A Warning Method for Rear-Side Obstacles based on Driver's Perceptual Risk Model

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***Abstract* - To prevent crashes of automobiles, many driver assistance systems have been proposed. Several warning systems have been proposed to reduce driver cognitive and judgment load. Such warning systems should have ability to evaluate collision risk and to start warning appropriate timing. Inversely, the system's efficacy can be decreased if the driver feels annoyance and/or mistrust with inappropriate warning timing etc. To overcome this problem, we propose a new warning method for rear-side obstacle based on driver's perceptual risk model that we derived from the analysis of driver's deceleration behaviour. Validity of the warning method will be shown by driving simulator experiments. In addition, there exists individual difference in expectation of meaning of warning. Thus, differences of the efficacy and driver's response behaviours against warning will be analysed based on the difference of their expectation.**

Index Terms - Automotive Safety, Warning System, Perceptual Risk, Driver Assistance System, Collision Avoidance

I. INTRODUCTION

Many driver assistance systems have been proposed and some of them have been commercialized to prevent crashes of automobiles. Several warning systems such as FCW(Forward Collision Warning) system and LCM(Lane Change and Marge) system have been proposed to reduce driver cognitive and judgment load. Such warning systems should have ability to evaluate collision risk and to start warning in the appropriate timing. Inversely, the system's efficacy can be decreased if the driver feels annoyance and/or mistrust with inappropriate warning timing etc. For example, warning system evaluates collision risk higher than that of the driver and the warning timing is earlier than driver's intention, then driver can feel annoyance. Inversely, if the warning timing is later than driver's expectation, then, driver may feel mistrust for the system.

There are many researches about trust for warning systems. For example, Lee and Moray[1] and Inagaki et al.[2] pointed out the importance of trust and reliance for machine to realize high efficacy system. Okuwa et al. investigated process of trust formation for warning system in detail [3]. Furthermore, there exist many researches dealing with a method to increase trust for warning systems. For example, Okabe et al. proposed a concept of risk communication that increases trust by exchanging information about probability of the risk[4]. Akita et al. proposed a new warning displaying method using reliability information of sensor recognition in the case that the sensor has relatively lower reliability and its reliability information can be calculated in real-time [5]. These researches can be understood as effort to increase trust for given system under the condition that false alarm and miss-alarm exist with limited sensor reliability. On the other hand, there exist research studies dealing with a method to adjust warning timing by taking individual differences into account. Abe et al.[6] investigate the effect of personal adaptive warning timing based on driver's braking timing on driver's trust in the system. In order to realize personal adaptation, parameter tuning corresponding to individual difference is indispensable and the result strongly depends on the method of parameterization. For this purpose, we propose a warning method that can suitable for personal adaptation by introducing driver's perceptual risk model we proposed [7]. In addition, it should be noted that process of forming trust for warning system is different if driver's expectation to the warning system is different.

In this paper, we propose a new warning method for rear-side obstacle based on driver's perceptual risk model that we derived from the analysis results of driver's deceleration behaviour. Validity of the warning method will be shown by driving simulator experiments. Differences of the efficacy and driver's response behaviours against warning will be analysed based on the difference of their expectation to the system.

II. EXPERIMENTS

A. *Experimental Apparatus*

Fig.1 shows an overview of a fixed-based driving simulator that is utilized for the experiments. There are three screens to display the road environment. A center screen is 100inch and the screens of both sides are 80inch. Computer graphics of the road environment is generated by World Tool Kit (Sense 8) that is C language library set based on Open GL. Vehicle dynamics are calculated by CarSim software (MSC corp.). In addition, a liquid crystal display is located near right side mirror so that drivers can see rear view information through the side mirror. In addition, warning sound is displayed by speakers located in the cockpit.

Fig.1 Experimental setup

B. Experimental Conditions

A straight road with two lanes in each direction is utilized for the driving simulator experiments as shown in Fig.2. In the test course, a subject vehicle (SV) follows a lead vehicle (LV) at 50 or 70km/h. There exists a principle other vehicle (POV) driving behind SV in the right lane and occasionally approaches to SV.

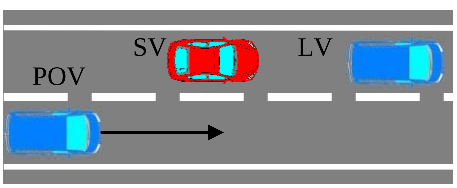


Fig.2 Experimental course

There are constant velocity condition and deceleration condition for the LV as shown in Table1. In the constant velocity condition, the SV approaches the LV with relative velocity V_{r_f} = V_{LV}-V_{SV} = -10km/h. In the deceleration condition, The LV and the SV drives with the same velocity and suddenly the LV decelerates with $dV_{LV}/dt=3m/s^2$.

Relationship between the SV and the POV is shown in Table2. There are three conditions in relative velocity of the SV and POV V_{r_r} = V_{SV}-V_{POV} = -10, -20, and -30km/h. Initial gaps between the SV and the POV are shown in Table2 as Dr0. As explained in the next section, different Dr0 is set according to the given warning method written as TTC warning and ϕ warning as well as approaching conditions of SV and POV. Dr0 is determined as 2s before onset of each warning condition. It should be noted that POV suddenly appears at this time in order to prevent from subjects overtaking the LV with very large gap with the POV. Subjects are 6 young student males of 21 to 26yrs with driver's licenses.

Table 1 Experimental conditions in relationship SV and LV

Proceeding vehicle Conditions	V_{SV} [km/h]	V_{LV} [km/h]	D_{f0} [m]	dV_{LV}/dt [m/s^2]
Constant Velocity cond.	50	40	50	
	70	60	45	
Deceleration cond.	50	50	35	3
	70	70	40	3

Table 2 Experimental conditions in relationship SV and POV

V_{SV} [km/h]	V_{r_r} [km/h]	D_{r0}[m] (*TTC* Warning)	D_{r0} [m] (ϕ Warning)
50	-10	13.8	21.0
	-20	27.7	37.7
	-30	41.6	56.6
70	-10	13.8	25.5
	-20	27.7	42.7
	-30	41.6	61.6

C. Warning Methods

In this paper, we propose a warning system for supporting lane changing operation. The system evaluates the risk between rear-side vehicle and own vehicle and displays auditory warning if its risk is higher than given threshold. In order to realize effective warning system, a method to determine warning onset timing is very important. In this research, we introduce risk index ϕ that is derived from expert drivers' braking behaviour analysis [8]. TTC(Time-to-Collision) is also utilized as alternative risk index because it is used in many warning systems [5].

(1) ϕ warning

From our previous study on analysis of expert driver's braking behaviour, we successfully derived a model of driver's perceptual risk against proximity of two vehicles as function of gap *D*, relative velocity *Vr*, and velocity of LV as eq.(1) [8].

$$\phi(V_r, V_{LV}, D) = K_{dB\_c}(V_r, V_{LV}, D, a) - b\log_{10} D - c \quad (1)$$

where $KdB\_c(V_r, V_{LV}, D, a)$ is defined as eq.(2).

$$KdB\_c(V_r, V_{LV}, D, a) = 10\log_{10}\left(4\times10^7 \times \frac{-V_r + aV_{LV}}{D^3}\right) \quad (2)$$

This function has been obtained by analyzing expert driver's brake initiation timing, that is, it was found that expert driver's brake initiation timing can be modeled accurately by equation of ϕ (*Vr*, *Vp*, *D*) =0. Therefore, we regard the function ϕ as driver's perceptual risk. Note that coefficients *a*, *b*, and *c* are determined as *a*=0.2, *b*=-22.66, *c*=74.71 from the experimental results with test drivers. This ϕ has been applied to brake assistance system[8].

Now, we apply this perceptual risk model to rear-side obstacle warning system. Namely, we calculate ϕ of POV against SV. If perceptual risk of proximity of POV's driver agasint SV is evaluated as higher than prescribed threshold, then the system installed in SV is judged that the lane change is risky and start warning display. In this paper, warning is displayed if inequality (3) is satisfied.

$$\phi(D,V_r,V_{LV},) \geq \Delta c \quad (3)$$

where Δc is threshold to activate warning. In this paper, threshold is set to Δc=0.

(2) TTC warning

TTC is defined by eq.(4) using relative velocity *Vr* and gap *D*.

$$\mathrm{TTC} = -D/V_r \quad (4)$$

TTC is utilized for many driver assistance systems because it is easy to understand because the index represent when to contact the two vehicles if the current relative velocity is continued. Thus, in TTC warning method, risk of collision of SV and POV is evaluated by TTC, then auditory warning is displayed if the inequality (5) is satisfied.

$$\mathrm{TTC} \leq \alpha \quad (5)$$

where *a* is threshold to activate warning signal. In this paper, *a* is set to *a* = 3 [5].

D. Experimental Method

In the experiments, SV approaches to LV. The subject takes his driving posture at the cockpit of the vehicle even though the operation of steering and pedal operation are not reflected to the vehicle motion. In addition, the subject is asked to read aloud one digit numbers displayed at the screen as shown in Fig.3. This task imitates increase of driver's workload because the proposed warning system is effective in such high workload situation.

Fig.3 Experimental sub task image

Suddenly, POV appears in the rear-side view display, and then the POV approaches to SV from the initial gap D_{r0}. In this period, subjects need to avoid collision between POV and/or LV by pedal and steering operations. The subjects are asked to avoid collision by lane change operation and overtaking the SV whenever collision risk is not high. The subjects are also asked to operate turn signal when overtaking the LV to his overtaking intention. Each trial is finished when overtaking the SV is finished. In the case that the subject avoids the collision to the LV by decelerating, each trial is finished when the collision avoidance is finished.

Subjects were asked to practice driving enough to get used to drive the simulator. Each subject experiences totally 96 trials, four times per each condition.

E. Expectation of Drivers to Warning Timing

Driver's expectation to the warning timing is investigated subjectively before experiments in order to investigate effect of difference of driver's expectation on difference of efficacy of the system. Subjects were asked to choose one from following two options about his expectation to warning timing:

(A) timing when a driver need to stop lane change
(B) timing when a driver can successfully realize lane changing if driver pays attention to peripheral environments.

As the results, subjects MY, KK, MI prefer (A) and subjects YK, TT, YN prefer (B). A set of subjects prefer timing (A) and (B) is referred to as group A and B, respectively.

III. Experimental Results

A. Number of Warning Displayed and Its Timing

Fig.4 shows number of trials in which the warnings are displayed. The number depends on how each subject drives against the given scenarios. Warning was displayed in the trial of 60 percent or more because total number of trials was 96. In the remaining part of this paper, only trials in which warning was displayed are analysed.

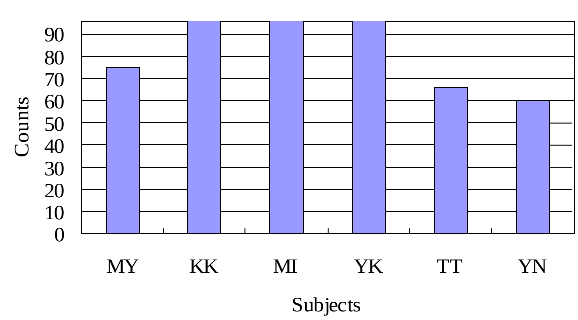


Fig.4 Number of trials where warning is displayed

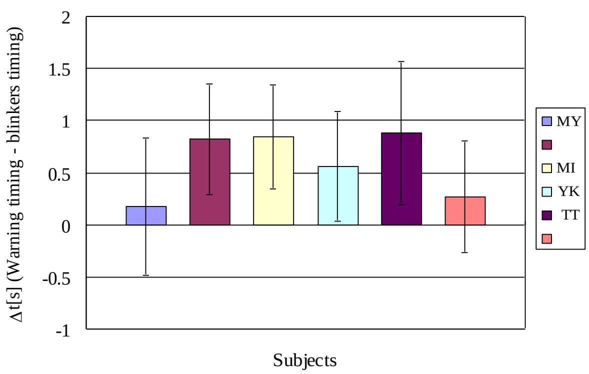


Fig.5 Average Δt (Warning timing – blinkers timing)

Fig.5 shows mean relationship of driver's turning signal initiation timing as driver's overtaking intention and warning onset timing. It is found that warning was displayed within about 1s after deciding overtaking.

B. Driver's Behavior against Warning

Figs. 6 and 7 illustrate overtaking intention and resultant operation of typical subjects group A and B, respectively. It should be noted that only trials with warning displayed is analysed. Left column illustrates in Overtaking intention that is measured by turning signal. Right column illustrates resultant operations. Operations (c) overtaking and (d) abandoning overtaking are followed by overtaking intention. Operation (e) braking is only seen in trials without overtaking intention.

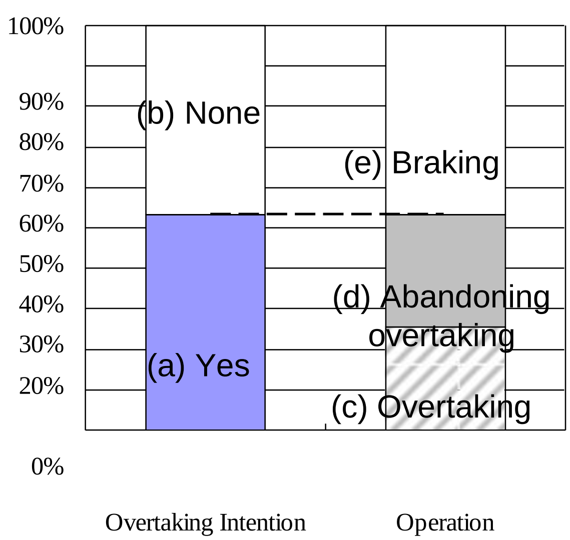


Fig.6 Overtaking intention and operation
(Subject MY: A group)

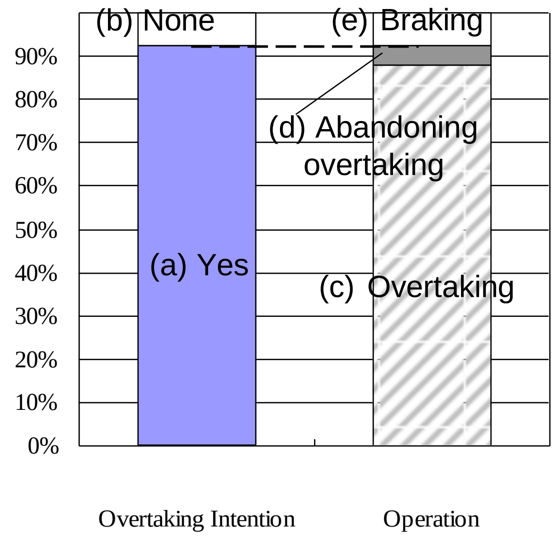


Fig.7 Overtaking intention and operation
(Subject TT: B group)

For overall, it is found that warning can successfully work to reduce overtaking by displaying warning.
As seen from these figures, the subject in B group has larger number of overtaking intentions. In addition, The subject in A group tends to be compliant to the warning. Inversely, the subject in B group tends to carry out overtaking even though warning is displayed.

Fig8 shows rate of trials in which driver abandoning overtaking by being displayed warning. As seen from the figure, rate of abandoning overtaking of group A is greater than group B even though no significance can be seen statistically due to lack of subject number. It is the same tendency with Figs.6 and 7 and it is understood that drivers in group A are more compliant to the warning system. It is

warning system that displays warning signal when driver need to stop lane changing. Inversely, drivers in group B tend not to stop overtaking even though warning is displayed.

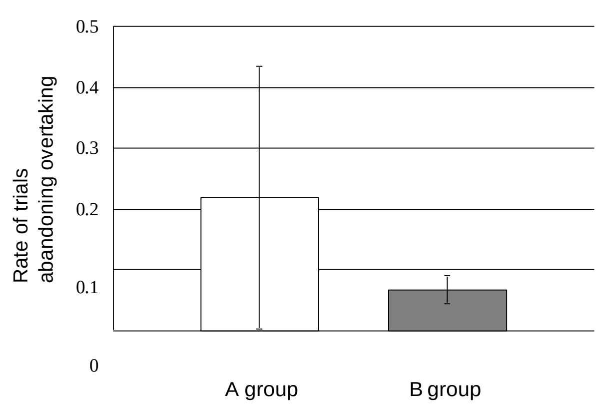


Fig.8 Rate of trails abandoning overtaking

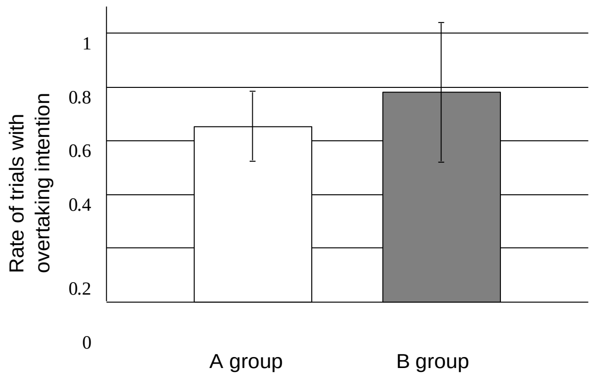
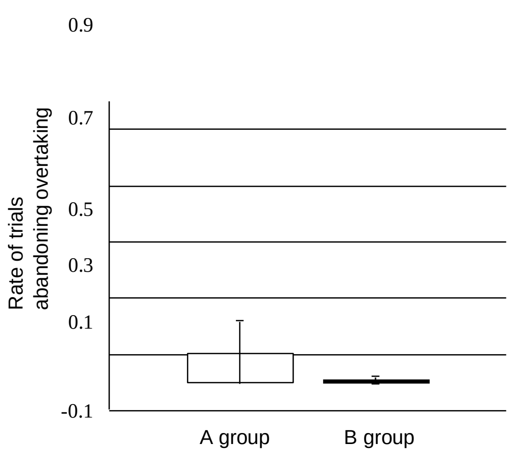


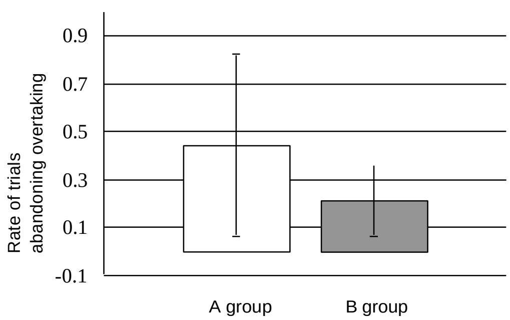
Fig.9 Rate of trails with overtaking intention

Fig.9 shows rate of trials with overtaking intention. The rate of overtaking intention of subjects in group B is likely larger than that in group A even though no statistical significance. It could be understood that drivers in B group can be more aggressive than A group. This tendency is same as that in Figs.6 and 7.

From these figures, driver's intention of overtaking and operation against warning can be changed by the driver's expectation to the warning system.



(a) ϕ warning

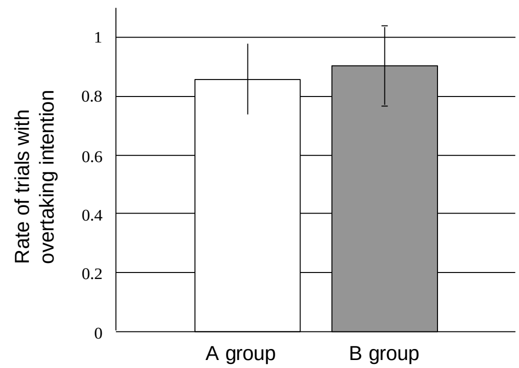


(b) TTC warning

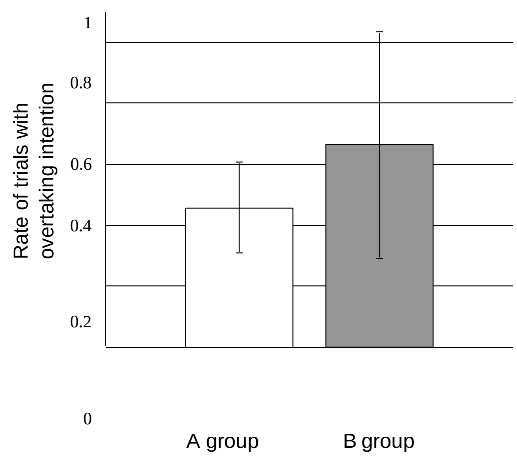
Fig.10 Rate of trails abandoning overtaking

Comparisonbywarningalgorithms

Fig. 10 shows rate of trials abandoning overtaking in each warning method. Fig.11 also shows trials with overtaking intention in each warning method. Similar tendency as the overall results can be seen also in each warning method.



(a) ϕ warning



(b) TTC warning

Fig.11 Rate of trails with overtaking intention

Namley, rate of trials with abandoning overtaking of A group is larger than that of B group. By comparing both warning methods, TTC warning shows greater abandoning rate than ϕ warning. On the other hand, rate of trials with overtaking intention of each warning method also shows similar tendency as the overall results but difference between groups is small in ϕ warning. These results imply that ϕ warning may work as calling for attention to the rear-side obstacles rather than warning. Namely, ϕ warning starts to work early and it leads to less difference in abandoning overtaking behaviour. As a results, it is found that threshold for these warning affects the forming intention of overtaking and compliance to the warning.

IV. CONCLUDING REMARKS

In this paper, we proposed a new warning method for rear-side obstacle based on driver's perceptual risk model. Validity of the warning system was shown by driving simulator experiments. The warning successfully reduces overtaking by displaying warning.

Differences of the efficacy and driver's response behaviours against warning was analysed based on the difference of their expectation to the warning system. It was found that driver group that prefer warning displayed for stopping overtaking is more compliant to the displayed warning. Inversely, the driver group that prefer warning displayed for calling attention to the rear-side obstacle is less compliant to the warning and interestingly, this group has also tendency to larger intention for overtaking. Namely, it is found that the expectation of the warning greatly affects the formation of compliance to the warning.

In addition, by comparing ϕ warning and TTC warning, ϕ warning forms less compliance to the system because this method displays in relatively earlier stage and it leads to less difference in overtaking intention and also in abandoning overtaking.

As the future study, effect of warning timing will be investigated and the results will be applied to a new design of warning method. Especially, the timing should be determined by considering relationship between driver's preferences of warning method and compliance to the system. Furthermore, in order to increase efficacy of the warning system by considering driver's expectation to the system, information displaying system with two phases is proposed. Namely, the system displays recommendation to pay attention to the target obstacle and to refrain from overtaking in low risk stage while it displays alarm in high risk situation. The recommend phase can work as cognition assist system rather than judgment assist because driver can be prompted to select operation in the phase. It is expected that this method can work well to driver groups with different expectation to the warning system.

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