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Impact of a forward collision warning system on headway and reaction time during car following

Meixin Zhu[a,b], Xuesong Wang[a,b,*]

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

Abstract

Forward Collision Warning (FCW) systems function by alerting inattentive drivers to upcoming forward hazards, and have been shown to help drivers respond more quickly under emergency situations. As FCW directly affects how vehicles interact longitudinally with one another, it may also influence drivers' car-following behaviors. To investigate this effect, driving data were collected by the on-going Naturalistic Driving Study conducted in Shanghai. Five data collecting vehicles are equipped with Mobileye® systems, which include an FCW function. Participants drive the instrumented vehicles for two months, with the Mobileye® system not activated for the first month, but activated for the second month. From 60,689 km of naturalistic driving data, 1,489 car-following events were identified. Headway and reaction time are major parameters of car-following behavior. Headway relates to the time available for a driver to react, and is a safety measure of car-following behavior. Reaction time refers to the delay between velocity changes of a lead and a following vehicle, and is a governing factor in determining traffic stability. The results of this study show that (1) drivers tended to maintain a longer headway when FCW activated; and (2) the FCW resulted in a 0.13s decrease of reaction time in daytime driving, and a 0.09s decrease when a following vehicle had higher speed than the lead vehicle. Moreover, this study further confirms that the reaction time is affected by relative distance, lead vehicle acceleration, and traffic density. These results would be valuable for driver reaction time modeling and simulation of traffic with FCW.

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Keywords: Forward Collision Warning; Naturalistic Driving Study; Car-following behavior; Headway time; Reaction time.

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* Corresponding author. Tel.: +86-21-69583946; fax: (86) 21-65982897.
E-mail address: wangxs@tongji.edu.cn

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1. Introduction

Forward Collision Warning (FCW) systems aim to reduce rear-end crashes. These in-vehicle systems monitor the roadway ahead and warn the driver when a collision risk reaches a certain threshold. Previous research mainly focused on the effects of FCW on driving behavior in rear-end scenarios, and found that FCW could reduce accelerator release time (McGehee et al., 2002; Lee et al., 2002) and brake delay time (Soma and Hiramatsu, 1998). As FCW directly affects how vehicles interact longitudinally with one another, it may also influence drivers' car-following behaviors.

Car following refers to a situation in which a vehicle's speed and longitudinal position are influenced by the vehicle immediately ahead of it. It is characterized by the headway and reaction time (Ranney, 1999).

Headway is defined as the elapsed time between the arrival of the lead vehicle (LV) and the following vehicle (FV) at a designated point (Ben-Yaacov et al., 2002). It relates to the time available for a driver to react, and is a safety measure of car-following behavior. Since the average of headways is the reciprocal of flow rate, headways represent microscopic measures of flow rate. To some extent, the minimum acceptable mean headway determines the roadway capacity (Zhang et al., 2007).

Driver reaction time was discussed back in the 1950s when the first stimulus-response car-following model was developed (Chandler et al., 1958). In stimulus-response car-following models, the FV observes a change in driving conditions, the stimulus, and responds to it after a lapse of time, called the reaction time (Gurusinghe et al., 2002). Reaction time is an essential factor contributing to traffic instabilities and, consequently, is an indispensable element in many car-following models (May, 1990). Moreover, it plays an important role in jamming transition (Zhu and Dai, 2008).

Several studies have investigated the impacts of FCW on headway maintenance. It was found that FCW could increase headway (Ben-Yaacov et al., 2002; Dingus et al., 1997) and reduce the time drivers spend in short headways (Shinar and Schechtman, 2002; Ervin et al., 2005). However, little effort has been devoted to investigating how FCW would affect car-following reaction time. Moreover, previous studies concerning reaction time estimation were mainly based on GPS (Gurusinghe et al., 2002) or vehicle trajectory data (Taylor et al., 2015), which have limited precision.

Naturalistic Driving Study (NDS) has given a new horizon to the observation of driver behavior. With NDS, driver behavior is observed as it occurs in the full context of real-world driving, and vehicle kinematic data (e.g., acceleration, velocity, position) are recorded continuously with high resolution (Fitch and Hanowski, 2012).

The on-going Shanghai Naturalistic Driving Study (SH-NDS) is the first NDS project conducted in China. Mobileye® systems are installed in the research vehicles, which include an FCW function. Participants drive the vehicles for two months, with the Mobileye® system not activated for the first month, but activated for the second month. The data collection procedure started in December 2012; as of July 2015, 55 drivers and 133,458 km of driving data have been collected. The detailed driving data provide an unprecedented opportunity for investigating car-following behavior.

This study seeks to quantify the impacts of an FCW system on car-following behavior. Specifically, with driving data collected by SH-NDS, car-following periods were identified. Then, headway and reaction time from both warning and no-warning phases were extracted and statistically compared to quantify changes in car-following behavior as a result of the activation of the FCW system.

2. Literature review

Several studies have investigated the impacts of FCW on car-following behavior, but focused on headway maintenance. Based on the experimental methods, these studies can be pooled into two categories: controlled field test and NDS.

Through controlled field tests, Dingus et al. (1997) found that driver headway maintenance increased by 0.5s when an appropriate visual display of headway was used; Ben-Yaacov et al. (2002) found that drivers maintained a longer following distance after a short exposure to an FCW system.

Because controlled field tests are conducted on test tracks, they have bias from relatively short experimental time and lack of real world driving data. As opposed to this, data collected by NDS represent real world driving. Ervin et al. (2005) conducted an NDS to evaluate an automotive collision avoidance system (ACAS), which included an FCW system and an Adaptive Cruise Control system (ACC). The results echoed the above field studies; they showed that, with FCW enabled, headways increased on freeways or in daytime.

Using data from the NDS of the Integrated Vehicle-Based Safety System (IVBSS) program, Bao et al. (2012) and Sayer et al. (2011) investigated the effect of an integrated in-vehicle crash warning system on headway maintenance for heavy trucks and light vehicles respectively. The results indicated that the warning system led to an increase of headway with heavy truck drivers, but a decrease of headway with light vehicle drivers.

In Europe's first large-scale Field Operational Test (euroFOT) project, Kessler et al. (2012) tested several in-vehicle systems in real traffic. They found that for both light vehicles and trucks, the headway increased significantly while using ACC and FCW.

However, none of these studies have explored the impacts of FCW on car-following reaction time. Therefore, this study aims (1) to further confirm FCW's effects on headway, and (2) to investigate how the system would affect car-following reaction time.

3. Data preparation

3.1. Shanghai naturalistic driving study

The data used in this study were collected by the on-going Shanghai Naturalistic Driving Study (SH-NDS) jointly conducted by Tongji University, General Motors (GM), and Virginia Tech Transportation Institute (VTTI). The SH-NDS aims to learn more about vehicle use, vehicle handling, and safety consciousness of Chinese drivers.

Five GM light vehicles equipped with SHARP2 NextGen Data Acquisition Systems (DAS) are used to collect real world driving data. The data collection procedure started in December 2012, planning to collect 90 licensed Chinese drivers' daily driving data, and will end in December 2015. Mobileye® C2-270 vehicle active safety system is also installed in each test vehicle to evaluate its effectiveness. Each participant drives the vehicle for two months, with the Mobileye® system not activated for the first month, but activated for the second month.

3.2. Data acquisition system

The SHARP2 NextGen DAS includes an interface box to collect vehicle CAN data, an accelerometer for longitudinal and lateral acceleration, a radar system that measures range and range rate to the LV and vehicles in the adjacent lanes, a light meter, a temperature/humidity sensor, a GPS sensor for location, and four synchronized camera views to validate the sensor-based findings (Fitch and Hanowski, 2012).

As shown in Fig. 1, the four camera views monitor the driver's face, the forward roadway, the roadway behind the vehicle, and the driver's hand maneuvers. The frame rate of the four views of videos is 14.98 FPS, and the data collection frequency for accelerometer and radar system is 50 Hz. The DAS automatically starts when the vehicle's ignition is turned on, and automatically powers down when the ignition is turned off.

Fig. 1. Four camera views for the SH-NDS.

3.3. Mobileye® vehicle active safety system

The Mobileye® C2-270 vehicle active safety system incorporates three subsystems: Forward Collision Warning, Lane Departure Warning, and Pedestrian Collision Warning. For the FCW subsystem, once the Time to Collision (TTC) drops to 2.7s, a series of loud, high-pitched beeps is sounded, and a red, flashing car icon (as shown in Fig. 2-a) is displayed.

The FCW system also provides headway monitoring and warning functions. As long as an LV with headway less than 2.5s is detected, the headway will be displayed numerically and continuously updated (as shown in Fig. 2-b). A green car icon is displayed if the headway remains greater than 0.6s. Once the headway drops to 0.6s, a red car icon is displayed (as shown in Fig. 2-c), and a single chime is sounded to indicate dangerous tailgating.

(a) FCW visual warning **(b) headway visual notice** **(c) headway visual warning**

Fig. 2. Visual display of the FCW system.

3.4. Data description

Nineteen drivers' data were used for analysis in this study. The data set used represent 60,689 km and 4,573 trips of driving, with 32,797 km in the Mobileye® system disabled phase and 27,892 km in the enabled phase. Among the 19 drivers analyzed, 3 are female and 16 are male. The drivers' age ranged from 28 to 61 (mean = 40.9) with an average of 6.6 years of driving experience (range = 1 to 16).

4. Methodology

4.1. Car-following periods extraction

Car-following periods were automatically extracted from the driving data to analyze drivers' car-following behaviors. The criteria used were mainly based on Ervin et al. (2005) and Higgs and Abbas (2013). The corresponding threshold for each criterion was adapted according to the characteristics of the data set.

The car-following filtering was an iterative process where initial criteria and thresholds were used. After the potential car-following periods were flagged, they were reviewed by videos to adjust the criteria and thresholds accordingly in order to obtain minimum noise.

As shown in Fig. 3, a car-following period was extracted if the following criteria were met simultaneously:

- Radar target's identification number>0 and remains constant; this criterion is set to guarantee that a same lead vehicle is detected.
- 7m<range<120m, and speed of the research vehicle>5m/s; the two criteria were set to eliminate free flow and traffic jam conditions. In free flow or traffic jam conditions, the research vehicle and the lead vehicle do not have a close interaction. As car following refers to a situation in which a vehicle interacts closely with the vehicle immediately ahead of it, therefore vehicles in free flow or traffic jam conditions are not in a car-following state.
- −2.5m<lateral distance<2.5m; this criterion guarantees that the following and leading vehicle are driving in the same lane.
- −2.5m/s<range rate<2.5m/s; this criterion eliminates scenarios in which the research vehicle is either rapidly closing in on, or falling back from, a lead vehicle.
- Length of car-following period>15s; this criterion guarantees that the research vehicle follows the lead vehicle for a long enough time period.

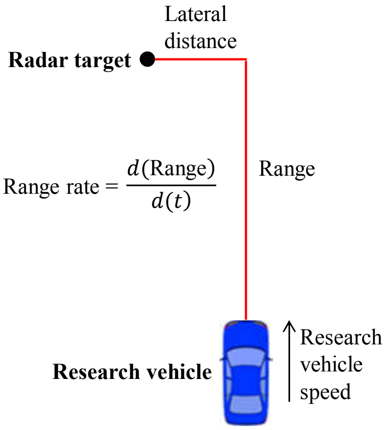

Fig. 3. Radar target's position and motion with respect to the research vehicle.

4.2. Independent variables

The method of analysis was a linear mixed model, where drivers were treated as random effects to account for individual differences in driving behaviors. Table 1 summarizes the independent variables. The key independent variable was warning condition, which included warning and no-warning phases indicating the availability of the Mobileye® system to drivers.

To consider whether the traffic was interrupted, the roadways were divided into two categories: freeway and surface road. Freeways refer to roadways with limited access such as an urban expressway. Arterial, minor arterial, collector, and local roadways were labelled as surface roads. Roadway type and ambient light information were derived from front view video by an analyst.

Traffic density was identified through radar data. The radar system can track, at most, eight vehicles simultaneously. Using the position information of detected vehicles, the headway distance between each pair of lead and following vehicles was calculated and averaged. The reciprocal of average headway distance was taken as traffic density. Traffic density was further classified into three categories: sparse (<40 vehicles/km/lane), moderate (40–65 vehicles/km/lane), and dense (>65 vehicles/km/lane).

Travel speeds were pooled into three categories: slow (20–40 km/h), medium (41–65 km/h), and high (>65 km/h). The first category is typical of city driving and the last category is typical of freeway driving.

Weather condition was not included as an independent variable because only car-following events with ideal weather condition were used. Considering the limited number of drivers, age, gender, and driving experience were not included as independent variables.

Table 1. Independent variables.

Variables	Conditions
Warning condition	No-warning phase, warning phase
Roadway type	Freeway, surface road
Ambient light	Daytime, nighttime
Traffic density	Sparse, moderate, dense
Travel speed	Slow, medium, high

4.3. Dependent variables

The three objective measures examined were mean headway, the proportion of time drivers spent in a short-time headway zone (i.e., 1s or less) and car-following reaction time. A 1s threshold was selected for short-time headway zone because 90% of the car-following events extracted had a mean headway greater than 1s.

Mean headway was calculated for each car-following event by dividing the following distance with the speed of FV. For a single car-following event, there is a high probability that the headway is always greater than 1s, meaning that the proportion of time in short headways is zero. To avoid this situation, a method to combine car-following events was adopted, which was proposed by Shinar and Schechtman (2002). Specifically, there were 72 combinations of car-following attributes, defined by: Warning condition (2) × Roadway type (2) × Ambient light (2) × Traffic density (3) × Travel speed (3). For each driver, the car-following events with the same combination of attributes were grouped together, outputting an overall short headway percentage.

Car-following reaction time was determined by a graphical method of manually comparing the acceleration and relative speed curves, which was proposed by Gurusinghe et al. (2002). Fig. 4 shows a plot of FV acceleration and relative speed versus real time. For every sharp change in relative speed, there is a corresponding sharp change in acceleration. These are points of stimulus and response. The time between them is reaction time.

For example, in Fig. 4, a peak occurs at point A_S on the relative speed curve. The corresponding peak on the acceleration curve is at A_R. The time between A_S and A_R is defined as the reaction time T_A. According to Ozaki (1993), reaction time changes during the process of driving, and it may correlate with relative distance, speed and LV acceleration. Therefore, for every stimulus point, besides the reaction time, the corresponding relative distance, speed and LV acceleration were also determined and will serve as additional independent variables when analyzing reaction time.

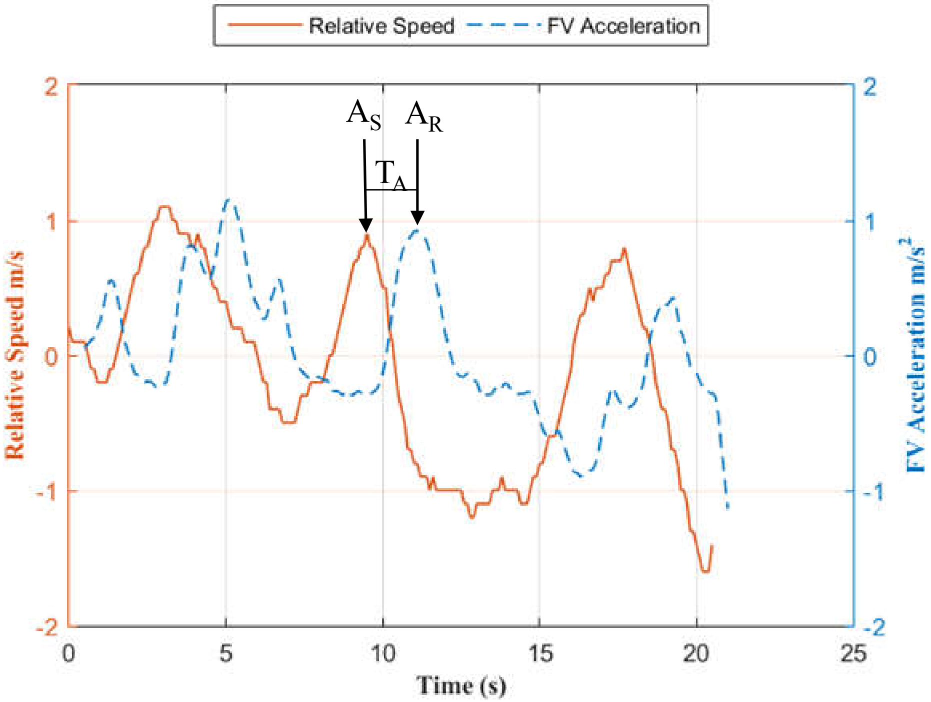

Fig. 4. Determining reaction time through identification of stimulus and response points.

5. Analyses and results

A total of 1,489 car-following events were identified and used in this study, which represent 11.5 driving hours. Mean headway and proportion of time in short headways were calculated for all car-following events, and reaction time was calculated for the 6,933 point pairs of stimulus and response identified in the curves of FV acceleration and relative speed. All three variables were continuous measures. The analyses were performed with linear mixed models using the PROC MIXED procedure in SAS® 9.2. The statistical significance level was set at $\alpha = 0.05$.

5.1. Mean headway

The analysis for mean headway showed significant main effects for travel speed, ambient light, roadway type, and traffic density. The directions of these significant main effects are shown in table 2.

Drivers generally maintained a longer headway in warning phase (least squares means = 1.75s) than in no-warning phase (least squares means = 1.68s), though the difference was not statistically significant ($F(1, 12) = 1.36$, $p = 0.27$). No significant interactions were found.

Table 2. Significant main effects for mean headway.

Variables	**Main effect**	**Statistical results**	**Conditions with longer headway**	**Mean headway**
Travel speed	Yes*	F(2,30)=74.29, p<0.0001	Slow speed vs. medium speed vs. high speed	2.11s vs. 1.58s vs. 1.45s
Ambient light	Yes	F(1,14)=11.44, p=0.005	Nighttime	1.79s vs.1.64s
Roadway type	Yes	F(1,14)=38.39, p<0.0001	Surface road	1.86s vs. 1.57s
Traffic density	Yes	F(2,34)=308.13, p<0.0001	Sparse traffic vs. moderate traffic vs. dense traffic	2.42s vs. 1.61s vs. 1.10s

* "Yes" means the main effect is statistically significant, as it is for other tables.

5.2. Proportion of time in short headways

Proportion of time in short headways was also analyzed across the five variables (listed in Table 1) and associated interactions. The results showed significant main effects for travel speed, roadway type, and traffic density. The directions of these effects are shown in table 3.

The main effects of the warning condition were not significant: F(1, 9) = 0.09, p = 0.78. The short-headway percentage in warning phase (17%) was just slightly lower than that in no-warning phase (18%).

Table 3. Significant main effects for proportion of time in short headways.

Variables	Main effect	Statistical results	Conditions with lower proportion of short headways	Proportion of time in short headways
Travel speed	Yes	F(2,27)=25.98, p<0.0001	Slow speed vs. medium speed vs. high speed	5% vs. 20% vs. 27%
Roadway type	Yes	F(1,13)=7.04, p=0.020	Surface road	14% vs. 21%
Traffic density	Yes	F(2,33)=59.69, p<0.0001	Sparse traffic vs. moderate traffic vs. dense traffic	2% vs. 17% vs. 34%

5.3. Reaction time

Besides the variables listed in Table 1, variables that may affect reaction time were also included as independent variables for the reaction time analysis. These variables were relative speed (LV speed minus FV speed), relative distance, and LV acceleration. The absolute values of relative speed and LV acceleration were used, and two corresponding discrete variables indicating their signs were added. The speed of FV was not included in independent variables because it was highly correlated with the relative distance (Pearson correlation coefficient = 0.62, $p < 0.001$).

The results showed that the warning condition had a significant effect on reaction time. Specifically, reaction time decreased from 1.55s to 1.53s from the no-warning phase to the warning phase: F(1, 12) = 5.51, p = 0.0369.

As shown in Fig. 5, two significant interaction effects with warning condition were observed: Warning Condition × Ambient Light, F(1, 4) = 17.36, p = 0.007, and Warning Condition × Relative Speed Sign, F(1, 12) = 9.74, p = 0.008. For the Warning Condition × Ambient Light interaction, presence of warnings resulted in a 0.13s decrease (an 8% decrease) of reaction time in daytime driving, F(1, 12) = 5.93, p = 0.03, while this difference was not statistically significantly in nighttime driving. Similarly, when the relative speed was negative (i.e., an FV had a higher speed than the LV), presence of warnings resulted in a 0.09s decrease (a 5% decrease) in reaction time, F(1, 12) = 7.16, p = 0.02, but this difference was not significant with positive relative speed.

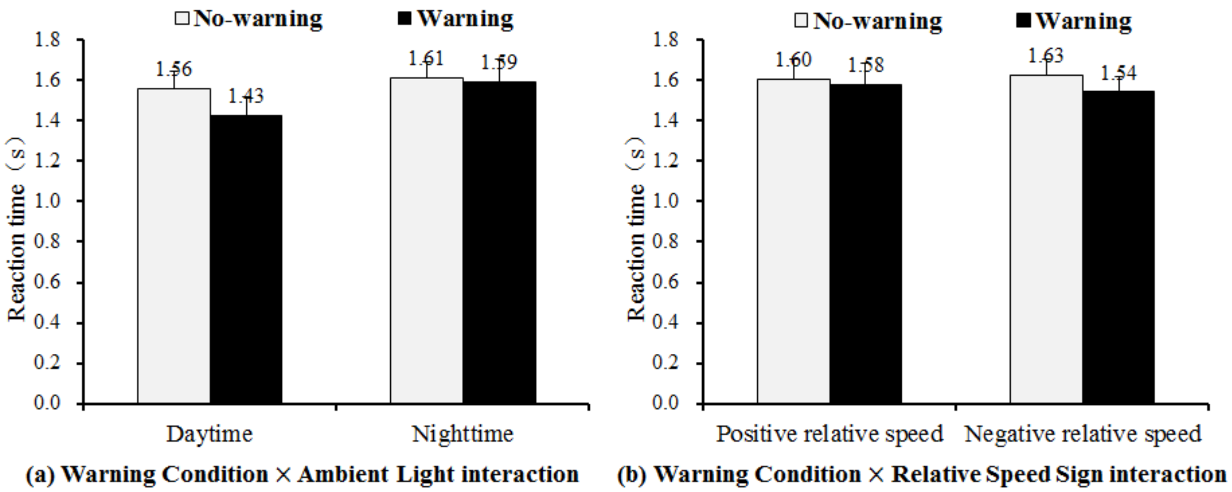

Fig. 5. Reaction time for the two significant interaction effects.

Several other independent variables were found to have main effects as well, including relative speed, relative distance, LV acceleration rate, ambient light, roadway type, and traffic density. The directions of these effects are shown in table 4 and table 5.

Table 4. Significant main effects of **discrete** variables on reaction time.

Variables	Main effect	Statistical results	Conditions with shorter reaction time	Reaction time
Warning condition	Yes	F(1,12)=5.51, p=0.0369	Warning phase	1.53s vs.1.55s
Ambient light	Yes	F(1,14)=9.24, p=0.008	Daytime	1.49s vs.1.60s
Roadway type	Yes	F(1,14)=16.90, p=0.001	Surface road	1.48s vs.1.61s
Traffic density	Yes	F(2,34)=19.33, p<0.0001	Dense traffic vs. moderate traffic vs. sparse traffic	1.39s vs. 1.55s vs. 1.70s

Table 5. Significant effects of **continuous** variables on reaction time.

Variables	Main effect	Statistical results	Conditions with shorter reaction time	Coefficient
Relative speed	Yes	F(1,6895)=31.95, p<0.0001	Lower relative speeds	0.1615*
Relative distance	Yes	F(1,6895)=160.60, p<0.0001	Shorter relative distances	0.02562
LV acceleration rate	Yes	F(1, 6895)=34.11, p<0.0001	Higher LV acceleration rate	−0.1127

Note: the units of relative speed, relative distance, and LV acceleration rate are m/s, m, and m/s^2 respectively.

6. Summary and discussion

This study investigates how an FCW system would affect the critical parameters of car-following behavior—headway and reaction time. The results show that drivers tended to maintain a longer headway with the FCW system enabled, while the proportion of time in short headways was not affected by the system. Also, drivers' reaction time during car-following decreased, especially in daytime driving and when an FV had a higher speed than the LV.

6.1. Headway

Similar studies have been done through controlled field tests and NDS to examine the effects of FCW systems on headway maintenance. Table 6 summarizes the results of these studies. With the exception of the IVBSS light vehicle project (Sayer et al., 2011), drivers tended to maintain longer headways and spent less time in short headways with FCW systems enabled, which suggests that FCW systems have positive effects in terms of driving safety.

However, the effect sizes and even effect directions differed among these studies. As discussed by Bao et al. (2012) and Sayer et al. (2011), the differences could be caused by the following: a) the warning logics and modalities of the FCW systems differed; b) drivers' behaviors in natural driving situations might be different from their behaviors in controlled experimental situations; c) drivers of different vehicle types (e.g., truck versus light vehicle) or from different countries might have variations in driving behaviors. For example, the average headway (1.79s) in this study was slightly lower than that (1.86s) reported by Sayer et al. (2011).

Table 6. Result summary for studies concerning effects of FCW on headway maintenance.

Studies	Approach	Headway changes with systems enabled	Changes of proportion of time in short headways with systems enabled
SH-NDS*	NDS	Had a tendency to increase	No statistically significant changes
Dingus et al. (1997)	Controlled field test	Increased	
Ben-Yaacov et al. (2002)	Controlled field test	Increased by 0.5s	
Shinar and Schechtman (2002)	NDS	Increased	Decreased by approximately 25%
ACAS (2005)	NDS	Increased on freeway and during daytime	Decreased on freeway
IVBSS heavy truck project (2012)	NDS	Increased by 0.28s with dense traffic; increased by 0.2s with wipers on	
IVBSS light vehicle project (2011)	NDS	Had a tendency to decrease	Increased by 3%
euroFOT (2012)	NDS	Increased	

* SH-NDS denotes the current study.

6.2. Reaction time

Driver reaction time has a substantial influence on traffic flow stability, and traffic stabilities increase with the decrease of reaction time (Treiber et al., 2006). We found that the presence of warnings resulted in a 0.13s decrease of reaction time in daytime driving and a 0.09s decrease in conditions of negative relative speed. This suggests that the FCW system could be beneficial to traffic stability in daytime driving and in gap closing situations.

According to Olson (2002), driver reaction time consists of four components: detection, estimation, decision, and movement. In a car-following process, the detection interval starts when the relative speed or relative distance changes and ends when the driver becomes consciously aware that the relative motion state has changed. Having become aware of that, the driver then estimates the relative distance or relative speed. With this estimation completed, the driver must decide what action, if any, is appropriate. The typical response action is a change of speed and/or direction. Last, in the movement interval, the driver lands his or her foot on the brake pedal or adjusts the steering wheel.

As shown in Fig. 6, the FCW system may shorten the detection and estimation interval of car-following reaction time, and thus shorten the total length of reaction time. The reason is that: with the Mobileye® FCW system enabled, the headway time from the LV is numerically displayed and is continuously updated. This may assist drivers to observe and estimate the changes of distance or speed more quickly.

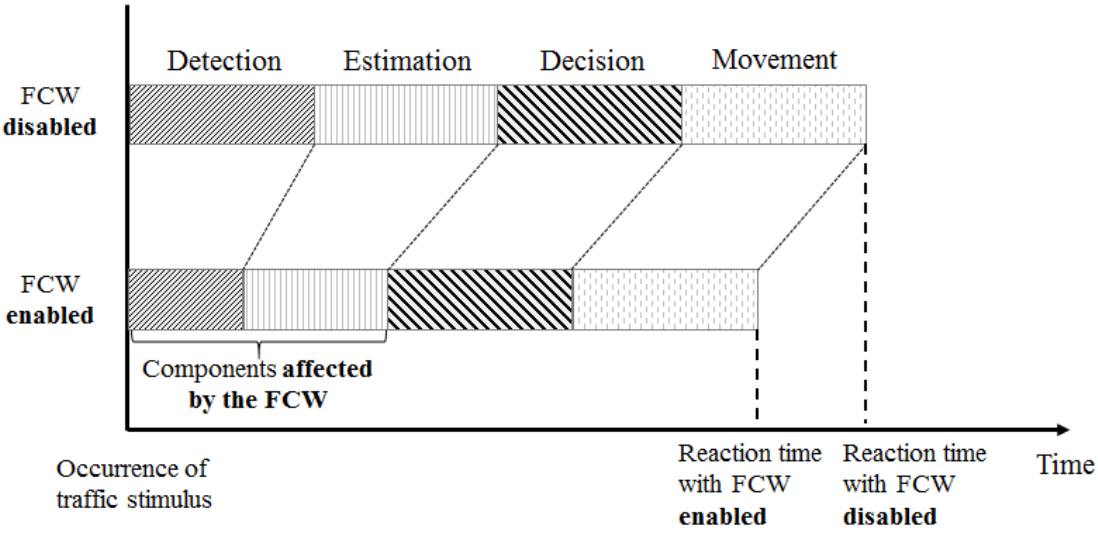

Fig. 6. Reaction time with FCW disabled and enabled.

Besides the warning condition, several other variables were also found to affect reaction time. Specifically, reaction time was found to be positively correlated with relative distance and negatively correlated with LV acceleration. This is consistent with the reaction time prediction function proposed by Ozaki (1993), as shown in Equation (*1*):

$$reaction\ time = \begin{cases} 1.5 + 0.01s(t) - 0.6a(t) & (acceleration) \\ 1.3 + 0.02s(t) + 0.7a(t) & (deceleration) \end{cases} \tag{1}$$

where $s(t)$ represents the relative distance, and $a_{LV}(t)$ is the acceleration (with signs) of the LV.

Additionally, drivers were found to have shorter reaction time as traffic density increased. This verifies Equation (*2*) proposed by Del Castillo (1994):

$$reaction\ time = \frac{1}{2k^2 v_e'} \tag{2}$$

where k is traffic density and v_e' is the derivative of the equilibrium speed–density function. In this equation, reaction time is a decreasing function of traffic density.

In addition to the factors discussed above, we found that roadway type and ambient light also affected reaction time. Drivers had shorter reaction times in daytime driving, as might be expected because drivers may acquire and process information more quickly in daytime than in nighttime. Reaction time on surface roads was shorter than that on freeways. A possible explanation is that the traffic flow on surface roads is interrupted, which makes drivers pay more attention to the driving task and respond faster.

Reaction times derived in this study ranged from 0.7s to 1.8s, which had a greater variation range than that (1.27s to 1.55s) reported by Ranjitkar et al. (2003). The mean and median values of the reaction times in our study were 1.45s and 1.20s respectively. Although several methods (Taylor et al., 2015; Ma and Andréasson, 2006) have been proposed to automatically calculate the instantaneous reaction time during car-following, this study chose to extract the reaction time manually in consideration of accuracy. A more efficient method could be included in future work.

Limited by the data collection progress of the SH-NDS, only 19 drivers' data were used, and some other factors that might relate to drivers' car-following behaviors, such as age and gender, were not examined. These factors could be examined in future studies.

7. Conclusion

This is the first study to investigate the impacts of an FCW system on car-following reaction time with high validity naturalistic driving data. Positive impacts of the FCW system on driving safety, as well as traffic stability, were identified. Specifically, drivers tended to maintain a longer headway with the system enabled. A decrease of reaction time was also found, especially in daytime driving and when an FV had a higher speed than the LV. Moreover, this study further confirmed that the car-following reaction time changed during the process of driving, and was affected by relative speed, relative distance, LV acceleration, traffic density, roadway type, and ambient light. The results of this study would be valuable for driver reaction time modeling and simulation of traffic with FCW systems.

Acknowledgements

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