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Rear Obstacle Warning System Using Sensor Reliability Information

Shigeyoshi Tsutsumi, Takahiro Wada, Shun'ichi Doi
Faculty of Engineering, Kagawa University

2217-20, Hayasi-chou, Takamatsu, Kagawa, Japan E-mail: {s10d502@stmail., wada@, sdoi@}eng.kagawa-u.ac.jp

ABSTRACT: Driver's workload tends to be increased during driving under complicated traffic environments like lane changing operation. In such cases, rear collision warning is effective for reduction of cognitive workload. On the other hand, it is pointed out that false alarm or miss alarm caused by sensor errors leads to decrease of driver's trust in the warning system and it can result in low efficiency of the system. Suppose that sensor reliability information is provided in real-time. In this paper, we proposed warning methods to increase driver's trust in the system even with low sensor reliability by utilizing the sensor reliability information. We investigate the effectiveness of the warning methods in high and low workload situations by driving simulator experiments.

KEY WORDS: Warning, Trust, Sensor Reliability, Rear Obstacle

1. Introduction

Driver assistance for cognition and judgment is effective for reducing driver's workload and potentially traffic accidents. For example, the Rear Obstacle Warning System (ROWS) has been proposed for the situation in which the cognitive loads are high like changing a lane. Akita et al. have been proposed a new ROWS using a rear-view camera that have been already widespread as the sensor of the parking assist system [(1)]. It should be noted that the object recognition with the sensor used for the warning judgment is not perfect in general. It causes the false alarm (FA) and the miss alarm (MA). Such errors might reduce the driver's trust in the warning system. Generally errors are included in the sensor used in the system and the errors cannot be avoided. Thus a method to maintain the driver's trust in the system is desired.

Fortunately, the image processing method can estimate sensor reliability information when detecting rear obstacle. In fact, Akita et al. also proposed a method to estimate the sensor recognition reliability based on Bayesian Network [(1)]. This information can reflect risk factor of the sensor errors. On other hand, Okabe et al. pointed out the importance of communication of risk information between the automated system and human for establishing effective human machine system [(2)]. Based on the concept of the risk communication, we propose new warning methods to increase the driver's trust in the system even with the relatively low reliability sensor. Moreover, we evaluated the effectiveness of the proposed method in environment with high collision risk [(3)].

In this paper, the effectiveness of the proposed methods will be shown by the experiments using the driving simulator in environmental conditions with various workload. Then we investigate the relationship between driver's workload in these warning presentation methods and the subjective evaluation on trust and effectiveness of the warning.

2. Warning Presentation Method

2.1. Proposed warning method

So far, Akita et al. have proposed the ROWS that used the sensor recognition reliability, and have realized to increase trust [(3)]. The system provides "information calling for attention" to the driver to reduce FA and MA if the sensor recognition reliability is low. The method is referred to as "SRR method".

Moreover, we proposed a warning method considering the collision risk and the sensor recognition reliability that is referred to as "RISK Method" [(4)]. This method can be regarded as the modified version of SRR method. The warning method displays "warning" when a collision risk is high even in the low sensor recognition reliability.

2.2. Warning algorithm used in this experiment

In this paper, We investigate the effectiveness of "RISK Method" by comparing with the conventional warning method in high and low workload situations. These warnings installed in ROWS. The feature and settings of each warning are described below. Relative velocity (V_r) and gap (D) between the subject vehicle and the approaching obstacle in longitudinal direction are measured by a sensor. Suppose that the existence probability of a vehicle is provided from measurement result by the sensor as $R_S \in [0,1]$. $R_S = 1$ means the probability that the approach vehicle exists is very high, say, the approaching vehicle exists absolutely. Oppositely, $R_S = 0$ means the existence probability is very low: there is no approaching vehicles. A middle value of Rs represents a dilemma zone with the most uncertain decision. In addition, Time To Collision (TTC) is given by the next expression.

$$TTC = \frac{D}{V_r} \quad [s] \tag{1}$$

A Front Collision Warning System (FCWS) is also equipped with the subject vehicle that is displayed by beep-like sound. The FCWS is issued if the following condition is satisfied:

$$TTC < 3 \quad \text{or} \quad D < 3 \tag{2}$$

The explanation of ROWS is written in following sections.

2.3. Conventional (CONV) method

The algorithm choose relatively lower threshold for warning to reduce miss alarm consequently. This warning system presents warning even when probability of vehicle existence is relatively low (Fig. 1).

For warning

$$TTC < 3 \quad \text{or} \quad D < 3$$
$$\text{and} \quad R_S > 0.2 \tag{3}$$

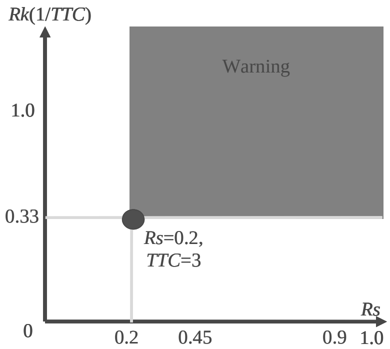


Fig. 1 The value of conventional warning threshold

Here, we describe how the conventional method works. Now let consider three points in Fig. 2. In addition, *Rk* is given by inverse of *TTC*. These points represents three situations that the sensor recognizes vehicles.

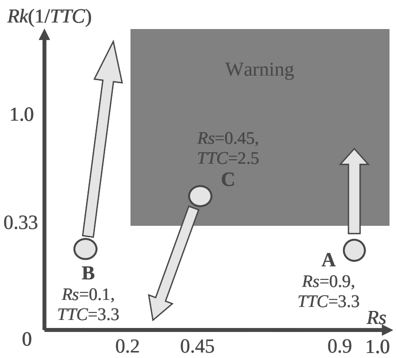


Fig. 2 The feature of conventional method

Point A (*Rs*=0.9 : *TTC*=3.3)

This point shows a situation with high *Rs* value and the vehicle is approaching. Assume that *TTC* is decreased in time due to approaching the vehicle while *Rs*. Then, warning is issued when *TTC* is less than three seconds.

Point B (*Rs*=0.1 : *TTC*=3.3)

This point shows a situation with low *Rs* value and the vehicle is approaching same as point A. Assumed that *Rs* is increased in time and *TTC* is decreased, due to approach of a vehicle. Warning is not issued even though *Rs* value becomes larger than 0.2.

Point C (*Rs*=0.45 : *TTC*=2.5 : No approaching vehicle)

This point shows a situation with medium *Rs* value and there is no approaching vehicle. Assume that *Rk* is decreased in time. In the situation, warning is presented at the beginning (False Alarm), then it disappeared.

2.4. RISK (RISK) method

"RISK Method" has three levels in the warning status: (1) warning, (2) calling for attention, and (3) none. These statuses are intended to be understood by drivers as follows: (1) warning is issued when collision risk is high, (2) calling for attention is issued when system cannot evaluate risk of collision due to lack of sensor reliability information, thus the driver is expected to judge by their selves. (3) none denotes nothing should be issued. The calling for attention status was introduced to overcome low sensor reliability as SRR method [3].

In addition, the RISK method utilizes the collision risk as well as the sensor reliability information. The method displays "warning" when a collision risk is high even in the low sensor reliability information (Fig. 3).

The warning or calling for attention is issued if the following condition is satisfied:

For warning

$$W_{th} \geq 0.3 \quad \text{or} \quad D < 3 \tag{4}$$

For calling for attention

$$0.3 > W_{th} \geq 0.15 \tag{5}$$

where the warning threshold W_{th} is defined as eq.(5).

$$W_{th} = R_S \times \frac{1}{TTC} \tag{6}$$

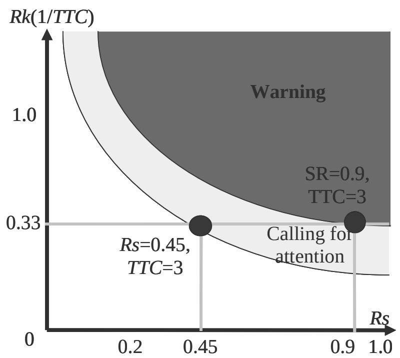


Fig. 3 The value of RISK Method warning threshold

We describe how the RISK method works. Now we consider three points in Fig. 4. These points are same as conventional warning.

Point A (*Rs*=0.9 : *TTC*=3.3)

Calling for attention is issued at the beginning, then warning is issued when *TTC* is less than 3s.

Point B (*Rs*=0.1 : *TTC*=3.3)

Calling for attention is issued by increasing *Rk* value, then warning is issued when *TTC* becomes much smaller,.

Point C (*Rs*=0.45 : *TTC*=2.5 : No approaching vehicle)

No warning but calling for attention is presented at the beginning, which can be regarded as a kind of False Alarm, then it is disappeared as decreasing *Rs* and *Rk*.

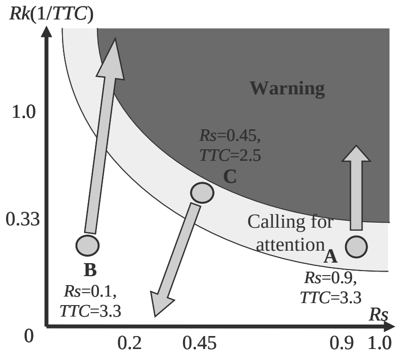


Fig. 4 The feature of RISK Method

3. Experimental Method

3.1. Experimental setup

A fixed-base driving simulator (DS) was used in the experiments. Overview of DS is shown in Fig. 5, composition of DS is shown in Fig. 6. Three of 100 inches screens were used to draw frontside information. A 22 inches LCD was arranged to reflect the rearward visibility in the side-view mirror.

A number is displayed at the left of the front screen in order not to focus on the confirmation of the backside and updated every 2 s. Namely, a task to read the number aloud was imposed to the participants during driving, so that they were distracted with a high visual and cognitive workload to prevent the participants from gazing the rear-side mirror.


Fig. 5 Overview of driving simulator

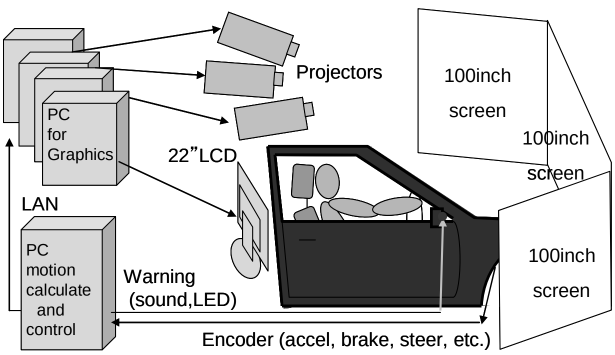


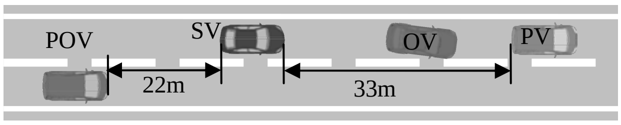
Fig. 6 Composition of driving simulator

A speaker was put on the DS, and an engine sound and a warning sound were displayed. Auditory warning was displayed for FCWS. ROWS was installed with color LEDs based on existing Rear Vehicle Monitoring system (RVM). The warning and calling for attention were displayed by the indicator using Red and yellow LEDs embedded on an A-pillar, respectively (Fig. 7).

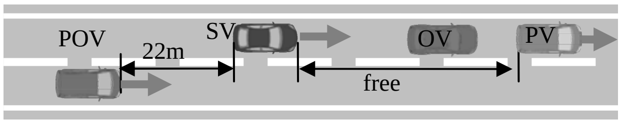
Fig. 7 Warning presentation method

3.2. Experimental course and scenario

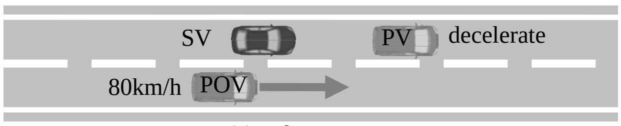
A straight road with two lanes in each direction was adopted for the experiments. Experimental scenarios and locations of the subject vehicle (SV), the preceding vehicle (PV), the principal other vehicle (POV), and the observed vehicle (OV) are shown in Fig. 8. In this experiment, the PV decelerated while followed by the SV, and the participants were instructed to avoid a collision with the PV using a lane change maneuver while also avoiding a collision with the POV. The participants were also instructed to return to the left traffic lane after avoidance. At the beginning of experiment, there were 2 vehicles in front of participant's as seen in Fig.8-(a). Then, the participants followed the PV in left lane with 60km/h (Fig.8-(b)). The POV following the backside occasionally approached from behind the SV. The position of the OV depended on the scenario conditions. In the risky scenario, the POV approached at 80 km/h from about 22 m behind the SV(Fig.8-(c)). When PV decelerates, *TTC* between POV and SV was approximately 3s. In the safe scenario, the POV stayed about 22 m behind (Fig.8-(d)).



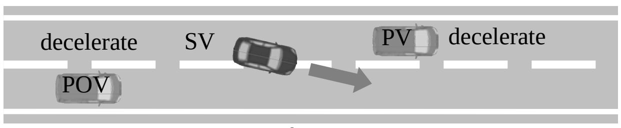
(a) car locations at initial condition



(b) following condition



(c) risky scenario



(d) safe scenario

Fig. 8 Experimental scenarios

There are three patterns in the risky scenario as illustrated in Fig. 9 (a), (b), and (c), at the time of deceleration of the PV. The deceleration and position of PV were different among patterns while the location of POV was identical among patterns. Fig.9-(a) illustrates higher workload pattern of the three. OV follows PV in front of SV and OV covers brake lamps of PV. PV decelerated at 5.9 m/s^2 while followed by the SV. Fig.9-(b) illustrates medium workload pattern. OV begins to change the lane to right traffic lane, and run away. PV decelerated at 4.9 m/s^2 while followed by the SV. Fig.9-(c) This is lower workload scenario in the three. After scenario begins, OV begins lane change to right traffic lane, and run away. PV decelerated at 2.9 m/s^2 while followed by the SV.

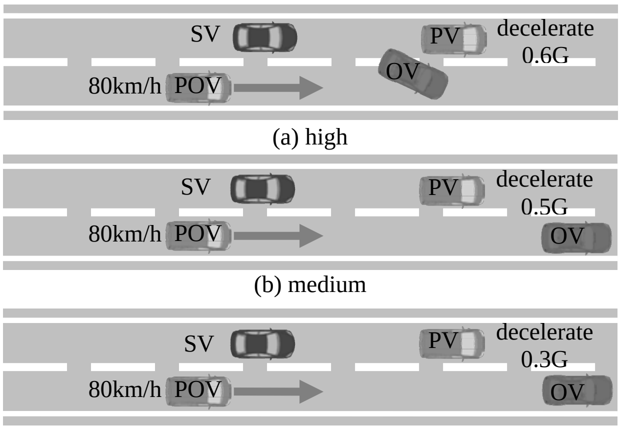


Fig. 9 Different workload patterns

3.3. Distribution of *Rs* and resultant frequency of warning

The distribution of the *Rs* assigned for scenarios was given in Fig. 10. The same distribution was used for both CONV and RISK method conditions. This distribution is introduced in order to verify the uncertain domain of sensor.

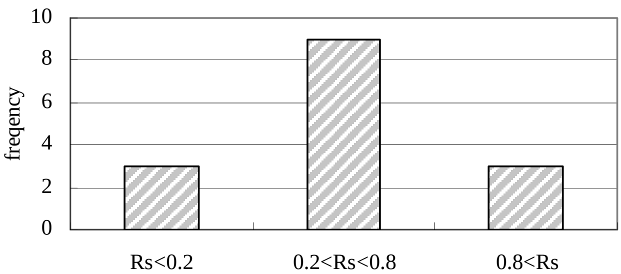


Fig.10 Distribution of the *Rs*

Table 1 shows the resultant presentation frequency of warning in each warning method, given the distribution of *Rs* as Fig. 10. In CONV method, there is false alarm because warning was presented even when sensor reliability was low. In RISK method, warning was presented when *Rs* is high or collision risk was high while information calling for attention was issued when *Rs* or collision risk was low.

Table 1 Number of presented warnings

Condition	safe scenario			risky scenario	
	no warning	calling for attention	warning	calling for attention → Warning	warning
Conv1	3		3		9
RISK	3	3		6	3

3.4. Experimental design and procedure

Twelve male students aged from 21 to 24 with driver's licenses who gave informed consent participated in the experiments.

There were two levels in the warning method condition as CONV and RISK for ROWS. The warning condition was dealt with the within-subject experimental factor, that is, all participants experienced both warning conditions. The order of the warning condition was counter-balanced in the participants.

At first the participants drove the DS as the practice to get used to driving the DS. At that time, they experienced the warning system to understand how they work. Then, the experiment started from either warning method. The order was counter-balanced in participants. For each warning method, a run in the high workload condition was experienced followed by a run in the medium condition and a run in the low condition. The length of course for a run was about 2km, it took about 3 minutes. Each run included 5 events, therefore, there were 15 events for each warning method.

3.5. Evaluation method

Subjective workload was evaluated by Japanese version of NASA TLX (Task Load Index) [(5)]. For this experimental evaluation, Weighted Workload (WWL) Scores was calculated and used.

In addition, the participants were asked to rate the trust and the effectiveness in the each warning method by using Visual Analog Scale (VAS). The participants answered the trust from 0% of not trustable at all to 100% of trustable perfectly, and effectiveness from 0% of not effective at all to 100% of effective perfectly.

4. Experimental Results

4.1. WWL

The results of the NASA-TLX WWL are shown in Fig. 11. WWL were decreased with RISK method in High and Medium workload levels scenario, but not decreased in Low workload scenario. However, workload by presented warning in RISK method is higher than CONV method.

The paired t-tests were conducted for each workload condition. Significant difference was found in WWL-M condition ($t(11)=2.334$, $p<0.05$) while no significance was found in WWL-H (p=0.189) and WWL-L (p=0.423) condition.

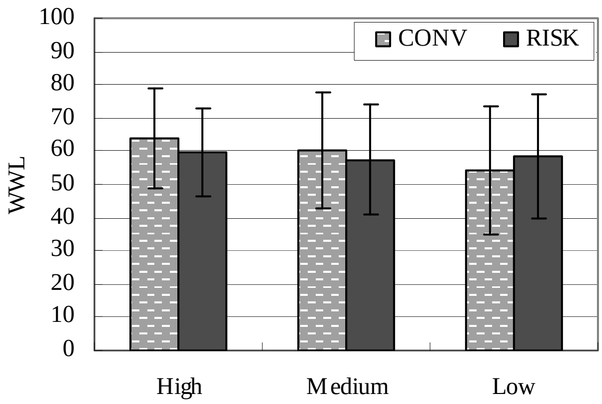


Fig. 11 The results of the WWL

4.2. Trust

The average of the participant's trust in the system are shown in Fig. 12. The subjective trust is improved with the RISK method by comparing with the CONV method in all cases even though the system uses the same sensors.

The paired t-tests were conducted for each workload condition. But significant difference was not found in Trust-H (p=0.453), Trust-M (p=0.211), and Trust-L (p=0.117), condition

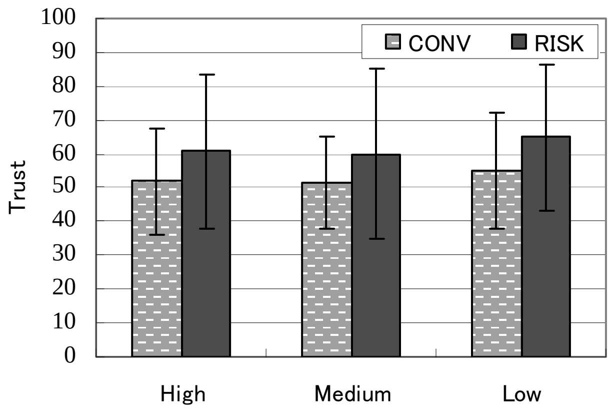


Fig. 12 Average of subjective evaluation of trust

4.3. Effectiveness

The average of the participant's effectiveness are shown in Fig. 13. The result of Effectiveness is high at RISK method, than CONV method in High and Low workload levels scenario.

The paired t-tests were conducted for each workload condition. But significant difference was not found in Effectiveness-H (p=0.188), Effectiveness-M (p=0.159), and Effectiveness-L (p=0.312), condition.

As the result, significant difference was not obtained most of evaluations.

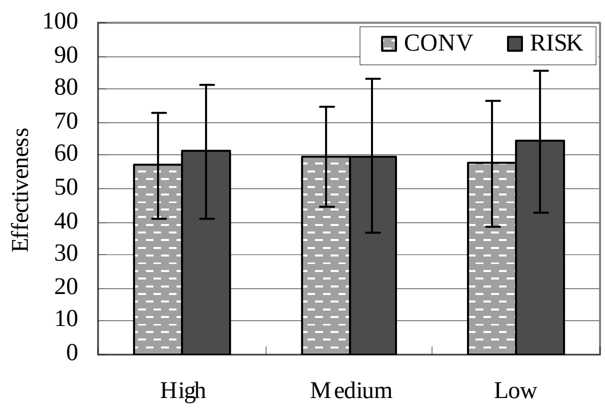


Fig. 13 Average of subjective evaluation of effectiveness

4.4. Effect of Subjective workload on evaluation of warning

The average of subjective evaluation in RISK method was better than that in CONV method. However, no statistical significance was found. We assume that subjective evaluation of trust and effectiveness was varied among participants. In fact, the evaluation of trust was increased with RISK method in 23 cases of total 36 cases. So, we investigate the relationship between subjective workload and evaluation for warning.

We thought the differences between participants were that of the workload sensitivity. Therefore, participants were divided into three groups by averaged WWL scores as follows. Namely, the participants' average of WWL (*WWL_ave*) was calculated from six trial's WWL. Then, the participants were classified into one of the three groups according to the obtained *WWL_ave* as follows:

Group-L (*WWL_ave*<33.3)

One participant was classified into this Group.

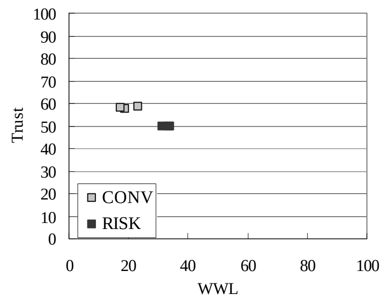
Group-M (33.3< *WWL_ave* <66.6)

Six participant were classified into this Group.

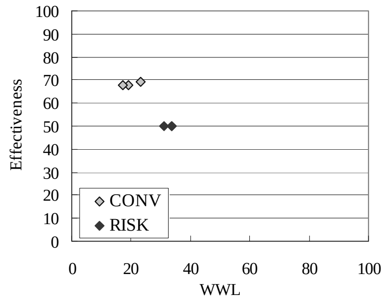
Group-H (66.6< *WWL_ave*)

Five participant were classified into this Group.

Fig.14 illustrates the relationship between WWL at each trial and the subjective evaluation of trust for Group-L. We think this group was understood that warning system is not so necessary for the participant. But the results of Group-L was not analyzed in detail here because only one participant was assigned to this group.



(a) Trust



(b) Effectiveness

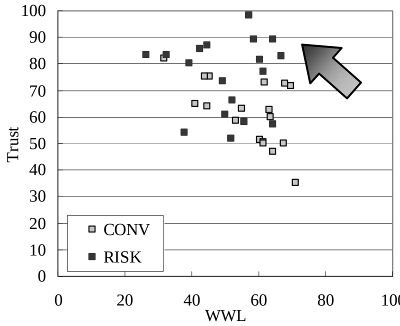
Fig. 14 Group-L

Fig.15 illustrates the relationship between WWL at each trial and the subjective evaluation of trust and effectiveness for Group-M.

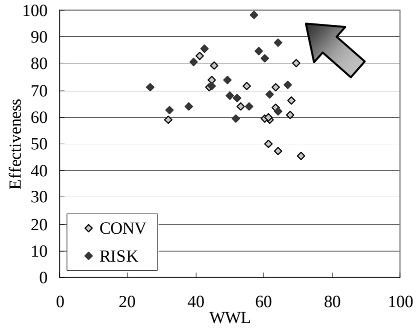
The evaluation of trust and effectiveness in RISK method seems to be on the left compared with that in CONV method. It is thought that RISK method could reduce workload and subjective evaluation was improved.

A paired t-test of WWL revealed that significant difference in warning method condition ($t(17)=2.593$, $p<0.05$), the workload with RISK method was smaller than that with CONV method. The paired t-test of subjective trust also showed that trust with

RISK method was significantly higher than that with CONV method ($t(17)=3.596$, $p<0.005$). The paired t-test of subjective effectiveness also showed that effectiveness with RISK method was significantly better than that with CONV method ($t(17)=2.287$, $p<0.05$). From this result, it is thought that warning acts effectively in RISK method.



(a) Trust

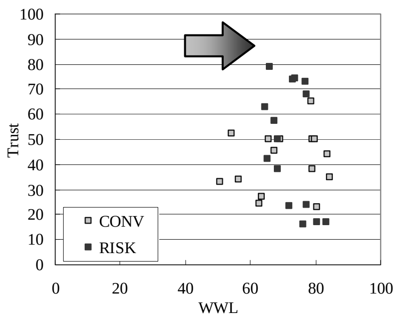


(b) Effectiveness

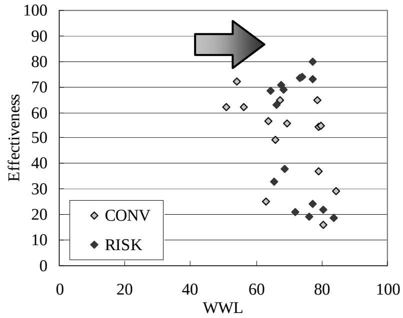
Fig. 15 Group-M

Fig.16 illustrates the relationship between WWL at each trial and the subjective evaluation of trust for Group-H.

The evaluation of RISK method seems to be on the right compared with that of CONV method. It is thought that the workload from driving environment and warning system was high, therefore it tends to be overloaded. So in this experiment, it may be hard to drive while evaluating warnings for participants in this group. The paired t-tests for WWL, trust, and effectiveness showed no significant differences in working method condition.



(a) Trust



(b) Effectiveness

Fig. 16 Group-H

5. Conclusion

We investigated the effectiveness of the ROWS by changing of the presentation method in different workload situations. The effectiveness of the methods were evaluated by the experiments using the DS. As the results, the participant's trust was significantly improved with the proposed methods where the WWL was in middle level. Thus, it suggests that the proposed warning method is effective where workload of traffic situation is in middle range. In addition, it was found that the subjective evaluation was changed by subjective workload WWL. It suggests that it is necessary to consider amount of workload in the case of the warning design.

As a future study, we will compare the driving behavior with this experimental result of the subjective evaluations. Moreover, the relationship between the workload and warning will be clarified further. Then, we will derive a warning method that is effective in Low and High workload condition.

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