Effect of Adaptive Caution on Driver's Lane-Change Behavior under Cognitively Distracted Condition

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Abstract. This paper investigates caution type message that is given to a driver in two ways. One refers to driver's characteristic of intentional eye movement for changing lanes, and the other is adaptive to driver state as well as the characteristic. Experimental results imply the two ways' effectiveness of improving the intentional checking behavior that might be degraded by a cognitively distracted secondary task. Meanwhile, this study also indicates that the later way is more effective for improving a maneuver of changing lanes. It is suggested that it would be more acceptable to consider driver state into a support system.

Keywords: Adaptive caution information · Driving safety · Cognitive distraction · Lane changes

1 Introduction

This study defines "driver distraction" as a diversion of a driver's attention away from activities critical for safe driving towards a competing activity [1]. The US National Highway and Safety Administration (NHTSA) reported that distraction-related crashes were responsible for 3,092 fatalities (9 % of all traffic-related fatalities) in 2012 [2]. Traditional crash studies based on eyewitness accounts or driver recall assigned responsibility for 10-12 % of all car-crashes to driver distraction [3–6]. Driver distraction was also reported as the most important contributing factor to the collision of lane changes. Many previous investigations showed that more than 60 % of accident of lane changes involved driver distraction [7–10]. In the United States, more than 60,000 people were injured each year due to in lane-change related accidents, and lane change crashes accounted for between 5-15 % of all motor vehicle fatalities [11]. Furthermore, research revealed that most drivers involved in lane-change accidents were not attempting to perform avoidance maneuvers when the mishap occurred because they did not see, or did not recognize, the presence of a collision hazard [12–14].

For enhancing driver recognizing some potential dangerous car, some support systems [15] have been made introduced into practical vehicles for recognizing a possible collision in a near future, e.g., caution-type support such as Volvo Blind Spot

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Information System (BLIS®) and Mazda Rear Vehicle Monitoring System (RVM). Meanwhile, the type of protection functions, i.e., soft protection and hard protection, are developed for avoiding a collision when a driver tends to initiate a lane change [16]. Though those systems were shown to be effective to avoiding the possible collisions, drivers might feel noisy in cases of the frequent caution message because drivers might also be surprised by sudden protections when they initiate the maneuver of changing lanes.

Therefore, in order to improve driver acceptance and avoid driver's surprise on system's performance, some issues become important to be discussed before system operating a sudden protection: inferring driver intention, detecting driver state, and adaptive caution message. Resolving such issues is aimed to improve driver's intentional checking behavior and to prevent a risk of a collision in a near future maneuver of changing lanes.

Zhou et al. [17] investigated driver's eye movements before changing lanes and proposed a method to infer driver intentions effectively. Furthermore, Zhou et al. [18] showed that driver distractions affected driver's intentional eye movements for changing lanes even when a driver had the definite intention.

This study investigates caution type message that is given to a driver in two ways: one refers to driver's characteristic of intentional eye movement for changing lanes, and the other is adaptive to driver state as well as the characteristic.

2 Driver Model of Checking Behavior & Adaptive Caution Support System

2.1 Driver Model of Checking Behaviors

The study constructs an individual driver model by using eye movement of looking at the side-view mirror. Driver's eye movement is characterized by a change of a frequency of intentional eye movements ($f_{eye.}$), i.e., the number of checking behavior of looking at the side-view mirror over a 12-s period based on the study by Zhou et al. [5].

Checking behaviors for constructing individual driver model is constructed from a time point (t_o) at which a host vehicle begins to get close to a slow forward vehicle until a time point ($t_{init.}$) at which the host vehicle's body firstly touches the center line (See Fig. 1). Time points are recorded when $f_{eye.}$ transits from 0 to 1, 1 to 2, 2 to 3 and 3 to 4. Time length from t_o to each of the time points is defined as $T_{f=1}$, $T_{f=2}$, $T_{f=3}$, and $T_{f=4}$ respectively. Note that $T_{f=2}$ and $T_{f=3}$ are used for developing caution support systems.

2.2 Adaptive Caution Support System

When a driver intends to change lanes in a near future, four-phase support message (See Fig. 1) is served for cautioning a slower lead vehicle and closed behind vehicles:

- Arousing attention information (INFO1) for a slower lead vehicle at T_{100m} when the lead vehicle is closing to the host less than 100 m.

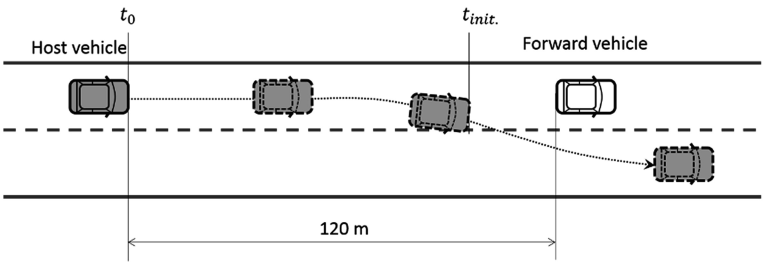

Fig. 1. Preparing phase of changing lanes

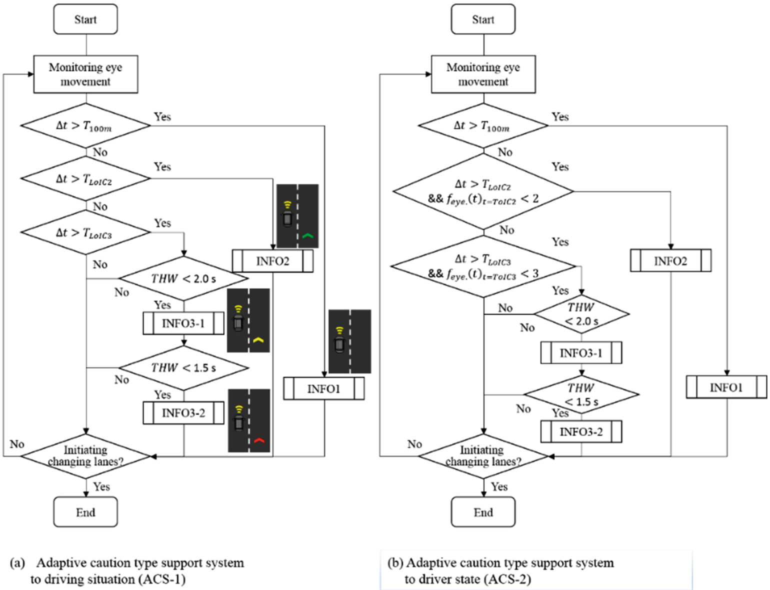

Fig. 2. Two types of adaptive caution systems

- Arousing information (INFO2) for an emergency of an approaching next-following car in cases of THW (the time headway) < 2 s after $T_{f=2}$ at which $f_{eye.}$ transited from 1 to 2 based on the individual model of checking behavior.
- Cautioning information (INFO3-1) for being approached by the next-following car in cases of $1.5\text{s} \leq \text{THW} < 2.0s$ after $T_{f=3}$ at which $f_{eye.}$ transited from 2 to 3.
- Cautioning information (INFO3-2) for being approached by the next-following car in cases of $\text{THW} < 1.5s$ after $T_{f=3}$.

This study proposes two ways of system supplying the four-phase caution message to a driver. One refers to driver's characteristic of intentional eye movement for changing lanes specified by driver's model (Adaptive caution system (ACS-1)) (See Fig. 1(a)). The other is adaptive to driver state as well as the characteristic (ACS-2) (See Fig. 1

(b)). Note that the four-phase support message is proposed for cautioning situation awareness, so that a collision risk would be not explained to participants when these messages are supplied to them.

3 Method

3.1 Apparatus

A fixed-base driving simulator is used in data collection for constructing driver model and a cognitive engineering experiment. It can simulate driving on an expressway with two lanes (See Fig. 1). A speed governor is set up for preventing a host vehicle from exceeding 90 km/h. One camera is equipped on the position of side-view mirror for monitoring driver's eye movement. Note here that vehicles drive on the left-hand side in Japan (Fig. 3).

Fig. 3. A fixed-base driving simulator

3.2 Participants

Five females and thirteen males, ranging from 19 to 23 years old (Mean = 20.4, SD = 1.1), participate in the data collection and the experiment. Each participant holds a valid driver's license. After receiving an explanation of the data collection and experiment, all of them signed in information consent of participating the data collection and experiment.

3.3 Driving Scenario and Task

One trial consists of two scenarios, in each of which one lane change is possible. In each scenario, all participants are instructed to drive at the maximum speed of 90 km/h on the cruising lane. Each of them is allowed for changing lanes from a time point t_0 at which the forward vehicle begins to decelerate from 90 km/h to 80 km/h (See Fig. 2). The lane change is initiated at a time point $t_{init.}$ at which the body of the host vehicle firstly touched the center line.

3.4 Secondary Task

A secondary task is conducted into the cognitive engineering experiment to simulate a distracting cognitive activity. In the secondary task, each participant is instructed to remember a route before a trial. He/she would be asked to choose the correct one from five choices during driving and to give the answer directly after finishing the trial.

3.5 Experimental Design

The experiment employs a 3 (support system: no caution support system (NCS), adaptive caution support system to driving situation (ACS-1), adaptive caution support system to and driver state (ACS-2)) × 2 (secondary task: no secondary task (NST) and a secondary task (ST)) design within participants. A two-factor analysis (ANOVA) is performed for all variables. A significant level of $p = .05$ is used.

3.6 Dependent Variables

This study investigates an effect of the secondary task on driver's intentional checking behavior of looking at the side-view mirror. Values of $f_{eye.}$ are collected at four phases:

- PreINFO1 from t_0 to T_{100m},
- INFO1to2 from T_{100m} to $T_{f=2}$,
- INFO2to3 from $T_{f=2}$ to $T_{f=3}$, and
- PostINFO3 after $T_{f=3}$.

In order to indicate effectiveness of the two types of support systems on driver's checking behavior. Averaged values of $f_{eye.}$ are analyzed at a phase after $T_{f=2}$, i.e. PostINFO2.

The time headways (THW) are recorded at $T_{f=1}$, $T_{f=2}$, $T_{f=3}$, $T_{f=4}$ and $t_{init.}$ for revealing effect of systems on driving behavior.

3.7 Procedure

On the first day, each participant is given an explanation of the data collection, including of apparatus and driving task. Then, he or she does approximately 5-minitue exercise for being familiar with the driving simulator. After 10-minitue rest, he or she is instructed to drive three trials and experience six lane changes for collecting his or he checking behaviors in order to construct individual driver model of checking behavior.

On the secondary day, each participant participate into the experiment. Firstly, after an explanation of driving task as same as that in the data collection, the two types of adaptive caution support system and the secondary task, the experimenter gives a training of familiarizing the two types of caution support system and the secondary task. All participants are asked to complete six blocks under 2×3 driving conditions. The 2×3 blocks' order is counterbalanced across participants. Each of which contains three trials.

4 Results

4.1 Driver Model of Checking Behavior

Figure 4 shows individual driver models for all participants and the mean value of $f_{eye.}$ as a function of time. Mean values of $T_{f=2}$ and $T_{f=3}$ are 17.1 s ± 7.6 s and 29.1 s ± 7.4 s.

Values of $T_{f=2}$ and $T_{f=3}$ are used for the two types of adaptive caution support systems.

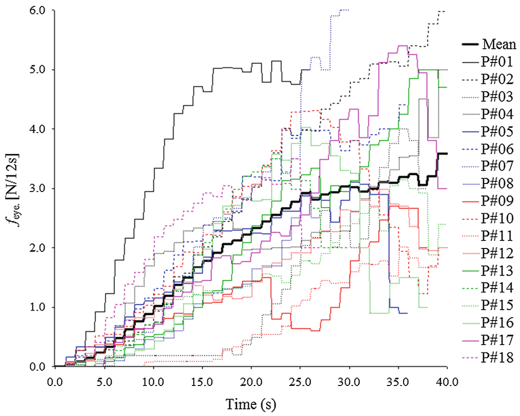

Fig. 4. Individual driver model of intentional checking behaviors

4.2 Effect of Adaptive Caution Message on Checking Behavior

Figure 5 shows averaged frequencies of intentional checking behaviors ($f_{eye.}$) at four phases of PreINFO1, INFO1to2, INFO2to3 and PostINFO3. An analysis of variance (ANOVA) was performed on averaged values of $f_{eye.}$. No interaction of driving condition × system type was shown (($F(2, 34) = .99$, $p = .38$), and a main effect of driving condition was significant (($F(1, 17) = 13.52$, $p < .01$). Furthermore, ANOVA was also operated at each of four phases. No interaction was shown at any phase of PreINFO1 ($F(2, 28) = .98$, $p = .39$), INFO1to2 ($F(2, 28) = 1.19$, $p = .32$), INFO2to3 ($F(2, 28) = 1.28$, $p = .88$), and PostINFO3 ($F(2, 28) = 0.38$, $p = .55$).

Figure 6 depicts averaged frequencies of intentional checking behaviors ($f_{eye.}$) at PostINFO2. An ANOVA showed no interaction of driving condition × system type

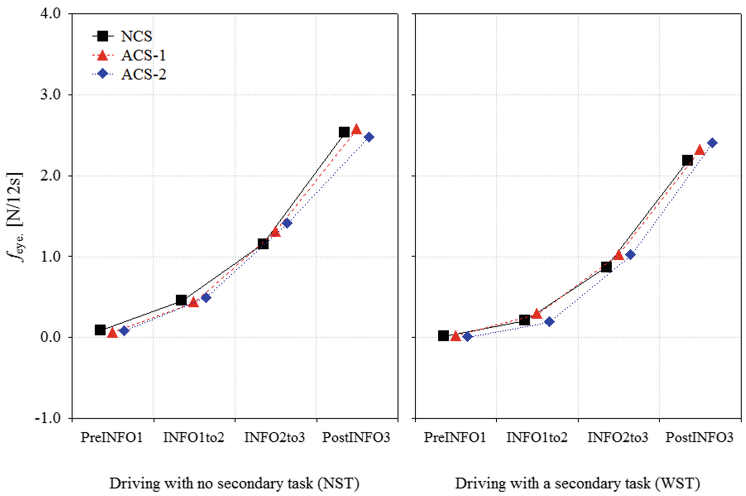

Fig. 5. Frequency of intentional checking behaviors ($f_{eye.}$) at four phases (PreINFO1, INFO1to2, INFO2to3 and PostINFO3). (Mean is shown.).

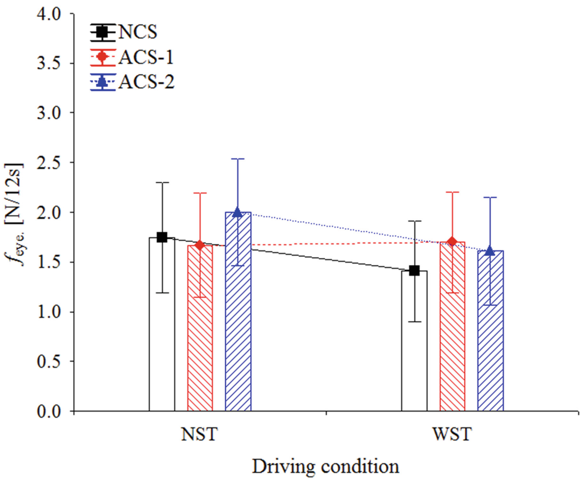

Fig. 6. Frequency of intentional checking behaviors ($f_{eye.}$) at a phase of PostINFO2. (Mean and standard errors are shown). NST = Driving with no secondary task, WST = Driving with a secondary task.

((F (2, 34) = 2.14, $p = .13$) and no effect of system type ((F (1, 17) = .71, $p = .50$), but a main effect of driving condition was significant ((F (1, 17) = 8.58, $p < .01$).

4.3 Effect of Adaptive Caution Message on Driving Behavior

Figure 7 depicts averaged THW at as a function of time points of $T_{f=1}$, $T_{f=2}$, $T_{f=3}$ and $T_{f=4}$. An ANOVA showed an interaction of driving condition × system type ((F (2, 114) = 5.66, p < .01). Tukey's test revealed the significant difference (p < .01) between any pair of ACS-1 v.s. NCS and ACS-2 v.s. NCS under each of driving conditions. Furthermore, the significant different between ACS-1 and ACS-2 was shown under WST driving condition (p < .05).

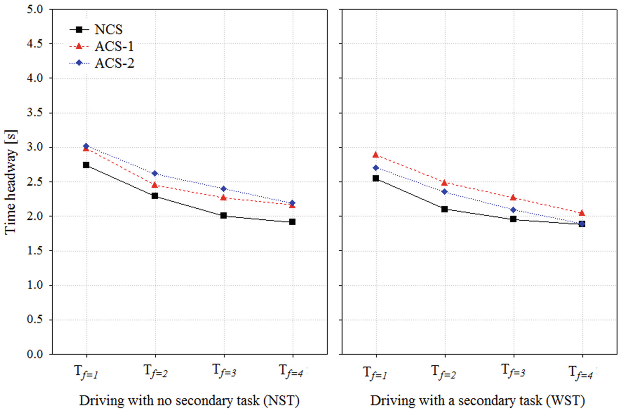

Fig. 7. The time headway (THW) as a function of time points of $T_{f=1}$, $T_{f=2}$, $T_{f=3}$ and $T_{f=4}$ under 2 driving conditions × 3 types of support systems. (Mean is shown.).

THW at the time point $t_{init.}$ at which changing lanes was initiated was shown in Fig. 8. An ANOVA showed no interaction of driving condition × system type (F (1, 17) = .15, p = .70) and no effect of driving condition (F (2, 34) = .06, p = .94). Main effect of system type was significant ((F (2, 34) = 5.72, p < .01). Tukey's test indicated that between any pair of ACS-2 v.s. NCS under each of driving conditions as shown in Fig. 8.

5 Discussion and Conclusion

Performing a cognitive activity affected driver's intentional checking behavior significantly, which agreed with Zhou et al. [18]. This study's results also indicated that a driver increased intentional checking to traffic environment through being given caution type message when he or she was distracted from driving task (See Fig. 5).

The four-phase caution message was supplied by two ways (ACS-1 and ACS-2). Results implied that both of the two ways were effective on improving driving behavior during the whole preparing phase for lane changes (See Fig. 7). More concretely, ACS-2 seemed more effective in cases of NST, ACS-1 seemed more effective in cases of WST.

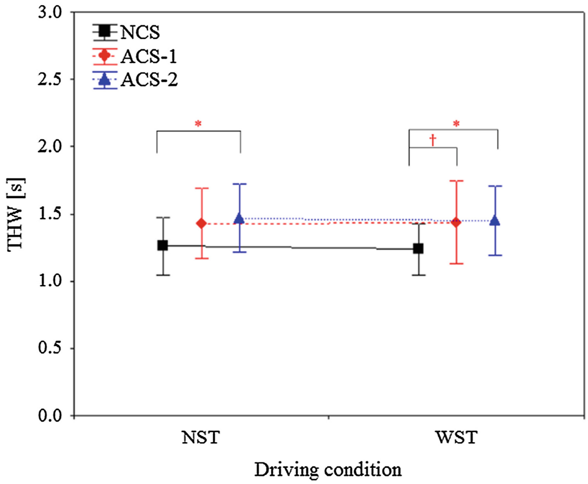

Fig. 8. Time headway (THW) at initiation of changing lanes ($t_{init.}$). (Mean and standard errors are shown.) Asterisk (*) indicates statistical significance ($p < 0.05$). NST = Driving with no secondary task, WST = Driving with a secondary task.

The caution information was not only effective during the preparing phase but also at initiating changing lanes (See Fig. 8). The result showed that a maneuver of changing lanes under ACS-2 was significantly improved with comparison to NST.

In this study, ACS-2 was adaptive to driver's state as well as driving situation. That is, a message would be given to a driver if the system did not think that he or she was distracted. Therefore, the investigation in this study implied that ACS-2 could decrease extra-message from support systems because ACS-2 was also shown effectively for improving driving safety.

Therefore, future work will try to investigate following issues:

- whether an adaptive caution information system can prevent a potential collision in near future lane changes,
- whether adaptive caution message could help driver to comprehend a sudden protection,
- what kind of information is essential at each of different phases.

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