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ORIGINAL ARTICLE

Motorcycle Accident Risk Could Be Inflated by a Time to Arrival Illusion

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ABSTRACT: *Purpose.* Drivers adopt smaller safety margins when pulling out in front of motorcycles compared with cars. This could partly account for why the most common motorcycle/car accident involves a car violating a motorcyclist's right of way. One possible explanation is the size–arrival effect in which smaller objects are perceived to arrive later than larger objects. That is, drivers may estimate the time to arrival of motorcycles to be later than cars because motorcycles are smaller. *Methods.* We investigated arrival time judgments using a temporal occlusion paradigm. Drivers recruited from the student population (n = 28 and n = 33) saw video footage of oncoming vehicles and had to press a response button when they judged that vehicles would reach them. *Results.* In experiment 1, the time to arrival of motorcycles was estimated to be significantly later than larger vehicles (a car and a van) for different approach speeds and viewing times. In experiment 2, we investigated an alternative explanation to the size–arrival effect: that the smaller size of motorcycles places them below the threshold needed for observers to make an accurate time to arrival judgment using tau. We found that the motorcycle/car difference in arrival time estimates was maintained for very short occlusion durations when tau could be estimated for both motorcycles and cars. *Conclusions.* Results are consistent with the size–arrival effect and are inconsistent with the tau threshold explanation. Drivers estimate motorcycles will reach them later than cars across a range of conditions. This could have safety implications. (Optom Vis Sci 2005;82:740–746)

Key Words: time-to-contact, time-to-collision, motorcycles, tau, size–arrival effect, driving, accidents

The most common cause of motorcycle accidents involves another vehicle violating the motorcyclist's right-of-way.[1–4] In postaccident interviews, the car driver often claims not to have seen the motorcycle (see Wulf et al.[3] for a review). This is consistent with the finding that drivers have been observed to pull out into smaller time gaps in front of motorcycles compared with cars.[5]

Most previous research has investigated the role of sensory conspicuity in which the physical qualities of the approaching vehicle that make it harder or easier to distinguish from its background.[3] Motorcycles are less visible than cars and therefore less likely to be seen. Previous studies have involved manipulating the sensory conspicuity of motorcyclists using daytime running lights, fluorescent or reflective clothing, and increased frontal area (see Wulf et al.[3] for a review and Hole et al.[6] for more recent work). Hancock et al.[1] described cognitive conspicuity as another potential factor that could lead to a driver failing to detect an approaching vehicle (the degree to which the observer's experience or intentions makes the approaching vehicle more or less salient). For example, Hurt et al.[2] found that car drivers involved in crashes with motorcycles were more likely to be unfamiliar with motorcycles. The relative rarity of motorcycles on the road compared with cars could reduce their salience.

This article examines a third and less well-studied explanation as to why drivers pull out into smaller time gaps in front of motorcycles: time-to-arrival estimation. Even when a driver has detected an oncoming vehicle, he or she must then judge whether there is sufficient time to pull out safely in front of it. To do this requires drivers to estimate the oncoming vehicle's time-to-arrival. If the strategies used by the driver to judge the time-to-arrival of oncoming vehicles yield a different estimate for motorcycles compared with cars, then this may also help explain the smaller time gap.

There is some time to arrival research that suggests the possibility of such a differential effect. DeLucia[7,8] found that object size affects time-to-arrival judgments. Large, far objects were incorrectly judged to arrive sooner than small, nearer objects. That is, pictorial depth cues appeared to override motion-based time-to-arrival cues such as tau (optical size divided by rate of optical expansion[9]) under certain circumstances (object size should not influence time-to-arrival estimates if tau is the cue being used). The existence of such an illusion leads to the prediction that larger vehicles such as cars and vans may be judged to arrive sooner than smaller vehicles such as motorcycles.

This prediction was tested by Caird and Hancock.[10] They used computer-generated stimuli in which different vehicles approached participants at a road junction. The oncoming vehicles were occluded before they arrived (the screen went black), and participants were asked to press a response button when they believed the vehicle would have reached them. It was found that time-to-arrival estimates were later for smaller vehicles (motorcycles or small cars) than larger vehicles (large cars or vans) consistent with the size–arrival illusion. Assuming that drivers' judgments of whether to pull out are based on time-to-arrival estimates, this would result in drivers choosing to emerge into smaller, and hence potentially more hazardous, gaps in front of smaller vehicles.

EXPERIMENT 1

The aim of experiment 1 was to extend Caird and Hancock's[10] finding. First, we planned to use filmed footage of actual road situations rather than computer-generated scenes to increase the realism of the stimuli. Manser and Hancock[11] argued that most time-to-arrival studies are limited as a result of a lack of realism. With the computer generation of stimuli for road scenes, there is an issue of what detail is put into the scene. When looming stimuli are close to threshold, it may be necessary for the observer to apply distance scaling to the scene to make early judgments of risk. With a virtual scene, the absence of appropriate textures, curbstones, or familiar geometric features may undermine scene scaling. Also, the assumed size of objects may be more ambiguous (for example, although participants may be confident judging the height of a real motorcycle presented in filmed footage, they may not be so confident about judging the height of a motorcycle known to be computer-generated because the virtual motorcycle could, in principle, be any height specified by the programmer). These problems are also conflated with the texture-scaling algorithms that are used when surfaces recede in depth and the difficulty in generating appropriate lighting conditions. Reciprocally, a virtual scene that has very distinct textured features (for example, flagstones) may allow a higher level of scaling than is possible in a natural scene. There is a fundamental problem in matching the level of detail in a virtual scene with that arriving at the eye of the observer in the natural world. Furthermore, the difficulty in generating realistic dynamics for vehicles within such a scene may also dilute the effectiveness of the display. For example, time-to-contact judgments are known to be sensitive to whether the texture of the object expands at the same rate as the object.[12] This could have implications for how well computer-generated displays can replicate real stimuli. For instance, Regan and Gray[13] suggest that the difficulty of "achieving realistic texture dynamics in (computer-generated) flight simulator displays might restrict the effectiveness in training. . ." (p. 196). The video-based stimuli used in the present experiments have the advantage that the level of detail arriving at the camera lens does represent that available to the eye, even if this is then reduced in resolution by conventional capture and display mediums. Previous work investigating the effect of realism on time-to-arrival judgments has provided mixed results. Cavallo et al.[14] compared five levels of increasing realism in a computer-generated scene (adding roadside, street furniture, and road texture). They found time-to-collision judgments decreased as the scene was enriched, with the more realistic scenes mapping more closely to real-world judgments. However, DeLucia et al.[15] found similar patterns of results in displays of differing realism when participants were asked to judge whether two objects would collide. In the situation we are exploring in the present study, it remains an open question as to whether greater realism yields a different pattern of results.

The second extension of Caird and Hancock[10]'s study is that we planned to vary the viewing time of the stimuli (the duration that the oncoming vehicle is seen before occlusion) to determine whether the vehicle size effect occurs across different durations that would be plausible in the given real-world situation. Viewing time has previously been found to affect the accuracy of time-to-arrival judgments in driving situations,[11] although this has not been investigated for different vehicle types or sizes. Our predictions were 1) that the time-to-arrival of motorcyclists will be judged to be later than that of larger vehicles when the actual arrival time is held constant, 2) that this will be true for different viewing times and different approach speeds, and 3) that there will a linear trend of vehicle size in time-to-arrival judgments, such that smaller vehicles are judged to arrive later than larger vehicles. In experiment 1, a disappearance paradigm was used, in which vehicles (filmed on a public road) approached the observer's (camera's) position at various speeds, and the scene blacked out 4 s before the vehicle reached a red strip of tarmac on the road just in front of the observer's position. Participants were asked to press a response button when they estimated the vehicle would have reached the red strip.

METHOD

Participants

Twenty-eight drivers who had never ridden a motorcycle were recruited from the student population. Their mean age was 21.43 years (standard deviation [SD] 3.76), the mean time since they had passed the U.K. driving test was 2.94 years (SD 2.33), and their mean annual mileage was 4654 miles (SD 5361). There were 12 males and 16 females. Informed consent was obtained.

MATERIALS

A Sony TRV900E 3CCD digital video camera was positioned by a T-junction to mimic a driver's view of oncoming vehicles as if the driver was waiting at the nonpriority road (in which they are required to yield to traffic on the priority road) to turn left and join the flow of traffic on the priority road (this was a U.K. road where vehicles travel on the left). The camera was set up on the road verge so that the red tarmac strip (used as the target for participants' time-to-arrival judgments) was in the foreground of the shot and there was a clear view down the road into the distance. Four types of vehicle (a small motorcycle, a large motorcycle, a car, and a van) were driven toward the junction a number of times at 30 (±1) miles per hour (mph; 48 kph) and 40 (±1) mph (64 kph). The speed of each approach was checked using a Muni Quip K-Gp radar speed gun. A still of the footage can be seen in Figure 1.

For each vehicle type, we selected six of these approaches (three at 30 mph and three at 40 mph). These scenes were chosen to be as free from other traffic as possible (especially traffic approaching in the same direction as the target vehicle). The scenes were edited with a PC-based video-editing system (Matrox RT2000) using Adobe Premiére 5.1. A tone was added to the audio channel at the beginning of each scene to provide a reference that allowed participant responses to each scene to be timed. All scenes were occluded (the screen turned black) 4 s before the vehicle reaching the red strip of tarmac could be seen on the road in the foreground. Four seconds of occlusion was chosen as a plausible timeframe in which drivers would have make a decision of whether to pull out in front of the oncoming vehicle.

Each of the vehicle approaches was displayed twice with 2 s of viewing time before occlusion and twice with 5 s of viewing time before occlusion. The 96 trials generated were arranged in a pseudorandom order such that no vehicle type repeated over consecutive trials. The occlusion (black screen) continued after the actual time-to-arrival for between 6 s and 8 s (in 400-ms intervals). This additional duration was randomly selected to avoid giving participants cues as to the actual time-to-arrival. The audio tone at the start of each scene triggered timing software. Participants pressed a response button to indicate their time-to-arrival judgments, which allowed the computer to calculate the response time to each trial.

Practice scenes were created for illustrative purposes at the beginning of testing (using footage of a different car). The scenes consisted of 1) a single example of an approach with no occlusion, 2) a freezeframe of the exact moment at which the car's wheels touched the red tarmac strip, and 3) three practice scenes that were occluded after a certain time in the same way as the test stimuli.

FIGURE 1.

Image from video footage shown to participants (original in color). This picture depicts the large motorcycle approaching. The red stripe across the road used as the intercept point can be seen as the slightly darker shade band of tarmac in the foreground.

Procedure

Participants were seated 70 cm from a 42.5-cm (17-inch) television connected to a S-VHS video player (resolution was approximately 400 lines). The stimuli were played without sound. The viewing distance was set to ensure that the stimuli were perspective-correct for the display size. Participants were told that the experiment was being run to find out more about how people estimate the time-to-arrival of vehicles at junctions. They were told that they would see a number of scenes of a single vehicle approaching a junction at which they were located and that they should press the response button at the time they estimated the front wheels of the oncoming vehicle would touch the leading edge of the red tarmac strip on the road. Participants viewed the practice scenes, responding to the three occluded scenes. Participants then responded to the 96 test scenes, which took 27 min. They received no feedback on their accuracy at any point. After testing, all participants completed a questionnaire, which included demographic and driving experience measures.

RESULTS

There were a small number of missing values (25 of 2688 responses overall). Means for conditions with missing values were calculated using the remaining responses in each condition (each condition comprised of six trials). Time-to-arrival estimates were not normally distributed (*Shapiro-Wilk* $_{28} = 0.88$, $p = 0.004$), but a logarithmic transform yielded normal data (*Shapiro-Wilk* $_{28} = 0.94$, $p = 0.143$). This transform was therefore used for all inferential statistics. Table 1 shows the motorcycle/other vehicle comparisons for all the different conditions (an analysis of variance [ANOVA] was considered unnecessary because we had no hypotheses regarding interactions between the independent variables in this study). Time-to-arrival estimations were significantly longer for motorcycles than for the larger vehicles for both speed and both viewing time conditions.

Using trend analysis, we found significant linear trends across vehicle type (small motorcycle, large motorcycle, car, and van) for both speeds (30 mph: $F_{1,27} = 52.7$; $p < 0.001$; 40 mph: $F_{1,27} = 8.5$, $p = 0.007$) and both viewing times (2 s: $F_{1,27} = 15.1$, $p = 0.001$; 5 s: $F_{1,27} = 31.3$, $p < 0.001$). The mean time-to-arrival estimations for each vehicle are shown in Figure 2 with all speed and viewing time conditions collapsed. The front surface area of each vehicle, as depicted in Figure 2, was calculated as follows. The relative image size of each vehicle in pixels was estimated from the video by using a custom pixel count algorithm developed in Matlab (version 6.5 r13). Then the front surface area of the small motorcycle was measured directly from the vehicle in meters squared. This enabled us to calculate the front surface areas of the other vehicles in meters squared using the relative size estimates.

DISCUSSION

All the hypotheses were confirmed. Under both viewing times and for both approach speeds, the time-to-arrival of motorcycles was estimated to be later than that of other vehicles (cars and vans). Also, there was a significant linear trend for vehicle size-, across all four vehicles (small motorcycle, large motorcycle, car, and van), which was consistent with the size–arrival effect reported by DeLucia.[7]

TABLE 1.
Comparisons between time to arrival of motorcycles (large and small) and other vehicles (car and van)

Condition	Mean (SD) of small and large motorcycle (Actual arrival at 0 ms)	Mean (SD) of car and van (Actual arrival at 0 ms)	Significance test
Vehicle speed 30 mph	−804 (1225) ms	−1272 (789) ms	$t_{27} = 7.3$, $p < .001$
Vehicle speed 40 mph	−489 (1209) ms	−986 (864) ms	$t_{27} = 3.9$, $p = .001$
View time 2 s	−703 (1223) ms	−1089 (785) ms	$t_{27} = 3.6$, $p = .001$
View time 5 s	−589 (1218) ms	−1169 (803) ms	$t_{27} = 7.7$, $p < .001$

SD, standard deviation.

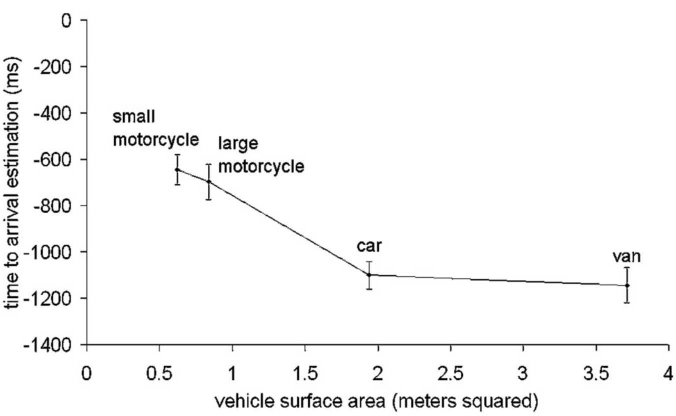

FIGURE 2.
Time-to-arrival estimation by vehicle type (collapsed across speed and viewing time). Negative estimates indicate early presses (the actual time to arrival is 0 ms). Error bars represent standard errors of the mean.

All mean time-to-arrival judgments were underestimated. This is consistent with virtually all time-to-arrival experiments involving prediction of motion,[16] including those in which participants viewed real stimuli in a driving situation.[17] This resulted in the arrival time estimate for smaller vehicles being more accurate than for larger vehicles. However, if we assume that drivers use their time-to-arrival estimations to choose whether it is safe to pull out, this greater accuracy does not favor smaller vehicles from a road safety perspective. That is, drivers may be more inaccurate when judging the time-to-arrival of larger vehicles, but this is likely to result in greater safety margins when they have to pull out in front of these vehicles. These findings are consistent with Keskinen et al.'s[5] observational finding that drivers leave less room when pulling out in front of motorcycles compared with cars.

EXPERIMENT 2

Although consistent with the size–arrival effect,[7] it is possible to argue that the difference between motorcycle/car time-to-arrival estimates found in experiment 1 could be a result of drivers using simple looming cues to judge the time-to-arrival of oncoming vehicles. Lee[9] argued that time-to-arrival judgments are made using tau (optical size divided by the rate of optical expansion) without the observer needing to know either the object's size or its velocity (see Tresilian[18] for a review). However, estimating time-to-arrival using only tau is limited by whether observers can detect the rate of object expansion in the first place. Hoffman and Mortimer[19] estimated that drivers' minimum threshold for detecting the rate of object expansion in approaching vehicles was approximately 0.003 radians/sec (this was done using filmed footage). If drivers do use tau to estimate the time-to-arrival of approaching vehicles, then this raises the question of whether the motorcycle estimates are different because the rate of motorcycle expansion is below or close to this threshold. That is, drivers may not be able to use tau to estimate the time-to-arrival of motorcycles at distances typically encountered in everyday driving.

To investigate this possibility, we estimated the front surface area of the small motorcycle and the car and used this to see whether the rate of object expansion would be below 0.003 radian/second at 4 s before arrival (the occlusion time used in experiment 1). The front surface area of the small motorcycle was approximately 0.62 m^2 and the car was approximately 1.94 m^2. The distance beyond which object expansion would be below threshold can be estimated as the square root of object size multiplied by its velocity and divided by the object expansion threshold (0.003 radians/s). Given the ratio of height to width is substantially different for motorcycles and cars, we treated both as square objects to allow comparison (that is, width of 0.62 and 1.94 m, respectively). At 30 mph (13.41 m/s), drivers would be able to detect tau at 3.93 s before arrival for the motorcycle and 6.94 s before arrival for the car. At 40 mph (17.88 m/s), drivers would be able to detect tau at 3.40 s before arrival for the motorcycle and 8.02 s before arrival for the car. That is, in both cases, drivers would be unable to estimate tau for the motorcycle but should be able to estimate tau for the car. This could account for differences in time-to-arrival estimates.

Although these threshold calculations are open to question (for example, if drivers use the vertical axis for comparison, then motorcycles with riders are taller than cars, which would lead to different conclusions), the point is that they raise the possibility that a rate of object expansion threshold could account for the vehicle difference in experiment 1 rather than a size–arrival illusion (which occurs even when object expansion is above threshold). Experiment 2 was designed to investigate this possibility by presenting motorcycles and cars in situations in which observers are able to detect object expansion. Using the disappearance paradigm described in experiment 1, we varied the duration of the occlusion (1 s, 2 s, 4 s, and 7 s before arrival). At both 1- and 2-s occlusion, participants should be able to detect object expansion for the small motorcycle (see previous calculation). We predicted that if sensitivity to object expansion is responsible for the vehicle size effect, then the motorcycle/car difference in time-to-arrival would disappear at these occlusion times.

METHOD
Participants

Thirty-three drivers were recruited from the student population. Their mean age was 21.55 years (SD 4.12), the mean time since they had passed their driving test was 3.72 years (SD 3.55), and their mean annual mileage was 4654 miles (SD 5529). There were 11 males and 22 females. Informed consent was obtained.

Materials

The six small motorcycle and six car approaches used in experiment 1 were reedited so that the scenes were occluded (the screen went black) 1, 2, 4, and 7 s before the vehicle reached the strip of red tarmac. The viewing time before occlusion was 4 s throughout. The black screen continued for 4 s after the vehicle had touched the red tarmac strip. Like in experiment 1, an audio tone was added to each scene to enable response times to be recorded. Each of the 48 scenes (24 car and 24 motorcycle) was seen twice during testing. Order was pseudorandomized according to the following rules. First, the 48 scenes were split into two blocks that followed each other without a break during testing. Second, the two blocks were randomized separately. Third, scenes were moved around (within their block) such that during the whole 96-trial sequence, no scene that originated from the same approach was repeated across consecutive trials. Response times were obtained using the same equipment as experiment 1.

Procedure

The procedure was identical to experiment 1, except that participants sat 152 cm from a 92.5-cm (37-inch) monitor. Like in experiment 1, this viewing distance rendered the stimuli perspective correct.

RESULTS

When there were missing values (27 of 3168 responses), condition means were based on the remaining scenes in each condition (there were six trials in each condition). The time-to-arrival estimates were normally distributed (*Shapiro-Wilk* $_{33}$ = 0.95, p = 0.17), and so no transformation was used.

Repeated-measures ANOVAs were carried out for each approach speed, with time-to-arrival estimation as the dependent variable and occlusion and vehicle type as independent variables. This is because, unlike experiment 1, the interaction between the independent variables was central to the hypothesis. For both speeds, there were significant main effects of vehicle type and occlusion as well as significant vehicle/speed interactions (vehicle type effect at 30 mph, $F_{1,32} = 11.71$, $p = 0.002$; occlusion time effect at 30 mph, $F_{1.23,39.39} = 84.98$, $p < 0.001$; sphericity assumption rejected so Greenhouse-Geisser statistic reported; vehicle/occlusion interaction at 30 mph, $F_{1.82,58.27} = 4.03$, $p = 0.026$; sphericity assumption rejected so Greenhouse-Geisser statistic reported; vehicle type effect at 40 mph, $F_{1,32} = 29.50$, $p < 0.001$; occlusion time effect at 40 mph, $F_{1.36,43.46} = 116.94$, $p < 0.001$; sphericity assumption rejected so Greenhouse-Geisser statistic reported; vehicle/occlusion interaction at 40 mph, $F_{2.22,71.18} = 9.90$, $p < 0.001$; sphericity assumption rejected so Greenhouse-Geisser statistic reported). The means are displayed in Figure 3.

At 30 mph, simple effects revealed significant vehicle type differences in time-to-arrival estimates for 1 and 7 s of occlusion ($t_{32} = 3.97$, $p < 0.001$ and $t_{32} = 2.95$, $p = 0.006$, respectively).

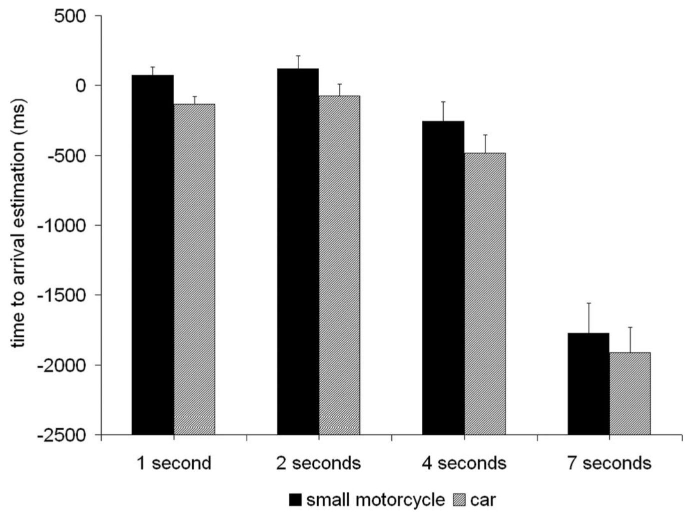

FIGURE 3.

Time-to-arrival estimates (ms) by occlusion duration (collapsed across speed). Negative estimates indicate early presses (the actual time to arrival is 0 ms). Error bars represent standard errors of the mean.

However, there were no significant differences in vehicle type for 2 and 4 s of occlusion ($t_{32} = 0.73$, $p = 0.471$ and $t_{32} = 0.498$, $p = 0.622$, respectively). At 40 mph, there were differences in time-to-arrival estimates between motorcycles and cars at 1, 2, and 4 s ($t_{32} = 5.86$, $p < 0.001$, $t_{32} = 6.22$, $p = 0.001$ and $t_{32} = 5.69$, $p < 0.001$, respectively). However, there was no significant vehicle effect at 7 s occlusion ($t_{32} = -.62$, $p = 0.537$).

DISCUSSION

Overall, motorcycles were estimated to arrive significantly later than cars, and this was significant when vehicles disappeared 1 s before they arrived (both at 30 and 40 mph). This indicated that vehicle differences were unlikely to be a result of threshold differences in detecting object expansion as all vehicles in the 1-s condition would be well above threshold before occlusion. The motorcycle/car differences in estimation were also significant in all but the 7-s occlusion for the 40-mph approach. It is worth noting that there were no motorcycle/car differences for the 2- and 4-s occlusions in the 30-mph approach. The reason for this is unclear, especially because we obtained a vehicle difference for 4-s occlusion at 30 mph in experiment 1 and the only systematic difference between the experiments being a small difference in viewing time (5 s for experiment 1, 4 s in experiment 2).

GENERAL DISCUSSION

One reason that motorcyclists could be at greater risk of being hit at road junctions is because of an unfortunate optical illusion. People estimated that motorcycles reached them later than cars when time-to-arrival was actually the same. This was found to be true under most conditions (with some exceptions in experiment 2) and is consistent with previous work.[10]

This effect is consistent with the size–arrival effect described by DeLucia,[7] in which participants judge, incorrectly, that approaching smaller objects will arrive later than larger objects. One possible alternative explanation for the results was that participants are using tau (object size on retina divided by rate of object expansion) to estimate time-to-arrival and that motorcycles are small enough to be below threshold under the type of conditions typically encountered in real driving. However, experiment 2 demonstrated that the tau threshold explanation was unlikely given that motorcycle/car differences in arrival time estimates occurred even at very brief occlusion times, when looming cues for both motorcycles and cars were well above the estimated threshold. The finding that tau is unlikely to account for time-to-arrival judgments in traffic situations is consistent with previous work.[20]

Why might observers not use tau in the situation under investigation? The stimuli used in our studies differs from that used in many tau experiments in that the approaching object is on a bypass trajectory rather than heading straight for the observer. Tau offers only an approximation for time-to-contact for bypass approaches with the degree of error determined by a number of parameters such as angle of the bypass and the proximity of the target.[18] However, the approximate time-to-arrival estimate given by tau in a bypass situation would still not predict any difference in time-to-arrival judgment accuracy between motorcycles and cars. Accurate time-to-arrival can be theoretically be estimated in the present situation if, as well as tau, observers also incorporate 1) the angle formed between the object and the position of the interception point (in this case, the red stripe on the road) and 2) the rate of change of this angle.[21] However, note that the utilization of these two additional parameters would still not predict a size–arrival effect.

What are the possible mechanisms behind the size–arrival effect we observed? DeLucia noted a few possibilities.[22] First, Smith et al.[23] argued that image expansion rate alone could account for the size–arrival effect. This predicts that smaller objects would appear to arrive later than larger objects assuming both are suprathreshold for detecting image expansion, although it is unclear what this hypothesis would predict when one object is sometimes subthreshold like in the present situation. A second possibility is that there is a size– distance coupling,[24] such that smaller objects appear further away than larger objects. However, note that DeLucia[25] cited evidence suggesting that it was unlikely that these explanations could account for the size–arrival effect. A third option is to assume that there is a continuum of detectability for motion-based cues and that these cues are less detectible for smaller objects (even when above threshold).[24] Fourth, Tresilian et al.[26] found that object size affected responses in interception–timing tasks (smaller objects yielded faster and shorter interceptive movements, resulting in the action being initiated earlier for larger objects). It is possible that although the present study did not involve interception, participants pressed the response button as if it did. Finally, it is possible that cognitive or attitudinal factors may influence judgments. For example, approaching vans may appear more threatening than approaching motorcycles and so drivers might give them more room when pulling into their path. Although the present experiments did not involve a ″pulling out″ response, participants may nonetheless transfer this vehicle bias into their time-to-arrival estimates. Further work would be needed to test these alternative possibilities in the situation under investigation.

Hancock and Manser[20] described the disappearance paradigm used in this, and other experiments, as unrealistic because, in real life, approaching vehicles do not spontaneously turn invisible. They demonstrated that participants' time-to-arrival estimates were more accurate when the approaching vehicle was naturally occluded (it passed behind a bush). We would argue that, in the scenario under investigation, the disappearance paradigm was appropriate because, in real life, drivers would be attempting to decide whether to pull out before the oncoming vehicle has reached them. If they did pull out, then they would eventually be forced to look away from the oncoming vehicle, which would remove that vehicle from their field of view as if it had disappeared. However, even if the disappearance itself is appropriate, it could still be argued that the response mode in these paradigms (generally involving pressing a button) is artificial.[10,20] Participants' performance might be influenced by strategies or biases that may not occur while they engage in actual driving. One way the perception–action coupling in drivers' gap acceptance behavior could be explored further is by asking drivers to indicate when they would pull out into an oncoming stream of traffic. We have used such a task in previous research, [27-29] although motorcycle/car differences have not yet been examined.

These findings suggest that perhaps drivers should be made aware that they are subject to an illusion when judging whether to pull into the path of an oncoming vehicle and that this illusion may lead them to choose smaller gaps in front of smaller vehicles such as motorcycles. This may potentially contribute to the high accident risk of motorcyclists.[27]

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