Journal of Safety Research xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Journal of Safety Research

journal homepage: www.elsevier.com/locate/jsr

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Using Naturalistic Driving Study data to investigate the impact of driver distraction on driver's brake reaction time in freeway rear-end events in car-following situation

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A R T I C L E   I N F O

Article history:
Received 6 January 2017
Received in revised form 10 October 2017
Accepted 10 October 2017
Available online xxxx

Keywords:
Naturalistic Driving Study
Rear-end event
Driver distraction
Reaction time
Car-following

A B S T R A C T

Introduction: rear-end crash is one of the most common types in freeway crashes, and driver distraction is often cited as a leading cause of rear-end crashes. Previous research indicates that driver distraction could have negative effects on driving performance, but the specific association between driver distraction and crash risk is still not fully revealed. This study aimed to understand the mechanism by which driver distraction, defied as secondary task distraction, could influence crash risk, indicated by driver's reaction time, in freeway rear-end events in car-following situation. *Method:* Analysis of variance was conducted to explore causal model structure regarding driver distraction's impact on reaction time. Distraction duration representing how long driver distraction lasted, distraction scenario depicting when driver distraction presented, and secondary task type indicating whether driver was visually, auditorily, or manually distracted, were chosen as distraction-related factors. Besides, exogenous factors including weather condition, visual obstruction, lighting condition, traffic density, and intersection presence and endogenous factors including driver age and gender have also been taken into consideration. *Results:* 103 freeway rear-end events were extracted from the SHRP 2 Naturalistic Driving Study database. The statistical analysis shows that there was association between driver distraction and reaction time in the sample events. Distraction duration, the distracted status when a leader braked, and secondary task type were related to reaction time, while all other factors did not show significant effect on driver reaction time in studied events. *Conclusions:* The analysis showed that driver distraction duration is the primary direct cause of the increase in reaction time, with other factors having indirect effects mediated by distraction duration. Longer distraction duration, the distracted status when a leader braked, and engaged in auditory-visual-manual secondary task tended to result in longer reaction times. *Practical applications:* Given drivers will be distracted occasionally, countermeasures such as driver education, traffic enforcement, and driver assistant system going to shorten distraction duration or avoid distraction presence while leader vehicle brakes are worth considering from safety point. This study helps better understand the mechanism of freeway rear-end events occurring in car-following situation. In addition, it provides the methodology that can be adopted to study the association between driver behavior and driving features.

1. Problem

The original goal of this study is to identify driving behaviors associated with freeway rear-end crashes. Driver distraction, which appears in 60% to 65% of rear-end events from extracted SHRP 2 Naturalistic Driving Study (NDS) dataset (Transportation Research Board of the National Academies of Science, 2013) in this study, received our attention as an important contributing factor in rear-end events.

Driver distraction leads to a substantial number of traffic accidents. National Highway Traffic Safety Administration (NHTSA) statistics (National Center for Statistics and Analysis, 2016), which is based on data from NHTSA's Fatality Analysis Reporting System (FARS) and National Automotive Sampling System (NASS) General Estimates System (GES), showed that distraction-affected crashes take up about 15 to 20% of total crashes every year between 2010 and 2014 in the United States. Knipling (1993) found that about 25 to 30% of the crashes could be attributed to distraction based on data in the National Automotive Sampling System-Crashworthiness Data System (NASS-CDS). In the 100-car Naturalistic Driving Study (Beanland, Fitzharris, Young, & Lenné, 2013), driver distraction presented in approximately 50% of crashes studied.

Previous qualitative and quantitative research has shown that driver distraction could have negative effects on driving performance (Beanland et al., 2013; Hickman & Hanowski, 2012; Klauer, Dingus, Neale, Sudweeks, & Ramsey, 2006; Klauer, Guo, Simons-Morton, et al.,

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https://doi.org/10.1016/j.jsr.2017.10.012
0022-4375/

Please cite this article as: Gao, J., & Davis, G.A., Using Naturalistic Driving Study data to investigate the impact of driver distraction on driver's brake reaction time in freeway rear-end events in car-following situation, *Journal of Safety Research* (2017), https://doi.org/10.1016/j.jsr.2017.10.012

2014; Regan, Hallett, & Gordon, 2011) such as reaction time (Knipling, 1993; Lee, McGehee, Brown, & Reyes, 2002; Liang, Lee, & Yekhshatyan, 2012) based on both naturalistic and simulation driving data, but the specific association between driver distraction and crash risk is still not fully revealed.

Both theoretical and empirical evidence show that reaction time is curial in rear-end crash occurrence. Brill (1972) provided a car-following model relating driver reaction time, temporal headway, and deceleration response to rear-end collision frequency. This kinematic model gives the collision condition for a platoon of vehicles involved in shockwave, showing that drivers with relatively longer braking reaction time compared to temporal headway reduced their available stopping distance thus making rear-end collisions more likely to occur. Davis and Swenson (2006) provided empirical validation of Brill's model. By examining vehicle trajectory information extracted from the video recordings of three rear-end collisions on a section of I-94 westbound near downtown Minneapolis, using a causal counterfactual framework proposed by Balke and Pearl (1994), they found that evidence that in all three collisions, at least one driver ahead of the colliding vehicles probably had a reaction time longer than his or her following headway, and the rear-end collision probably would be avoided if that driver's reaction time had been equal to his or her following headway.

The following is a revisit of Brill's model for a simple two-vehicle case. For two vehicles involved in a brake-to-stop event, with leader vehicle denoted by index i and the follower vehicle denoted by $i + 1$, both vehicles are assumed to be traveling at constant speed v_0 with a forward spatial headway $T_{i+1}v_0$, where T_{i+1} is the forward time headway measured from the rear bumper of the leader vehicle to the front bumper of the follower vehicle. At time $t = 0$, the leader vehicle begins to brake with a constant deceleration a_i, and after a positive reaction time r_{i+1}, the follower vehicle driver also brakes, with constant deceleration rate a_{i+1}. During reaction time r_{i+1}, the follower is assumed to continue to travel at speed v_0. To avoid a rear-end collision, it is required that the stopping distance of follower vehicle is less than the sum of leader vehicle's stopping distance and the spatial headway, that is:

$$v_0 T_{i+1} + \frac{v_0^2}{2a_i} \geq v_0 r_{i+1} + \frac{v_0^2}{2a_{i+1}} \quad (1)$$

And the available stopping distance, S_{i+1}, of the follower vehicle is given by:

$$S_{i+1} = v_0(T_{i+1} - r_{i+1}) + \frac{v_0^2}{2a_i} \quad (2)$$

Eqs. (1) and (2) show that, when other things are equal, follower's reaction time is the key determinant of rear-end crash occurrence. Furthermore, previous research (Muttart, Messerschmidt, & Gillen, 2005; Summala, Lamble, & Laakso, 1998) indicates that drivers could have longer reaction time when they are disturbed by environment or performing in-car tasks. Thus, reaction time was chosen as the driving feature indicating rear-end crash risk in this study, and it would be worthy to study on determinants of reaction time from traffic safety standpoint.

This study aims to understand the influence of driver distraction on reaction time in freeway rear-end events in car-following situation. The association between driver distraction and reaction time was tested through causal model exploration. This study provides a way to better understand the mechanism of freeway rear-end crashes.

2. Method

2.1. Database overview

The study analyzed data were collected from the SHRP 2 NDS database. The SHRP 2 NDS has recorded second by second data on what happened in vehicle from 3,542 drivers and 1,600 crashes and 2,900 near-crashes (Transportation Research Board of the National Academies of Science, 2013). It's a 3-year data collection from 6 data sites: Bloomington, Indiana; Central Pennsylvania; Tampa Bay, Florida; Buffalo, New York; Durham, North Carolina; and Seattle, Washington.

2.2. Study sample selection

Included cases in this study are freeway rear-end events including crash, near-crash, and safety-related incidents. Filter in Table 1 has been built to extract the subject events for this study.

By the filter in Table 1, 130 events were extracted from the NDS database (Transportation Research Board of the National Academies of Science, 2013).

2.3. Data collection

In this study, only the event analysis and time-series data shown on the Insight website (https://insight.shrp2nds.us/) were available for analysis. All the event detail data were entered by the data reductionists during manual event analysis.

2.4. Data coding

In this study, "reaction time" was defined as "the time gap between the time point when leader vehicle's brake light first went on and that

Table 1
Event extraction filter.
(Source: InSight Data Access Website Summala et al., 1998).

Variable	Definition	Conditional statement
Event nature	The nature of the other object(s) of conflict the subject vehicle encountered for the event.	(i) "Conflict with a lead vehicle"
Incident type	The type of conflicts the subject vehicle has with other objects.	(i) "Rear-end, striking"
Precipitating event	The state of the environment or action at the beginning of the event.	(i) Other vehicle ahead - at a slower constant speed; or (ii) other vehicle ahead – decelerating.
Pre-incident maneuver	The last driving maneuver that the subject vehicle driver engaged in or was engaged in just prior to or at the time of the *Precipitating Event*.	(i) Going straight, constant speed; (ii) going straight, accelerating; (iii) decelerating in traffic lane; or (iv) maneuvering to avoid a vehicle.
Locality	The surroundings influencing traffic flow at the beginning of *Precipitating Event*.	(i) Interstate/bypass/divided highway with no traffic signals; or (ii) bypass/divided highway
Event severity	The outcome of the event.	(i) Crash; (ii) near-crash; or (iii) crash relevant
Intersection influence	A judgment whether the subject vehicle's movement is under the influence of an intersection during the event.	(i) Yes, interchange; or (ii) no
Traffic flow	Roadway design presents at the start of the *Precipitating Event*.	(i) Divided; or (ii) one-way traffic
Relation to junction	The spatial relation of the subject vehicle to a junction at the time of the start of the *Precipitating Event*.	(i) No junction

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