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9 Effects of Oncoming Vehicle Size on Overtaking Judgments

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Abstract

During overtaking maneuvers on two-way highways drivers must temporarily cross into the opposite lane of traffic, and may face oncoming vehicles. To judge when it is safe to overtake, drivers must estimate the time-to-contact (TTC) of the oncoming vehicle. Information about an oncoming vehicle's TTC is available in the optical expansion pattern, but it is below threshold during high-speed overtaking maneuvers, which require a large passing distance. Consequently, we hypothesized that drivers would rely on perceived distance and velocity, and that their overtaking judgments would be influenced by oncoming vehicle size. A driving simulator was used to examine whether overtaking judgments are influenced by the size of an oncoming vehicle, and by whether a driver actively conducts the overtaking maneuver or passively judges whether it is safe to overtake. Oncoming motorcycles resulted in more accepted gaps and false alarms than larger cars or trucks. Results were due to vehicle size independently of vehicle type, and reflected shifts in response bias rather than sensitivity. Drivers may misjudge the distances of motorcycles due to their relatively small sizes, contributing to accidents due to right-of-way violations. Results have implications for traffic safety and the potential role of driver-assistance technologies.

Keywords: Overtaking, Gap acceptance, Right-of-way violation, Motorcycles, Size-arrival effect, Time-to-collision

1. Introduction

1.1. Overtaking

In 2012, there were 91,000 accidents in the United States in which one vehicle passed another vehicle (including overtaking), resulting in 672 deaths and 19,000 injuries (NHTSA, 2012). To avoid a collision with an oncoming vehicle, the driver who is overtaking presumably must estimate how much time is left before a collision would occur with that vehicle. Specifically, the driver must judge whether the time required to overtake the lead vehicle (TRO) is shorter than the time it will take the oncoming vehicle to arrive at the location where the driver will re-enter the right lane, referred to as time-to-contact (TTC; Gray & Regan, 2005). This is represented in Figure 1, based on analyses by Gray and Regan (2005), who identified the physical variables that are necessary to determine whether a temporal gap between an overtaking driver and an oncoming vehicle is large enough to complete an overtaking maneuver. The purpose of the current study is to examine whether overtaking judgments are influenced by the size of an oncoming vehicle, and by whether a driver actively conducts the overtaking maneuver or passively judges whether it is safe to overtake.

Figure 1. Representation of the physical variables that must be considered when determining whether a gap is large enough for an overtaking maneuver. Adapted from “Perceptual Processes Used by Drivers During Overtaking in a Driving Simulator” by R. Gray and D. M. Regan, 2005, *Human Factors*, 47, p. 409. Copyright 2005 by the Human Factors and Ergonomics Society.

A safe overtaking maneuver is possible only if the difference between TTC and TRO ($TTC - TRO$) is greater than zero. If TTC minus TRO is less than zero, a safe overtaking

maneuver is not possible and a collision will occur if an overtaking maneuver is attempted, unless one of the vehicles takes evasive action.

An equation provided by Gordon and Mast (1970) can be used to determine the difference between TTC and TRO. This equation is based on an analysis of actual overtaking performance, and predicts the distance required to overtake (DRO, in meters) at various speeds:

$$DRO = 34.20 + 2.88V + .01094V^2 \quad (1)$$

where V represents the driver's (and lead vehicle's) initial velocity in km/h. This method of estimating DRO has been used in previous research (Gray & Regan, 2005) and is employed here.

As the overtaking vehicle's velocity increases, DRO also increases. The TRO can be calculated by dividing the DRO by the overtaking vehicle's average velocity across the maneuver, estimated by the overtaking vehicle's initial speed and its acceleration profile. The TTC of the oncoming vehicle can be derived by dividing DTC (distance to contact—the oncoming vehicle's distance from the location where the overtaking driver re-enters the right lane) by the oncoming vehicle's average velocity across that distance. If TTC is greater than TRO, overtaking is possible.

1.2. Visual information available for overtaking judgments

It is evident from the preceding analysis that it is important for drivers to accurately estimate TTC during an overtaking maneuver. It has been proposed that individuals can estimate TTC (the time remaining before an approaching object reaches their eye) on the basis of an optical invariant, tau (e.g., Lee, 1976). Tau is the instantaneous ratio of an approaching object's visual angle and the rate of change of that angle. Tau provides accurate information about TTC (assuming certain conditions are met, e.g., the object is rigid and moves at a constant velocity) and does not require perceptual estimates of distance or velocity.

92 However, even when tau is available, TTC judgments can be influenced by less reliable
93 information. Of particular relevance to this study is the effect of size on such judgments: A small
94 near approaching object can appear to arrive later than a large far approaching object that is
95 specified by tau to arrive later, known as the size-arrival effect (DeLucia, 1991; DeLucia &
96 Warren, 1994; Smith et al., 2001). For example, when participants used a driving simulator to
97 estimate when an approaching vehicle would reach their intersection during a left-turn scenario,
98 mean TTC judgments generally decreased as the approaching vehicle size increased (e.g.,
99 motorcycle vs delivery van; Caird & Hancock, 1994). Similarly, when participants viewed
100 videos of vehicles that approached a traffic intersection, filmed from the view of a driver waiting
101 on the non-priority road, estimates of when the approaching vehicles would arrive at a tarmac
102 strip in front of the driver's location were greater for motorcycles than larger vehicles (Horswill
103 et al., 2005).

104 These results suggest that vehicle size can influence TTC judgments when tau is
105 available. Importantly, it is unlikely that tau is available during most high-speed overtaking
106 scenarios because of the large distances involved (Gould et al., 2013). Tau is effective only when
107 an approaching object's rate of optical expansion is above the threshold for the detection of
108 expansion, which is between about .003 and .006 radians per second (Muttart et al., 2005). In
109 contrast, an oncoming vehicle's rate of optical expansion is below this threshold during a typical
110 overtaking maneuver.

111 When tau is not effective, it is reasonable to expect drivers to base overtaking judgments
112 on other information. We considered the possibility that drivers rely on the oncoming vehicle's
113 apparent distance and velocity (Cavallo & Laurent, 1988; Smeets et al., 1996). In this case,
114 judgments would be expected to be influenced by depth cues such as relative size (e.g.,

Hochberg, 1986), and consequently the size-arrival effect (e.g., Horswill et al., 2005). Smaller vehicles would appear farther, and to arrive later, than larger vehicles.

1.3. Motorcycle safety

Effects of size on TTC judgments have implications for motorcycle safety, which are over-represented in accident statistics (NHTSA, 2012). In 2012, 4,957 motorcyclists were killed and another 93,000 were injured in the United States, representing a 7% and 15% increase, respectively, compared to 2011 (NHTSA, 2014). Moreover, in 2012, motorcycles made up only 3% of the registered vehicles and accounted for only 0.7% of all vehicle miles travelled, but represented 15% of the fatalities and 4% of the injuries (NHTSA, 2014). Hurt et al. (1981) reported that compared to large and heavyweight motorcycles, smaller motorcycles are overrepresented in traffic accidents, but noted that this finding could be due to factors other than size per se. In the current study, we tease apart the effect of size from vehicle type on overtaking judgments.

The most frequent accident scenario involving a motorcycle and another moving vehicle is one in which the vehicle violates the motorcycle's right-of-way (Hurt et al., 1981; Pai, 2011). In this type of accident, the vehicle travels into the motorcycle's path, for example, when turning left in front of the motorcycle or overtaking in front of it. In a review of right-of-way accidents involving motorcycles, Pai (2011) identified two major causes of such accidents: detection errors, in which a motorist fails to see a motorcycle, and decision errors, in which the motorist detects the motorcycle but nevertheless performs an unsafe driving maneuver.

Detection errors suggest that motorcycles have low conspicuity. For example, accident risk can be reduced when a motorcyclist increases conspicuity by using daytime headlights and wearing reflective or fluorescent clothing (Hurt et al., 1981; Wells et al., 2004), though the

effectiveness of such conspicuity treatments may depend on the scene that constitutes the background of the motorcycle (Pai, 2011). Other factors that can affect a driver's ability to detect an oncoming motorcycle include expectancy and the motorist's experience with motorcycles (Hurt et al., 1981; Pai, 2011). However, ensuring detection is not sufficient to eliminate accidents. Even when motorists detect a motorcycle, they must decide whether there is sufficient time to complete a driving maneuver without colliding with the motorcycle. Errors in decision-making account for a substantial number of motorcycle accidents (Pai, 2011). The current study focuses on overtaking—specifically, on gap-acceptance decisions that occur after an oncoming vehicle has been detected. We hypothesized that the size of an oncoming vehicle would influence overtaking judgments, and that drivers would accept a greater number of gaps for small oncoming vehicles than large oncoming vehicles.

Improving the accuracy of overtaking judgments would increase safety. To improve accuracy in overtaking judgments, it is important to identify whether errors are due to a motorist's inability to discriminate between safe and unsafe gaps or to a greater likelihood of choosing one response over the other. These response characteristics can be measured with sensitivity and response bias in the framework of signal detection theory (Stanislaw & Todorov, 1999), which we use here.

1.4. Effects of feedback on overtaking judgments

Judging whether a gap is acceptable during overtaking is difficult for drivers. Observations of drivers on an English highway indicated that 14% of overtaking maneuvers were initiated when gap size was insufficient, resulting mostly in lane sharing (overtaking while partially in both lanes) and cutting in (re-entering the original lane with an unsafe headway in front of the overtaken vehicle) (Wilson & Best, 1982). Furthermore, when participants judged

the last safe moment at which an overtaking maneuver could be initiated in the face of an oncoming vehicle, more than 30% of responses were too late—when there was insufficient time to safely pass (Jones & Heimstra, 1964). In a similar task, in which drivers estimated the last moment at which they could pass a lead car and still return back to the right lane before reaching a specified location in the road, the differences between the drivers' estimates and their actual performance ranged from 20% to 50% (Gordon & Mast, 1970).

Judgment errors in the studies by Jones and Heimstra (1964), and Gordon and Mast (1970), may have occurred, in part, because participants did not receive feedback on their overtaking decisions. This is supported by a study of overtaking in which on-road participants first estimated the last safe moment to pass a lead car in front of an oncoming vehicle (Lucas et al., 1973) and then made the same judgments using filmed scenes. Participants who were given feedback on judgment accuracy showed significant improvement in subsequent on-road judgments, as compared to a group who did not receive the feedback. The importance of feedback was shown more recently in a driving simulator study in which participants made more unsafe passive overtaking judgments than they did active overtaking maneuvers (Gray & Regan, 2005). During passive trials, participants reported overtaking decisions by pressing a button whereas during active trials participants completed the overtaking maneuver and thus received visual feedback from their actions. The implication for transportation safety is that drivers' overtaking decisions may improve after completing active training (i.e., getting visual feedback) in a driving simulator. Consequently, we included active and passive conditions in our study and expected that active participants would make safer overtaking judgments than passive participants.

2. Experiment 1

The purpose of the current study was to determine whether overtaking judgments are influenced by the size of an oncoming vehicle, and by whether a driver actively conducts the overtaking maneuver or passively judges whether it was safe to overtake. Because optical expansion is below threshold during high-speed overtaking, putatively leading drivers to use depth cues to judge distance, we anticipated that drivers would be more likely to accept a gap as safe for overtaking when the oncoming vehicle was a motorcycle rather than a larger car or truck. The gap acceptance paradigm is commonly employed (Kirkby & Stroud, 1978; Pai, 2011) and has been characterized as the most direct test of a driver's likelihood of accepting a gap in different traffic scenarios (Sager et al., 2014). We also expected safer judgments during active overtaking maneuvers than passive judgments because active control provides visual feedback.

2.1. Method

2.1.1. Participants

Twenty-four college students (12 male, 12 female) between 17 and 35 years of age ($M = 21.83$, $SD = 3.91$) participated for course credit in an introductory psychology course. Participants were recruited through an online sign-up system. All held a driver's license for between 1 and 9 years ($M = 4.32$, $SD = 2.11$) and reported normal or corrected visual acuity, and normal hearing and motor control. None currently or previously held a motorcycle license.

2.1.2. Apparatus

Traffic scenes were created with a STISIM Drive™ simulator housed in a 2.40 GHz computer. STISIM Drive™ is a medium-fidelity driving software package (Tilak et al., 2008; Tippey et al., 2014), and is widely used to evaluate driving performance (Freund et al., 2002; 2005; Lee et al., 2003; Shechtman, 2010). Data collected with STISIM Drive™ have been shown to correlate with data collected during on-road testing (Bédard et al., 2010; Lee et al., 2003;

Shechtman, 2010). A Logitech force-feedback steering wheel and floor-mounted throttle and brake pedals were used by participants to drive the simulated vehicle. Sound was also used to provide road noise, engine acceleration and deceleration, and tire screeches. STISIM DriveTM has been characterized as a driving simulator that responds to driver inputs and presents realistic traffic scenes in real time (Freund et al., 2005).

Scenes were presented in 1280 x 1024 pixel resolution on a flat panel LCD monitor subtending 68° diagonally, and were updated at 30 frames/s. Levers on the steering wheel allowed participants to rotate their viewing positions, which simulated looking over one's shoulder while changing lanes.

2.1.3. Displays

Scenes depicted a car-following scenario on a straight, two-lane, two-way highway (see Figure 2). Each lane was 4.27 m wide and the lanes were divided by a dashed yellow line. The speed limit was posted with a 65-mph sign (104.61 km/h). At the start of each scene, the participant's vehicle traveled 16.76 m behind a lead car (white Dodge Intrepid) in the right lane. The steering and speed of the participant's vehicle were automatically controlled; speed matched that of the lead car. An oncoming vehicle was visible, and consisted of a motorcycle, a town car, or a large delivery truck. The vehicle widths were 0.76 m, 2.13 m, and 2.59 m for the motorcycle, car, and truck, respectively. Seven seconds after the start of the scene, a 1000-Hz auditory tone signaled participants to make their decision. The oncoming vehicle was visible for the entire approach. In contrast to Gray and Regan (2005), the oncoming vehicle's rate of optical expansion, and thus tau, was always below previous threshold estimates (Muttart et al., 2005) when the tone occurred.

Figure 2. A screen shot of a scene.

2.1.4. Procedure

Participants viewed displays from 41.13 cm. First, they were familiarized with the handling, acceleration, and braking capabilities of the simulated vehicle by passing lead cars with maximum acceleration on a two-lane highway without oncoming vehicles. Then participants practiced the overtaking task with five trials that presented a safe overtaking opportunity. Participants were randomly assigned to the active or passive condition. In both conditions, participants were told that their car would initially follow a lead car on a two-lane, two-way highway, and that an oncoming vehicle would be present in the opposite lane.

2.1.4.1. Active condition

Participants were informed that, at the beginning of each scene, the steering and speed of their vehicle would be automatically controlled, and that the speedometer on their simulated dashboard would display their current speed. They were told that they would get complete control of their vehicle when a tone occurred and that they should pass the lead car if they felt it was safe to do so. They were further instructed to drive the simulated car as they would on a real highway, obey the rules of the road, and avoid accidents.

2.1.4.2. Passive condition

The passive condition was identical to the active condition except that participants were informed that the steering and speed of their vehicle would be controlled for the duration of each scene. They were told that, when the tone occurred, they should report whether they felt it was safe to pass the lead car, using buttons on the steering wheel.

Feedback on decision accuracy was not provided, but active participants received visual feedback when they maneuvered the vehicle. Participants in both conditions completed four blocks of 27 trials, each separated by a rest period. The entire experiment lasted approximately 70 minutes.

2.1.5. Design

Our main variable of interest was oncoming vehicle size. To include both safe gaps and unsafe gaps, we created different temporal gap sizes at the time the tone occurred. We did this by manipulating the speed of the participant's car (and lead car; 48.28 km/h, 64.37 km/h, 80.47 km/h) and the speed of the oncoming vehicle (72.42 km/h, 88.51 km/h, 104.61 km/h). In addition, the distance between the oncoming vehicle and the front of the participant's vehicle was either 457.20 m or 609.60 m at the time of the tone. These manipulations resulted in nine safe gaps ($TTC - TRO > 0$) and nine unsafe gaps ($TTC - TRO < 0$). Both safe and unsafe gaps occurred within each level of the manipulated parameters so that accurate overtaking judgments could not be achieved on the basis of any one of these variables (e.g., distance). Each temporal gap was presented twice for each vehicle size, resulting in 108 trials. The order of trials was counterbalanced across participants. The largest optical expansion rate of the oncoming vehicle when the tone signaled the participant to respond was 0.0009 rad/s. This is well below previous estimates of expansion detection threshold.

2.1.6. Analyses

Data from 24 of the 2592 total trials (0.93%) were removed due to a software bug that prevented the tone from being presented. We separately analyzed the percentage of accepted gaps and false alarms, and signal detection theory measures of sensitivity (d') and response bias (β). For passive participants, an accepted gap occurred when they reported it was safe to pass. For active participants, an accepted gap occurred when their vehicle crossed the center line. A false alarm occurred when a participant accepted a gap when a safe overtaking maneuver was not possible ($TTC - TRO < 0$).

To further understand the effect of oncoming vehicle size on overtaking decisions, we analyzed d' and β . In each trial, a signal (safe gap) was either present ($TTC - TRO > 0$) or absent ($TTC - TRO < 0$), and the participant indicated that the signal was either present (accepted the gap) or absent (rejected the gap). When the hit rate or false alarm rate for a given subject and vehicle was 0.00 or 1.00 it was replaced with 0.01 and 0.99, respectively (DeLucia & Novak, 1997).

The hit rate and false alarm rate were used to calculate d' and β for each subject and vehicle size. A value of 0 for d' indicates an inability to discriminate between safe and unsafe gaps. Relatively larger d' values indicate relatively greater sensitivity. A value of 1 for β indicates no bias: the participant reported that the gap was safe equally as often as reporting that the gap was unsafe. β values above 1 indicate a conservative criterion: participants' judgments were biased toward rejecting the gap—reporting that it was unsafe (Stanislaw & Todorov, 1999). β values below 1 indicate a liberal criterion: participants' judgments were biased toward accepting the gap—reporting that it was safe.

Analyses focused on our primary variables of interest—the size of the oncoming vehicle (motorcycle, car, truck), and control type (active, passive). Each dependent variable was

analyzed with a 2 (control type: active, passive) x 3 (vehicle size: motorcycle, car, truck) mixed analysis of variance (ANOVA) with control type as a between-groups factor. The same pattern of results occurred when we analyzed the arcsine transformation of the percentage of accepted gaps and false alarms. Significant main effects of vehicle size were followed up with Tukey HSD tests with alpha set to .05.

2.2. Results

2.2.1. Accepted gaps

Results are summarized in Table 1, and indicated a main effect of vehicle size on the percentage of accepted gaps. Tukey HSD tests indicated that participants accepted a larger percentage of gaps in front of motorcycles than cars and trucks. The difference between cars and trucks also was significant. The main effect of control type was not significant.

Table 1

Main effects of oncoming vehicle size in Experiment 1

Effect	Oncoming vehicle size <i>M (SD)</i>			<i>F</i>	<i>df</i>	<i>p</i>	η_p^2
	Motorcycle	Car	Truck				
Accepted gaps (%)	63.15 (29.89)	43.55 (25.97)	31.90 (23.59)	52.06	2, 44	.0001	0.70
False alarms (%)	24.93 (16.04)	12.76 (10.95)	7.87 (9.26)	33.73	2, 44	.0001	0.61
<i>d'</i>	1.13 (0.59)	1.27 (0.75)	1.12 (0.74)	0.56	2, 44	.5740	0.03
β	0.92 (1.08)	2.45 (3.85)	2.70 (3.36)	3.22	2, 44	.0496	0.13

2.2.2. False alarms

The main effect of vehicle size on the percentage of false alarms was also significant. Participants exhibited a larger percentage of false alarms in front of motorcycles than cars and trucks. The difference between cars and trucks was not significant. The main effect of control type was not significant.

2.2.3. Signal detection theory measures

Results indicated that mean d' was not affected by either vehicle size or control type. The main effect of vehicle size on β was significant. However, Tukey HSD tests did not indicate any significant pairwise differences among vehicle sizes. The main effect of control type was not significant.

2.3. Discussion

Our hypothesis that participants would be more likely to accept a gap as safe for overtaking when the oncoming vehicle was a motorcycle rather than a car or large truck was supported. The percentages of accepted gaps and false alarms were higher for motorcycles than for either cars or trucks. Our signal detection theory analyses suggest that these differences were not due to changes in sensitivity for the different vehicles, consistent with the idea that tau was below threshold. Results of response bias were ambiguous; the overall F -test showed a main effect of vehicle size, but the perhaps too conservative Tukey tests did not indicate any significant pairwise differences among vehicles.

Our hypothesis that overtaking judgments would be safer for participants who actively conduct overtaking maneuvers than for those who passively judge whether it is safe to overtake was not supported. Effects of control type were not significant for any of our dependent measures. This result is not consistent with those of Gray and Regan (2005), who reported that overall performance was worse for passive overtaking judgments: participants made unsafe overtaking maneuvers on a smaller percentage of active trials than they did unsafe overtaking judgments in passive trials. This discrepancy may be partly due to differences in visual information provided in the two studies. Whereas Gray and Regan (2005) reported presenting some scenes in which tau was above threshold, in the current study, tau was always below

threshold at the moment the overtaking decision occurred. The ineffective expansion information in our study may have reduced the benefits of feedback from active control.

3. Experiment 2

Results of Experiment 1 suggest that the size of an oncoming vehicle influences overtaking judgments. However, we cannot rule out the effect of vehicle type, which covaried with size as it does in the real world. It may be that drivers were using a simple rule to pass in front of motorcycles but not delivery trucks (e.g., perhaps trucks are seen as more harmful than motorcycles). To rule out this interpretation, we conducted Experiment 2 to tease apart the effects of vehicle size and type. Using 3D modeling software, we reduced the size of the original delivery truck until it was the same size as the motorcycle. Similarly, we increased the size of the original motorcycle until it was the same size as the original delivery truck. This allowed for comparisons among a small motorcycle, small delivery truck, large motorcycle, and large delivery truck. If vehicle size is the basis for the results of Experiment 1, we should find differences between the small and large vehicles regardless of whether they are motorcycles or trucks. If vehicle type underlies the results, we should find differences between the motorcycle and truck regardless of their sizes.

3.1. Method

3.1.1. Participants

Twenty-four college students (12 male, 12 female) between 18 and 48 years of age ($M = 21.88$, $SD = 7.24$) participated for course credit in an introductory psychology course. Participants were recruited through an online sign-up system.. All held a driver's license for between 0.3 and 30 years ($M = 5.30$, $SD = 5.66$) and reported normal or corrected visual acuity, and normal hearing and motor control. None currently or previously held a motorcycle license.

3.1.2. Displays and procedure

The apparatus, displays, procedure, and design were as described in Experiment 1 except for modifications necessary to accommodate a fourth oncoming vehicle. We used Google SketchUp, a 3D modeling program, to alter the sizes of the original motorcycle and delivery truck to produce two sets of vehicles that were identical in size. Specifically, the delivery truck from Experiment 1 was reduced in size until it matched that of the motorcycle. The motorcycle's size was increased until it matched that of the delivery truck. Because the original vehicles did not have identical width-to-height ratios we also slightly altered their dimensions to produce vehicles of equal size that did not appear distorted on the width or height dimensions. The final vehicle dimensions were as follows: small motorcycle and small truck: 1.10 m (width) by 1.52 m (height); large motorcycle and large truck: 3.20 m (width) by 4.42 m (height). As in Experiment 1, each of the 18 temporal gaps was presented twice for each vehicle. This resulted in a total of 144 experimental trials. The entire experiment lasted just under 90 minutes.

3.1.3. Analyses

Analyses were identical to Experiment 1, except that we had four oncoming vehicles. Each dependent variable was analyzed with a 2 (control type: active, passive) x 4 (oncoming vehicle: small motorcycle, small truck, large motorcycle, large truck) mixed ANOVA with control type as a between-groups factor. Due to violations of sphericity, probability values for all effects of the oncoming vehicle reflect Greenhouse-Geisser corrections.

3.2. Results

3.2.1. Accepted gaps

Results are summarized in Table 2, and indicated a main effect of the oncoming vehicle on the percentage of accepted gaps. Participants accepted a larger percentage of gaps in front of

small motorcycles and small trucks than either large motorcycles or large trucks. The differences between small motorcycles and small trucks and between large motorcycles and large trucks were not significant. The main effect of control type was not significant.

Table 2

Main effects of the oncoming vehicle in Experiment 2

Effect	Oncoming vehicle M (SD)				F	df	p	η_p^2
	Small motorcycle	Small truck	Large motorcycle	Large truck				
Accepted gaps (%)	79.16 (16.64)	72.09 (23.48)	20.53 (23.49)	23.49 (25.74)	119.17	3, 66	.0001	0.84
False alarms (%)	33.61 (12.33)	29.74 (16.22)	5.22 (9.10)	7.22 (11.09)	87.87	3, 66	.0001	0.80
d'	0.92 (0.69)	0.89 (0.87)	0.91 (0.74)	0.82 (0.69)	0.09	3, 66	.9138	0.00
β	0.58 (0.36)	1.59 (2.75)	4.14 (4.58)	3.58 (4.34)	6.12	3, 66	.0026	0.22

Note. p values reflect Greenhouse-Geisser corrections

3.2.2. False alarms

The main effect of the oncoming vehicle on the percentage of false alarms was significant. Participants exhibited a larger percentage of false alarms in front of small motorcycles and small trucks than large motorcycles and large trucks. Just as for the percentage of accepted gaps, the differences between small motorcycles and small trucks, and between large motorcycles and large trucks, were not significant. The main effect of control type was not significant.

3.2.3. Signal detection theory measures

The main effect of the oncoming vehicle on mean d' was not significant. The main effect of control type also was not significant. The main effect of oncoming vehicle on mean β was significant. Mean β was greater for large motorcycles than for either small motorcycles or small trucks, and was greater for large trucks than small motorcycles. Differences between large trucks

and large motorcycles, and between small motorcycles and small trucks, were not significant. The main effect of control type was not significant.

3.3. Discussion

In Experiment 2, participants accepted more gaps and exhibited more false alarms in front of small motorcycles and small delivery trucks than they did in front of larger versions of the same vehicles. The implication is that participants did not base their judgments on vehicle type (and associations such as differential harm), but rather used vehicle size as a primary cue. These findings support our interpretation of the results from Experiment 1. Furthermore, our analyses of d' and β suggest that the differences in overtaking behavior among the different vehicles was due to changes in response bias rather than sensitivity.

4. General discussion

The purpose of the current study was to determine whether overtaking judgments are influenced by the size of an oncoming vehicle, and by whether a driver actively conducts an overtaking maneuver or passively judges whether it is safe to overtake. We hypothesized that the size of an oncoming vehicle would influence overtaking decisions because rate of optical expansion is below threshold during high-speed overtaking, putatively leading participants to rely on perceived distance and velocity. Results of Experiment 1 supported this hypothesis: participants accepted more gaps as safe, and committed more false alarms, when the oncoming vehicle was a motorcycle than a car or large truck, consistent with previous reports of the size-arrival effect on driving-related judgments (Caird & Hancock, 1994; Horswill et al., 2005).

By carefully controlling the sizes of the different vehicle types in Experiment 2, we demonstrated that results of vehicle size—apart from vehicle type, affected overtaking decisions. Results of Experiment 2 suggested further that effects of size on overtaking decisions were due

to changes in response bias rather than sensitivity. Participants were more biased towards rejecting a gap as unsafe when the oncoming vehicle was a large motorcycle or large truck compared to smaller versions of these vehicles.

Our hypothesis that overtaking judgments would be safer for participants who actively conduct overtaking maneuvers (and thus receive visual feedback) than for those who passively judge whether it is safe to overtake was not supported. Effects of control type were not significant for any of our dependent measures in either experiment. This result is not consistent with those of Gray and Regan (2005), who reported that performance was worse for passive participants.

4.1. Vehicle size

In Experiment 1, participants exhibited almost twice as many accepted gaps and more than three times as many false alarms when the oncoming vehicle was a motorcycle compared to a delivery truck. Drivers may be particularly susceptible to effects of size during high-speed overtaking because optical expansion (and thus tau) is below threshold, presumably leading them to rely on less reliable heuristic information. Whether observers rely on accurate information such as tau, or heuristics such as relative size, during TTC judgments may depend on the distance of an approaching object and thus the quality of optical motion information such as expansion (DeLucia, 2008). Accepting more gaps in front of motorcycles than larger vehicles would increase a driver's risk of collision with motorcycles, and this effect of vehicle size may contribute to the relatively high rate of accidents in which a vehicle violates a motorcycle's right-of-way.

Our results regarding vehicle size both corroborate and extend studies of size in earlier studies. For example, effects of oncoming vehicle size on TTC judgments were demonstrated in

both left-hand turn (Caird & Hancock, 1994) and merging (Horswill et al., 2005) scenarios. Consistent with these studies, we obtained an effect of size on overtaking. However, these studies measured TTC estimations with a prediction-motion task. In this task, participants press a button to indicate the TTC of an approaching object after it has disappeared from view. This method has been criticized as being artificial (Hancock & Manser, 1997). In the current study, the oncoming vehicle was always visible and (active) participants performed an overtaking task. In addition, our study employed scenes with self-motion, whereas Horswill et al. (2005), and Caird and Hancock (1994) only used object (vehicle) motion. Compared to object motion alone, the addition of forward self-motion can increase the threshold for object motion detection (Probst et al., 1987) and can result in shorter and less accurate TTC estimates (Gray & Regan, 2000). The current study showed that the effects of size obtained with a prediction-motion task and object motion in prior studies generalize to a more realistic context that included self-motion, an oncoming vehicle that was always visible, and an active task.

4.2. Control type

Unexpectedly, the difference between active and passive conditions was not significant in either Experiment 1 or 2, which is not consistent with Gray and Regan (2005). A potentially important difference between studies was that Gray and Regan reported presenting some scenes in which optical expansion, and thus tau, was above threshold. In our study, optical expansion was always below threshold at the moment of the overtaking decision, which may have reduced the benefits of feedback from active control. Consequently, reliable information may not have been available to support perceptual learning. It would be worthwhile to determine whether drivers could benefit from other sources of information when tau is not available. This may

include lateral or downward motion of the vehicle in the driver's visual field (e.g., Sager et al., 2014).

A second possible contributor to the discrepant findings may be display differences. In Gray and Regan's (2005) passive trials, all vehicles except the participant's vehicle disappeared when the overtaking response was made. Consequently, participants did not see the entire approach of the oncoming vehicle in the passive trials, as they did in the active trials. In the latter, participants received additional visual information from the oncoming vehicle, potentially resulting in better performance. In contrast, in our study, active and passive participants saw the entire approach of the oncoming vehicle, reducing the differences between groups. Future research should investigate the conditions under which different forms of feedback influence performance. In addition to viewing the oncoming vehicle's approach, other sources of feedback might include information about an oncoming vehicle's absolute TTC or whether overtaking was actually safe on a given trial.

Finally, another possible source of the discrepancy between the results of Gray and Regan (2005) and the current study pertains to the transition from automated to manual control. In Gray and Regan's study, participants completed a series of 10 overtaking maneuvers during each active trial, and maintained control of their vehicle for the duration of the trial. In our study, when active participants decided to overtake, they only completed a single overtaking maneuver during a trial, and were given control of the vehicle seven seconds after the scene's onset. This transition from automated to manual control may have made the active task more difficult than the passive task and should be investigated in future studies.

4.3. Limitations

Although our results indicate that oncoming vehicle size influences overtaking judgments, the current study has limitations that warrant further research. For example, the overtaking scenarios used in the current study were less complex than those typically encountered in real-world driving: the current study employed straight sections of roadway in good weather and visibility, and vehicles that behaved predictably and travelled at constant speeds. However, in the real world, characteristics of roadway geometry, weather, visibility, and driver behavior are much more variable. In addition, the use of a simulator may have produced biases in decision-making, in which participants took more risks than they would have in the real world (Gray & Regan, 2005). Even if such biases occur, it is reasonable to expect that they would occur in the same manner under all conditions of oncoming vehicle size. That is, we aimed to measure the relative rather than the absolute effects of size on overtaking judgments. Indeed, studies comparing an on-road assessment to results generated from STISIM DriveTM exhibited such relative validity (Shechtman et al., 2009; Wang et al., 2010). In other words, our finding that motorcycles resulted in a greater percentage of accepted gaps than cars and trucks—the rank ordering of conditions—can be expected to occur in the real traffic environment, although the absolute percentage in each condition may not be the same as in the real world.

A further limitation of the current study is in the method we employed to determine gap safety. Specifically, gaps were defined as safe or unsafe a priori, using a formula derived from previous overtaking performance (Gordon & Mast, 1970), rather than with the participants' actual data. This was necessary because we did not have performance data for passive participants and needed an equivalent method for determining gap safety across the two conditions. Consequently, if a participant in our active condition accepted a gap as safe but failed to successfully execute the maneuver (e.g., because they lost control of the vehicle), their

judgment would have been correct. In other words, the current study focused on driver perception and the decision to overtake, rather than on vehicle control during overtaking.

4.4. Practical implications

Inaccurate judgments of temporal gap size during overtaking can have negative consequences for transportation safety. Accepting unsafe gaps increases the risk of collision with an oncoming vehicle. Rejecting safe gaps can result in traffic delays and decreased highway throughput. Reducing both types of errors has practical value. One possible remedy is to provide drivers with technological aids, for example, an “overtaking assistant” that provides drivers with information about when it is safe to overtake. Prototypes of driver-assistance systems to support overtaking maneuvers have been developed (e.g., Chiang et al., 2014; Hageman et al., 2007), but are not yet commercially available. Other interventions that improved a motorist’s ability to detect a motorcycle or judge its approach include increasing a motorcycle’s apparent size by employing alternative fairings or front lighting configurations (Gould et al., 2012; Mortimer & Schuldt, 1980; Williams & Hoffman, 1979), and instructing motorcycle riders to travel in the right portion of their lane, which may provide the overtaking driver with more motion cues (Sager et al., 2014). To the extent that the current results generalize to real-world traffic, it is worthwhile to pursue such measures to reduce the incidence of collisions in which a vehicle violates a motorcycle’s right-of-way.

Furthermore, effects of size on response bias during overtaking judgments suggest that such judgments are malleable. The implication is that training may ameliorate the size-arrival effect and improve overtaking judgments. Training via visual feedback alone may not be effective, implicated by the absence of control-type effects in the current study. Providing drivers with experience riding motorcycles (e.g., via driving simulations) is worthy to consider: drivers

with such experience appear to be less frequently involved in crashes in which a vehicle violates a motorcycle's right-of-way (Hurt et al., 1981). Similarly, drivers involved in motorcycle-car crashes who hold a motorcycle license are less likely to be at fault than those without a motorcycle license (Magazzu et al., 2006). This may be due to differences in perceptual strategies: drivers with motorcycle licenses attended more to motorcycles (Shahar et al., 2012) and were better at hazard perception (Horswill & Helman, 2003), compared to drivers without motorcycle licenses.

Another difference between drivers with and without motorcycle licenses is that the former group putatively has greater familiarity with motorcycles and consequently might be more accurate at estimating a motorcycle's distance based on its optical size. Familiar size information can increase the reliability of TTC judgments (Lopez-Moliner et al., 2007), and reduce size-arrival effects (DeLucia, 2005; but see Hosking & Crassini, 2011). The implication is that familiarity with motorcycles, particularly their sizes, may improve judgments of their TTCs.

4.5. Conclusions

This study showed that overtaking judgments are influenced by the size of an oncoming vehicle and that this effect is independent of vehicle type. Participants accepted more gaps as safe and committed more false alarms in front of relatively smaller oncoming vehicles. Results suggest further that effects of size on overtaking decisions were due to changes in response bias rather than sensitivity. Participants were more biased towards rejecting a gap as unsafe when the oncoming vehicle was a large motorcycle or large truck compared to smaller versions of these vehicles. The current results have important practical implications for roadway safety and the development of driver-assistance systems that could help drivers make safer overtaking judgments.

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