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Drivers' rear end collision avoidance behaviors under different levels of situational urgency

Xuesong Wang [a,b,*], Meixin Zhu [a], Ming Chen [b], Paul Tremont [b]

[a] The Key Laboratory of Road and Traffic Engineering, Ministry of Education, Shanghai 201804, China
[b] School of Transportation Engineering, Tongji University, Shanghai 201804, China

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ABSTRACT

Rear-end collisions have been estimated to account for 20–30% of all crashes, and about 10% of all fatal crashes. A thorough investigation of drivers' collision avoidance behaviors when exposed to rear end collision risks is needed to help guide the development of effective countermeasures. Urgency or criticality of the situation affects drivers' collision behavior, but has not been systematically investigated. A high fidelity driving simulator was used to examine the effects of differing levels of situational urgency on drivers' collision avoidance behaviors. Drivers' braking and steering decisions, perception response times, throttle release response times, throttle to brake transition times, brake delays, maximum brake pedal pressures and peak decelerations were recorded under lead vehicle decelerations of 0.3 g, 0.5 g, and 0.75 g and under headways of 1.5 s and 2.5 s. Results showed (1) as situational urgency increased, drivers released the accelerator and braked to maximum more quickly; (2) the transition time between initial throttle release and brake initiation was not affected by situational urgency; (3) at low situational urgency, multi-stage braking behavior led to longer delays from brake initiation to full braking. These findings show that effects of situational urgency on drivers' response times, braking delays, and braking intensity should be considered when developing forward collision warnings systems.

1. Introduction

In the US, rear-end collisions account for approximately 32% of all crashes and 6% of fatal crashes (Traffic Safety Facts, 2013), in Japan, about 35% of all crashes (Watanabe and Ito, 2007), and in Germany about 22% of all crashes (German Federal Statistical Office, 2009). In Shanghai, China, Wang et al. (2011) reported that rear-end crashes accounted for about 20% of all crashes, but 49% of elevated expressway crashes and 67% of tunnel crashes.

Rear-end collisions are usually attributed to (1) insufficient headway, (2) late brake response, and (3) insufficient brake force (Winsum and Heino, 1996). A thorough investigation of how drivers respond and brake in collision imminent situations is needed to improve FCW systems.

Perception Response Time (PRT), a component of collision avoidance behaviors, is defined as the time required to perceive, interpret, decide, and initiate a response to some stimulus, e.g., sudden brake of the lead vehicle (LV) (Sohn and Stepleman, 1998). PRT is an important component of Forward Collision Warning (FCW) timing algorithms (Kiefer et al., 1999) and is essential for accident reconstruction analyses (Ising et al., 2012). Previous research has reported PRTs from

* Corresponding author at: School of Transportation Engineering, Tongji University, Shanghai 201804, China.
E-mail address: wangxs@tongji.edu.cn (X. Wang).

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0.5 to 10 s for various tasks (Muttart, 2005). This large range is attributable to the dependence of PRT on a myriad of factors including expectation, age, gender, and cognitive load (Green, 2000).

One key variable affecting PRTs is urgency or criticality of the situation (Summala, 2000). Situational urgency has been measured using two types of indicators. One type characterizes situational urgency by the initial state of the scenario, e.g., the following distance, headway, and Time to Collision (TTC) at LV brake onset. Another type characterizes situational urgency by the rate of LV deceleration.

Using the initial state urgency indicator, Liebermann et al. (1995) and Schweitzer et al. (1995) tested effects of both speed and following distance on PRT. Neither study found an effect of speed, however both studies found shorter following distances (6 m vs. 12 m) produced faster responses. Summala et al. (1998) tested drivers' PRTs under 4 different initial distance and speed combinations (15 m, 30 km/h; 30 m, 30 km/h; 30 m, 60 km/h; 60 m, 60 km/h). They also found no speed effect. PRT increased with increases in following distance. Aust et al. (2013) reported that PRT was overall significantly longer in the long initial headway (at LV brake onset) condition. Based on a meta-analysis of several experimental studies, Engström (2010) found that PRT was almost linearly correlated with initial headway, that is, the shorter the initial headway, the faster the response. Using the rate of LV deceleration urgency indicator, Hulst (1999) tested the effect of LV deceleration rate on PRT, and found the PRT for fast decelerations (2 m/s^2) was shorter than for slow decelerations (1 m/s^2).

To date, few studies, e.g., Lee et al. (2002), manipulated situational urgency using both the initial state and deceleration rate urgency indicators. Considering that urgency as defined by an initial state is operationally different from urgency defined by deceleration rate, it is advantageous to consider both definitions to realize a full understanding of the effects of situational urgency on PRT.

Previous studies concerning the effects of situational urgency focused on drivers' response times before braking by capturing brake/perception response times or accelerator release times. These measures reflect what drivers do before braking, but tell us nothing about what drivers do with the brake after the foot gets to the pedal. However, studies on braking behaviors have consistently shown that a driver-related delay was observed between initial brake application and full emergency braking (Ising et al., 2012; Hirose et al., 2008; Perron et al., 2001; Kiesewetter et al., 1999; Yoshida et al., 1998). Also, studies have shown that drivers, especially unskilled ones, often fail to apply sufficient force on the brake pedal in an emergency (Kassaagi et al., 2003; Roody, 2011). Therefore, investigating effects of situational urgency on braking delay and intensity is necessary to fully understand drivers' braking behaviors.

The objective of this study was to quantify the response times and braking behaviors drivers exhibit under varying levels of situational urgency. Driving simulators are ideal for performing these kinds of studies because of their ability to systematically vary perceived urgency while capturing quantitative data on relevant aspects of driver and system performance (Boyle and Lee, 2010). In this study, the Tongji University Driving Simulator was used to generate different urgency levels by varying headway and LV deceleration while capturing data on perception response times (PRT), throttle release response times, throttle to brake transition times, brake delays, maximum brake pedal pressures and peak decelerations. The relationships uncovered between situational urgency and drivers' collision avoidance behavior measures can provide information that can be used to develop improved FCW systems.

2. Methods

2.1. Experimental design

2.1.1. Independent variables

A three-factor within-subjects design was used. The independent variables were LV deceleration, initial headway and exposure. Three levels of LV deceleration (0.3 g, 0.5 g, and 0.75 g) and two levels of initial headway (1.5 s and 2.5 s) were combined to produce rear-end scenarios with different urgency levels. The order of presentation was counterbalanced across drivers using a pseudo-randomization procedure described by Curry et al. (2005). This procedure resulted in $2 \times 3 = 6$ trials experienced by each participant. The exposure referred to the presentation order of the trial within a subject, and had 6 levels, and aimed to test whether drivers behaved differently across the 6 trials. A description of the independent variables is presented in Table 1.

Effects of driver age, gender, and driving experience were considered, but were not reported in this research. All the decelerations mentioned in this article refer to absolute values of deceleration rates and therefore no minus signs were added.

Table 1
Description of independent variables.

Independent variables	Conditions
Initial headway (within)	1.5 s; 2.5 s
LV deceleration (within)	0.3 g; 0.5 g; 0.75 g
Exposure (within)	1st trial; 2nd trial; 3rd trial; 4th trial; 5th trial; 6th trial