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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.

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 and Regan, 2005). This is represented in Fig. 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.

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:

$$\text{DRO} = 34.20 + 2.88V + .01094V^2$$

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 and 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

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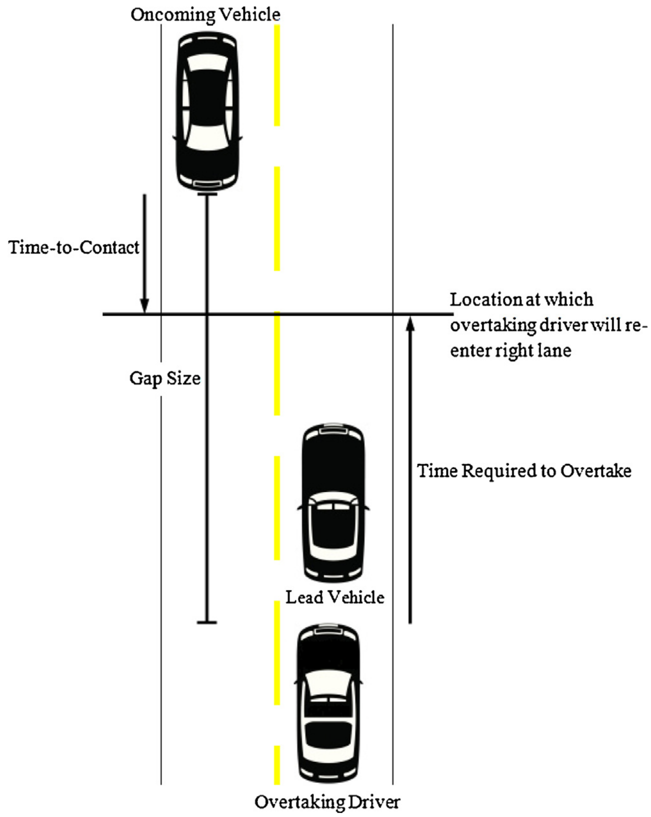

Fig. 1. Representation of the physical variables that must be considered when determining whether a gap is large enough for an overtaking maneuver.
Adapted from "Perceptual Processes Used by Drivers During Overtaking in a Driving Simulator" by R. Gray and D.M. Regan, 2005, Human Factors, 47, p. 409.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

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 they 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.

However, even when tau is available, TTC judgments can be influenced by less reliable information. Of particular relevance to this study is the effect of size on such judgments: a small near approaching object can appear to arrive later than a large far approaching object that is specified by tau to arrive later, known as the size-arrival effect (DeLucia, 1991, 2013; DeLucia and Warren, 1994; Smith et al., 2001). For example, when participants used a driving simulator to estimate when an approaching vehicle would reach their intersection during a left-turn scenario, mean TTC judgments generally decreased as the approaching vehicle size increased (e.g., motorcycle vs delivery van; Caird and Hancock, 1994). Similarly, when participants viewed videos of vehicles that approached a traffic intersection, filmed from the view of a driver waiting on the non-priority road, estimates of when the approaching vehicles would arrive at a tarmac strip in front of the driver's location were greater for motorcycles than larger vehicles (Horswill et al., 2005).

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

When tau is not effective, it is reasonable to expect drivers to base overtaking judgments on other information. We considered the possibility that drivers rely on the oncoming vehicle's apparent distance and velocity (Cavallo and Laurent, 1988; Smeets et al., 1996). In this case, 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, 4957 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 traveled, 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 motorist 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