$ and an interaction between vehicle and stimulus type, $F(1,16) = 8.42$, $p = .01$ at the far distance only. Paired samples t-tests revealed that it was judged less safe to pull out in the videos than the photographs condition for far cars, $t(16) = 4.15$, $p = .001$ but there was no difference for far motorcycles.

4. Discussion

Previous gap acceptance studies have shown that drivers accept smaller gaps in front of motorcycles than cars (Hancock et al., 1991; Hancock & Caird, 1993; Nagayama et al., 1980) which has been proposed to be the result of the "size arrival effect", whereby drivers believe that the smaller vehicle will reach them later than the larger (Caird & Hancock, 1994; DeLucia, 1991; Horswill et al., 2005). This paper asked whether gap acceptance errors made by drivers are due to their overestimating the distance available in front of the approaching motorcycle or underestimating its speed. By comparing the video condition, where speed and distance information is present, with a static photo condition in which only distance information can be used to make a decision about whether to accept the gap, we could determine the probable basis of this vehicle effect.

Drivers were more likely to judge it was safe to pull out in front of motorcycles than cars specifically for video stimuli although only when the approaching vehicles were located at a far distance. This is consistent with the idea that video stimuli give rise to a vehicle effect (Caird & Hancock, 1994; DeLucia, 1991; Horswill et al., 2005) while photographs do not (Crundall et al., 2008; Lee et al., 2015). The lack of difference for the photograph only stimuli suggests that when drivers can only use a vehicle's distance to make their decision, they do not differentiate between cars and motorcycles. However, drivers may find it harder to perceive or process the motion of approaching motorcycles as compared to cars (Lee & Sheppard, 2016). The appraisal errors drivers make about the safety of pulling out at junctions could be due to drivers estimating the speed of approaching motorcycles to be slower than approaching cars which are in fact travelling at the same speed.

However, an alternative explanation that may account for the findings is that when presented with video stimuli, rather than directly perceiving the distance and speed of the approaching vehicle, drivers make a judgment about its distance based on its rate of optical expansion in relation to its optic size, a statistic known as tau (Lee, 1976). Although tau varies systematically with the distance of a vehicle such that it could be a reliable cue to judging its distance, it has been pointed out that using tau could be problematic if the rate of change in optical size falls below the threshold for perception (Horswill et al., 2005). Because motorcycles have a smaller optical size than cars (at any given distance) it may be that when they appear at some distances, the rate of optical expansion falls below this threshold. In such videos, the motorcycle may be perceived as close to static in the scene and its distance could not be judged accurately (Gould et al., 2012a; 2012b). In contrast, for photographs there is no optical expansion of either vehicle, so this cannot be used as a cue to infer distance.

The above explanation is consistent with the observation that the vehicle effect was only evident when the vehicles were at the far distance – where the rate of change of topic size would be lowest for both vehicles. However, it is also the case that if two vehicles at a far position are perceived as travelling at different speeds from one another, the difference in their perceived time-to-arrival would be greater than for two vehicles at an intermediate or near distance. Hence, it may be that the misperception of speed merely has a greater impact when it is at a far distance. Further, it is worth noting that the nature of the question is different when it comes to gap-acceptance and time-to-arrival. The former type of study asks drivers to judge whether it is safe to pull out, which is not necessarily equivalent to judgments about when the approaching vehicle will arrive. Drivers may perceive two vehicles as arriving at different times but believe it is safe (or not safe) to pull out in front of both of them. Therefore, this may also contribute to the lack of vehicle effect at the near distance, where drivers tended to say it was not safe to pull out across all conditions.

In conclusion, drivers' tendency to accept smaller gaps in front of motorcycles than cars is more likely to be due to underestimation of the speed of approaching motorcycles instead of overestimation of the gap/distance available in front of them. The smaller size of the motorcycles may also cause difficulties for drivers to detect the motion especially at further distances. This could either be due to problems with processing speed itself or the use of rate of optical expansion as a cue to infer speed/distance falling below perception threshold for motorcycles (Gould et al., 2012a; Gould et al., 2012b).

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