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Developing an inverse time-to-collision crash alert timing approach based on drivers' last-second braking and steering judgments

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Abstract

Drivers were asked to execute last-second braking and steering maneuvers while approaching a surrogate target lead vehicle. This surrogate target was designed to allow safely placing naive drivers in controlled, realistic rear-end crash scenarios under test track conditions. Maneuver intensity instructions were varied so that drivers' perceptions of normal and non-normal braking envelopes could be properly identified and modeled for forward collision warning timing purposes. The database modeled includes 3536 last-second braking judgment trials. A promising inverse time-to-collision model was developed, which assumes that the driver deceleration response in response to a crash alert is based on an inverse time-to-collision threshold that decreases linearly with driver speed.

Keywords: Crash avoidance; Collision warning; Rear-end crashes; Time to collision; Time to contact; Braking

1. Introduction

Forward collision warning (FCW) is an emerging automotive safety technology that provides alerts intended to assist drivers in avoiding rear-end crashes. Key to driver acceptance of this technology is appropriate *crash alert timing*, which refers to the necessary underlying vehicle-to-vehicle kinematic conditions for triggering the onset of crash alerts. The goal of the alert timing approach is to allow the driver enough time to avoid the crash, and yet avoid annoying the driver with alerts perceived as occurring too early or unnecessary.

To develop appropriate FCW timing, two driver behavior parameters should be considered, which serve as input into kinematic equations that determine the alert range necessary to assist the driver in avoiding a potential crash. The first parameter is driver brake reaction time, which refers to the time between crash alert onset and the driver triggering the brake switch. The second parameter is the driver deceleration behavior in response to the crash alert. The current research is aimed at continuing to develop assumptions for this second parameter, which have been previously examined by Kiefer et al. (1999) under test track conditions with both surprised and alerted drivers.

Kiefer et al. (1999) asked drivers to perform last-second braking maneuvers while approaching a *surrogate target* lead vehicle without FCW system alerts. The surrogate target, shown in Fig. 1, refers to the vehicle ahead of the following driver's vehicle during a driving maneuver. This target was designed to allow for safe impacts at low impact velocities and allow experimenters to safely place naive drivers in controlled, realistic rear-end crash conditions. The need for obtaining data under these conditions is dictated by the infrequency of near and actual collisions in the real world, the sparseness of electronic crash recording data available during these situations, and the inherent difficulties involved in precisely reconstructing an accident. Furthermore, attempts to define crash alert timing based on research that places drivers under minimal risk or no crash risk (e.g., driving simulator) conditions has the potential to lead to alerts that occur too late (Kiefer et al., 1999).

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Fig. 1. The surrogate target lead vehicle methodology and test track employed in the Kiefer et al. (1999) study.

In the Kiefer et al. (1999) study, drivers were instructed to use either normal or hard braking intensity during last-second braking judgments under various in-lane approaches. These data were used to identify drivers' perceptions of normal and non-normal braking envelopes, and to generate a brake onset model, which estimates the assumed driver deceleration in response to a FCW alert based on prevailing vehicle-to-vehicle kinematic conditions. An underlying assumption of this approach is that alert timing based on rules for judging threatening conditions that are different than those employed by drivers may well be considered unnatural and unacceptable by drivers.

Unlike the Kiefer et al. (1999) study, the current study examined both last-second braking and steering maneuvers, both normal and long (3 s) following headway conditions, and in-lane approaches to a lead vehicle moving at a slower but constant speed. This additional last-second steering data was used to examine the extent to which a FCW timing approach based on driver braking assumptions could annoy drivers intending to perform a lane-change maneuver around the vehicle ahead.

There are a number of commonalities between the current and Kiefer et al. (1999) studies that enabled the possibility of combining these data sets, provided comparable results were observed across studies. First, a subset of the Kiefer et al. normal and hard last-second braking scenarios were included in the current study. Second, identical age and gender requirements were used in both studies. Third, both studies were conducted on a straight, level, smooth, asphalt, dry road under daytime conditions. The previous Kiefer et al. data was gathered at the General Motors Milford Proving Ground test site in Milford, Michigan, and the current data was gathered at the Transportation Research Center in East Liberty, Ohio.

2. Method

2.1. Subjects

Seventy-two subjects were recruited from three age groups. The younger, middle-aged, and older groups ranged from 20 to 30, 40 to 50, and 60 to 70 years old, respectively. Each age group contained 12 males and 12 females. Each subject was tested individually in one 2–2.5 h session and paid $150 for their participation. The General Motors Institutional Review Board approved the experimental protocol.

2.2. Subject vehicle, surrogate target lead vehicle, and principal other vehicle

As illustrated in Fig. 1, the following vehicle driven by the participant was a 1997 Ford Taurus SHO, referred to as the subject vehicle (or SV). The principle other vehicle (or POV), also a 1997 Ford Taurus SHO, towed the surrogate target lead vehicle. The surrogate target was a three-dimensional mock-up of a 1997 Mercury Sable rear end mounted on a lightweight trailer frame. The mock rear end was constructed of polyurethane with a thin, reinforcing fiberglass undercoat, and equipped with working brake lights. The trailer was equipped with a high-density Styrofoam and coiled spring bumper. The mock rear end and trailer was attached to a 40-foot (12.2 m) telescoping, tow-beam capable of collapsing approximately 9 feet (2.7 m).

2.3. Data acquisition and experimenters

The SV and POV were instrumented to record the speed and longitudinal acceleration of both test vehicles and the range between the two vehicles at 30 Hz. The SV and POV data acquisition systems were networked using a LAN link. Two experimenters rode in the SV with the test participant. The back-seat experimenter instructed participants through the trials and operated the data acquisition system, which included the ability to automatically control the POV speed and deceleration levels.

The front-seat, passenger–experimenter was a trained test driver who had access to an override brake pedal to prevent collisions with the surrogate target. The SV experimenters and the POV test driver communicated during the study via digital radio.