NOVEL INTERFACES THAT ENHANCE A DRIVER'S ABILITY TO PERCEIVE FORWARD COLLISION RISKS

Takahiro Matsuoka
Tsuyoshi Nojiri
Honda R&D Co., Ltd.
Japan

Vanessa Krüger
Honda R&D Europe GmbH
Germany

Matti Krüger
Honda Research Institute Europe GmbH
Germany

Paper Number 23-0196

ABSTRACT

Forward Collision Warning (FCW) systems that alert a driver about the risk of rear-end collisions can contribute to a reduction of traffic accidents caused by human errors. Typically, FCWs create alerts that appear late when the risk is already high and are of binary nature, i.e., either in an alerting state during high risk or not producing any alert at lower risks. The choice at what risk level to start alerting in a binary manner is subject to a tradeoff between how much time an alert gives the driver to react and how necessary the alert appears to the driver. Our goal is to circumvent this limitation of classical binary FCWs to allow drivers to perceive developing risks early and in an intuitive manner and, accordingly, better avert developing risks with foresight. To that end, we propose a new system that assesses potentially hazardous situations in real time and continuously outputs a signal that alters its strength depending on the risk level. Here we report a study on the effect of variations of the proposed system on driving behavior and user acceptance.

The experiment was carried out in a driving simulator equipped with prototypes of visual, auditory, and tactile human-machine interfaces (HMIs). The participants performed driving tasks in two different driving scenarios. The subjective ratings of system acceptance were assessed with questionnaires on two dimensions, a usefulness scale and an affective satisfaction scale. The results indicate that, compared to an existing FCW system, all HMIs reduced driver reaction times and the visual HMI showed positive average scores of both usefulness and satisfaction in the driving scenario with high and medium collision risk. On the other hand, there was no HMI that achieved a good balance between the effect on driving safety and system acceptance in the scenario with lower criticality. These results suggest that the proposed notification system can improve driving safety and be perceived as subjectively acceptable in situations with high and medium collision risk despite the early signal. This makes

it a promising approach for circumventing the tradeoff between notification timing and risk perception. To address system effects on driving safety in situations with lower risk, further development iterations and long-term evaluations in a variety of traffic situations may be required.

INTRODUCTION

Forward Collision Warning (FCW) systems that alert a driver about the risk of rear-end collisions can contribute to a reduction of traffic accidents caused by human errors [1]. However, it is not guaranteed that a driver will successfully avert an accident after such an alert as it is typically triggered rather late when the risk is already high [2]. One approach to address this issue is to provide alerts at an earlier point in time to give drivers more time to react. One issue of such an approach lies in the risk of causing annoyance to the driver. Early warnings are more frequent than warnings that only appear in critical conditions and are thus at higher risk of appearing in situations regarded as uncritical by the driver [see 3, p. 31]. The driver could then consider system alerts as irrelevant or even as false alarms. This can lead to a *cry wolf effect* [4, 5], which is characterized by the ignoring of alarms that were "wrong" previously - even in critical cases. Another approach consists of adapting the timing of an alert to the capabilities of the driver. For instance, Jamson et al. [6] have proposed an adaptive FCW system that adjusts the timing of its auditory alarms according to each individual driver's brake reaction time. However, it is difficult to collect such individual reaction data in real-world driving environments because the driver's response to a hazardous event including risk cognition, judgment and averting action can vary depending on not only individual drivers but also driving situations.

To nevertheless convey an increasing collision risk early and successfully in various driving situations, we are proposing a system that assesses potentially hazardous situations in real time and continuously outputs a signal that alters its strength depending on the risk level to intuitively convey increased forward collision risk to drivers. As such it may be considered to represent an instance of so-called *likelihood alarm systems* [7]. The potential benefit of this approach is a circumvention of the tradeoff between notification timing and risk perception. Thus, a driver may perceive the signal as less annoying despite its early onset. Our goal is to encourage drivers' early voluntary risk averting action before there is a need for a more salient alert such as those used by present FCW systems. Such early and gradual risk communication may further be combined with existing salient FCWs as additional "guarantee" (see Figure 1).

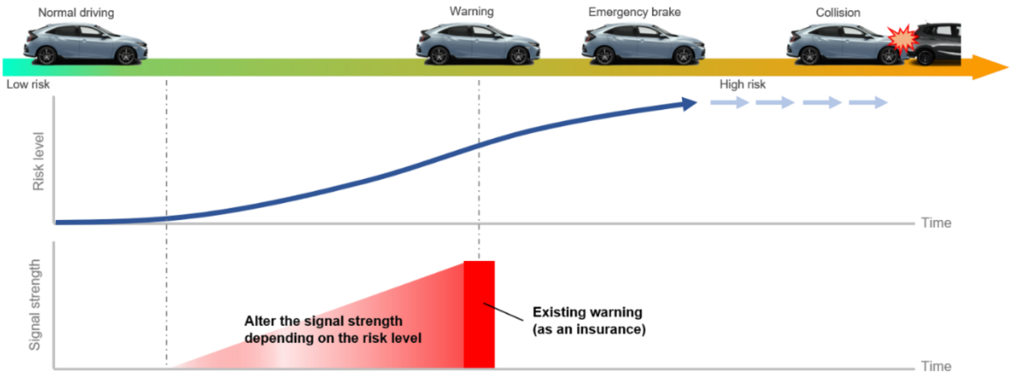

Figure 1. Illustration of the new notification that we propose.

Here we present an investigation of the effect and system acceptance of the proposed method in situations with low or medium risk levels. In particular, we try to answer the following research questions for a selection of continuous risk level communication methods:

1. Does the proposed method reduce driver reaction times to developing front collision risks compared to classical FCW?
2. Does driving safety with the proposed method increase compared to classical FCW?
3. How subjectively acceptable is the proposed method?

To address these questions, a driving simulator experiment was carried out. Because each signal modality may have a different effect on driver behavior, such as reaction times [8], four variations of Human-Machine Interfaces (HMIs) for risk level communication that utilize visual, auditory and tactile sensation were implemented into the driving simulator. The stimulus changing rate can vary depending on the risk increasing rate in our HMI concept, and thus the driver can differently perceive each HMI according to the driving situation. In this study, each HMI was tested in two different driving scenarios, which had in common that the ego vehicle eventually approached a leading vehicle, resulting in varying degrees of front risk and HMI activation. In one scenario the driver was distracted by a secondary task at the moment a sudden front risk appeared. In the second scenario the driver was indirectly motivated to produce tailgating behavior and thus become the primary source of front collision risk him or herself. Tailgating can produce an insufficient inter-vehicular distance and is one of the most severe driver-related causes of traffic accidents [9], which makes techniques that reduce such behavior particularly desirable.

METHODS

Participants

The experiment involved 17 participants (13 males and 4 females), whose ages ranged from 23 to 51. All participants had a valid Japanese driving license and reported normal, or corrected-to-normal, vision. Prior to the start of the experiment, all participants received an explanation of the contents and risks of the experiment as well as their rights and voluntarily signed a participation agreement. This study was approved by the Ethical Committee of the Honda Motor Co., Ltd.

Materials and Apparatus

The driving simulation used in this study was connected to Logicool G29 vehicle controls (Logitech Inc., CA, U.S.) for steering, accelerating, and braking. The steering wheel was mounted on a cockpit frame situated directly in front of the participant. The foot pedals were placed in a comfortable position on the floor in front of the participant. A curved monitor (effective display area: 88.0 x 36.7 cm, LG Electronics, Korea) showing an image of the driving scene was positioned 1 m from the participant. A secondary task was displayed on a touch screen (29.2 x 20.1 cm, Surface Pro, Microsoft Corporation, U.S.) positioned on the right-side of the steering wheel.

For analyzing not only the data of driving behavior from the simulator but also the gaze direction of each participant, a non-contact driver monitoring system (sampling frequency: 25 Hz, Advanced Driver Monitoring System, Seeing Machines, Australia) was mounted on the cockpit frame toward the participant's face.

For visual stimuli, a meter display (29.2 x 11.0 cm, LG Display, LG Electronics, Korea) and head-up display (18.0 x 13.6 cm, HUD622, Maxwin, Japan) were placed between the monitor and steering wheel. The velocity of the subject vehicle was also displayed on the head-up display during a driving task. Environmental sounds of the driving simulator and an auditory stimulus generated by one of the HMIs were delivered through cordless headphones (WH 1000X M3, Sony, Japan). A seatbelt component, which included a webbing, tongue plate, buckle, and retractor with a motor for generating force sensation, was installed to a pillar joined to the seat. Tactors (Vp6, Acouve Laboratory Inc., Japan) were attached inside the seat to present vibrotactile signals. Figure 2 illustrates the simulator setup.

Scenarios of the driving simulator were designed with Unity (Unity Software Inc., U.S.) and the program for HMI control was written in MATLAB / Simulink (The MathWorks Inc., U.S.).

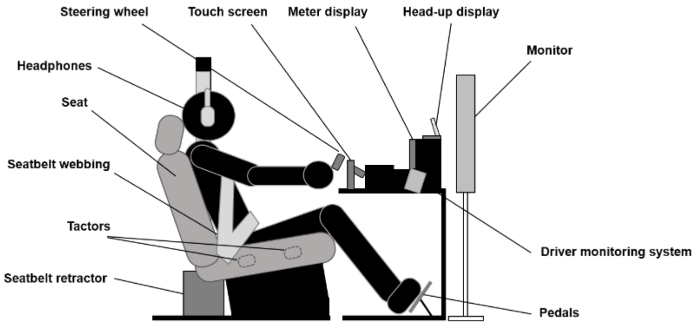

Figure 2. Schematic illustration of the driving simulator setup.

HMI Design

To convey a forward collision risk, five different HMIs, including an existing FCW as a baseline system and the other HMIs as candidates for a new notification system, were implemented into the driving simulator. For representation of continuous collision risk change, the risk estimation method is an important factor to alter the strength of stimuli. Typically, Time-to-Collision (TTC) is used for collision risk estimation. However, its value has a large variation and can quickly jump between a few seconds and infinity, especially when the subject vehicle is far away from the target vehicle or the velocities of the two vehicles are similar. To avoid sudden and extreme variations, in this study the Time to Closest Point of Approach (TCPA) was used as a risk estimation method for stimulus control. The TCPA extends the concept of the TTC by addition of a term that represents the potential deceleration of the leading vehicle at any time [10]. Effectively this makes it not just sensitive to the temporal but also the spatial distance between two cars, resulting in a less erratic variation. For two vehicles driving on the same trajectory one behind the other, the stop time t_L of the leading vehicle is given as follows:

$$t_L = -\frac{v_L}{a_L} \qquad Equation\ (1)$$

where a_L is the potential acceleration or deceleration of the leading vehicle and v_L is the velocity of the leading vehicle. When the stop time of the leading vehicle is larger than the TTC (the leading vehicle is assumed not to stop before the collision), the TCPA is given as follows:

$$TCPA = \frac{-\Delta v - \sqrt{\Delta v^2 - 2a_L d}}{a_L} \qquad Equation\ (2)$$

Where Δv is the relative velocity of the leading vehicle to the subject vehicle and d is the inter-vehicular distance between the two vehicles. In other cases, the TCPA is given as follows:

$$TCPA = \frac{d - \frac{{v_L}^2}{2a_L}}{v_S} \qquad Equation\ (3)$$

where v_S is the velocity of the subject vehicle. The outcome of this calculation, up until an upper bound, determines the stimulus strength of each HMI. The following paragraphs describe each investigated HMI.

(a) Head-up warning (HUW): This represents an existing forward collision warning system in the form of an amber ellipse (FOV: 4 x 1.5 degrees) that flashes two times on the head-up display. It is triggered when the Time-to-Collision (TTC) between the participant vehicle and another simulated vehicle falls below a 1.8 second threshold. The TTC describes the time that remains before the two vehicles collide based on their current locations and velocities.

(b) Display color: This HMI conveys the approach of the leading vehicle visually. When the TCPA falls below 4 seconds, a 9 x 10 cm red rectangle is displayed on the meter display. The color brightness continuously changes according to the TCPA value such that it increases when the TCPA becomes smaller and decreases when it becomes larger.

(c) Road sound: This HMI conveys the approach of the leading vehicle aurally. When the TCPA falls below 4 seconds, a pre-recorded sound consisting of road noise and engine sounds of the leading vehicle is played back through the headphones. Both pressure and playback speed of the sound are modulated depending on the TCPA value such that these increase when the TCPA falls (risk increase).

(d) Seatbelt tightening: This HMI conveys the approach of the leading vehicle via touch. When the TCPA falls below 4 seconds, the seatbelt webbing is retracted by the motor, resulting in seatbelt tightening. The current of the motor used for seatbelt tightening is set to depend on the TCPA value such that it increases when the TCPA falls (risk increase).

(e) Seat vibration: This HMI exemplifies another form of approach communication through touch. Even before the risk increases, vibrations are always generated by transducers inside the seat in a steady rhythm during a drive. The stimulus is designed to imitate the vibration that arises when the subject vehicle crosses a hump. When TCPA falls below 4 seconds, the interval between vibrations falls with decreasing TCPA (risk increase).

Driving Simulator Scenarios and Tasks

To evaluate the effects of each HMI on driving behavior and system acceptance, two different driving scenarios were designed on a single roadway. The roadway was made up of two lanes for each direction without stops or intersections. In both scenarios, the participants could always see a leading vehicle in front of them and a vehicle in the right-side lane. In addition, oncoming vehicles sometimes appeared (see Figure 3).

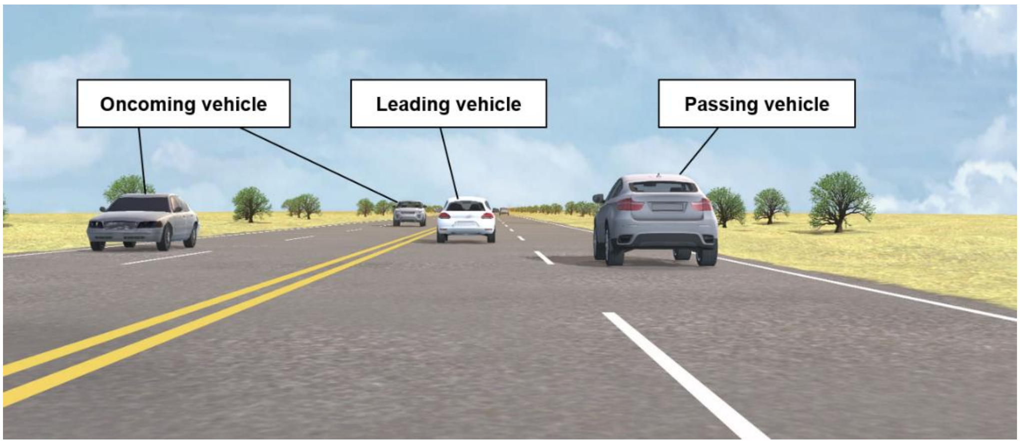

Figure 3. Driving scene of the driving simulator.

(i) Distracted driving scenario: The participants were instructed to drive at approximately 72 km/h (45 mph) without changing lanes. In addition to carrying out the driving task, the participants were instructed to perform a Surrogate Reference Task (SuRT), which required the participants to find and select the one stimulus that differed from others surrounding it [11] on the touch screen, as a secondary task (see Figure 4). A 36-pixel white circle as the target and 18-pixel white circles as the distractors were used on a black background of the touch screen and these stimuli were updated every second. For controlling driving workload between participants, a lane keeping assist system that allowed the participants to easily steer the subject vehicle was applied. After the leading vehicle continued to drive 30 meters ahead of the subject vehicle for a period selected randomly between 30 and 50 seconds, it decelerated at 0.4 G at an unanticipated timing for the participants.

(ii) Motivated tailgating scenario: Before starting to drive, the participants were required to imagine an urgent situation in which they would have to quickly drive to the airport to avoid missing their flight. The participants were instructed to continue to drive for approximately 4 minutes. Lane changes were inhibited. The leading vehicle always drove in front of the subject vehicle at approximately 72 km/h (45 mph) and sometimes slowed down at 0.08 G. This created a conflict with the driver's goal to arrive at the destination in time and may have facilitated tailgating behavior.

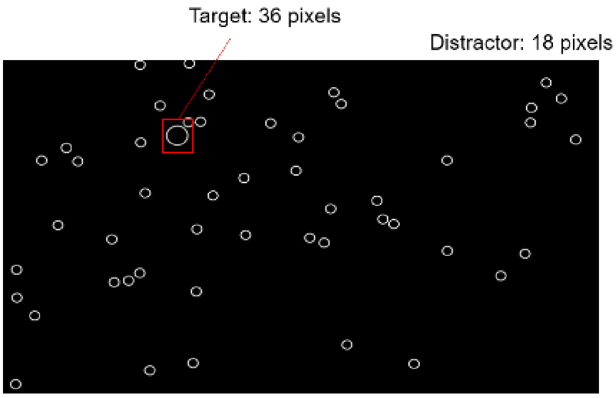

Figure 4. SuRT screen.

Procedure

The experiment consisted of three sessions: practice, evaluation in the distracted driving scenario, and evaluation in the motivated tailgating scenario. In the practice session, the participants were required to familiarize themselves with the simulation environment and the operation of the steering wheel and pedals. After this session, the participants received an explanation of how each HMI works according to hazardous events. In each evaluation session, a combination of the HUW and any one of display color, road sound, seatbelt tightening, and seat vibration HMIs was applied to investigate the effect of the proposed notification system, whereas only the HUW was additionally applied as a baseline condition (in total five HMI conditions). The participant performed five driving iterations under each HMI condition in the distracted driving scenario and a single drive under each HMI condition in the motivated tailgating scenario (see Table 1 for a list of test conditions). The test conditions were randomized in each evaluation session. After every drive, the participants answered nine questions (five for usefulness and four for affective satisfaction) on a scale from -2 to +2 (five grades) to assess subjective acceptance [12].

Table 1.

Test conditions

Session	Task	HMI	Number of drives
Practice	Driving	None	1
Evaluation in the distracted driving scenario	Driving + SuRT	Only HUW (Baseline)	5
		Display color + HUW	5
		Road sound + HUW	5
		Seatbelt tightening + HUW	5
		Seat vibration + HUW	5
Evaluation in the motivated tailgating scenario	Driving	Only HUW (Baseline)	1
		Display color + HUW	1
		Road sound + HUW	1
		Seatbelt tightening + HUW	1
		Seat vibration + HUW	1

RESULTS

Distracted Driving Scenario

In this scenario, when the leading vehicle started to decelerate, almost all the participants were looking at the touch screen to perform the secondary task and did not see the driving situation. After becoming aware of a potential danger, they suspended the secondary task, looked ahead to understand the situation, and decelerated the subject vehicle. To evaluate how soon the participant responded to the hazardous event, the time from when the leading vehicle started to decelerate until the participant looked ahead, released the gas pedal, and started to press the brake pedal was analyzed. The yaw and pitch angles of the gaze were used to determine where the participant was looking at and distinguish between seeing the monitor (driving situation) and seeing the touch screen for the secondary task.

Figure 5 shows the reaction times with each HMI condition. A one-way ANOVA was carried out to determine whether the response of participants varied depending on the HMI. Significant main effects of HMI on time to looking ahead [F(4, 397) = 215.48, p < .001], time to gas pedal release [F(4, 397) = 102.83, p < .001], and time to brake start [F(4, 397) = 80.38, p < .001], respectively, were found. Subsequent multiple comparison tests (Bonferroni corrected) revealed that, compared to the baseline condition, the participants responded significantly sooner to the hazardous event when any of the display color, road sound, seatbelt tightening, and seat vibration HMIs were activated. The display color, seatbelt tightening, and seat vibration HMIs reduced the reaction time by a greater margin than the road sound HMI did (see Table 2).

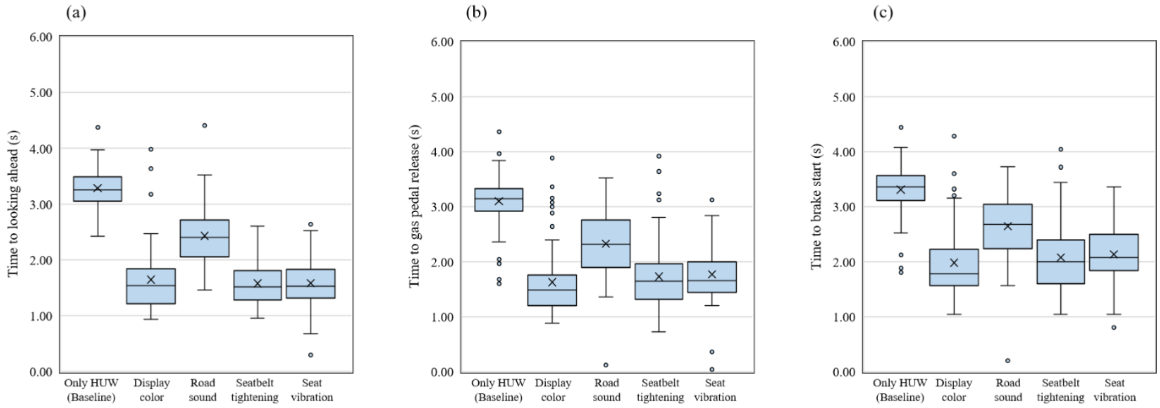

Figure 5. Comparison of reaction time of (a) looking ahead, (b) gas pedal release, and (c) brake start.

To evaluate how hazardous the situation became in consequence of reactions to the hazardous event, the minimum inter-vehicular distance after the leading vehicle started to decelerate was calculated for every drive (see Figure 6). A larger value means a longer distance to the leading vehicle, i.e., a safer situation. A one-way ANOVA and multiple comparison tests were carried out. A significant difference was found [F(4, 397) = 82.58, p < .001] and the difference in inter-vehicular distance between conditions had a similar tendency as the differences for reaction times (see Table 2).

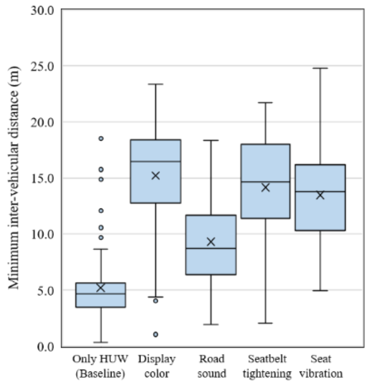

Figure 6. Comparison of minimum inter-vehicular distance.

Table 2.

Multiple comparison test of the reaction time and minimum inter-vehicular distance

HMI condition 1	**HMI condition 2**	**Time to looking ahead**		**Time to gas pedal release**		**Time to brake start**		**Minimum inter-vehicular distance**	
		Mean difference	**p value**	**Mean difference**	**p value**	**Mean difference**	**p value**	**Mean difference**	**p value**
Only HUW	Display color	1.65	p < .001***	1.47	p < .001***	1.33	p < .001***	-10.0	p < .001***
Only HUW	Road sound	.86	p < .001***	.77	p < .001***	.67	p < .001***	-4.11	p < .001***
Only HUW	Seatbelt tightening	1.71	p < .001***	1.37	p < .001***	1.23	p < .001***	-8.96	p < .001***
Only HUW	Seat vibration	1.71	p < .001***	1.33	p < .001***	1.18	p < .001***	-8.27	p < .001***
Display color	Road sound	-.79	p < .001***	-.70	p < .001***	-.67	p < .001***	5.91	p < .001***
Display color	Seatbelt tightening	.069	n.s.	-.10	n.s.	-.10	n.s.	1.06	n.s.
Display color	Seat vibration	.063	n.s.	-.14	n.s.	-.16	n.s.	1.75	n.s.
Road sound	Seatbelt tightening	.86	p < .001***	.60	p < .001***	.57	p < .001***	-4.85	p < .001***
Road sound	Seat vibration	.85	p < .001***	.56	p < .001***	.51	p < .001***	-4.16	p < .001***
Seatbelt tightening	Seat vibration	-.0057	n.s.	-.036	n.s.	-.056	n.s.	.69	n.s.

***Statically significant at $p < 0.001$, n.s. = Not significant at $p > 0.05$

Motivated Tailgating Scenario

Because the participants drove in a different manner according to their preferences in this scenario, the stimulus strength and activation frequency of HMI during 4 minutes of driving can vary depending on the individual participant. To evaluate how far the participants drove from the leading vehicle in consequence to the interaction between HMI activation and participant reaction during a drive, the average Time-Headway (THW) between the subject vehicle and leading vehicle was analyzed for every drive. Furthermore, although the HUW was set with the same threshold as in the distracted driving scenario, it was not activated due to the small deceleration of the leading vehicle in all drives of this scenario. In consequence, the drive with only HUW (baseline condition) equaled a non-HMI drive. Therefore, for evaluation of the effects of each HMI, the variation of the average THW ($\Delta \mathrm{THW}_{\mathrm{ave}}$) in each drive with each HMI relative to that of non-HMI drive was calculated for every participant. To consider the participant characterization, based on whether the average THW in non-HMI drive exceeds 1.5 seconds, the participants were divided into two groups: non-aggressive (8 participants) and aggressive (9 participants).

Figure 7 shows $\Delta \mathrm{THW}_{\mathrm{ave}}$ of each participant group. With the aggressive participants, a trend for an increase of the average THW relative to the non-HMI condition is observed ($\Delta \mathrm{THW}_{\mathrm{ave}}$ exceeded zero for many participants) and the effect of seat vibration HMI was significant ($t(8) = 2.17$, $p < .05$). To compare the effect of each HMI, a two-way ANOVA was carried out with the factors of HMI and participant group and the analysis indicated no main effect of both HMI and participant group (HMI: [$F(3, 60) = 1.75$, $p = .33$], participant group: [$F(1, 60) =$

9.79, p = .052]). The interaction between HMI and participant group was not significant [F(3, 60) = .39, p = .76].

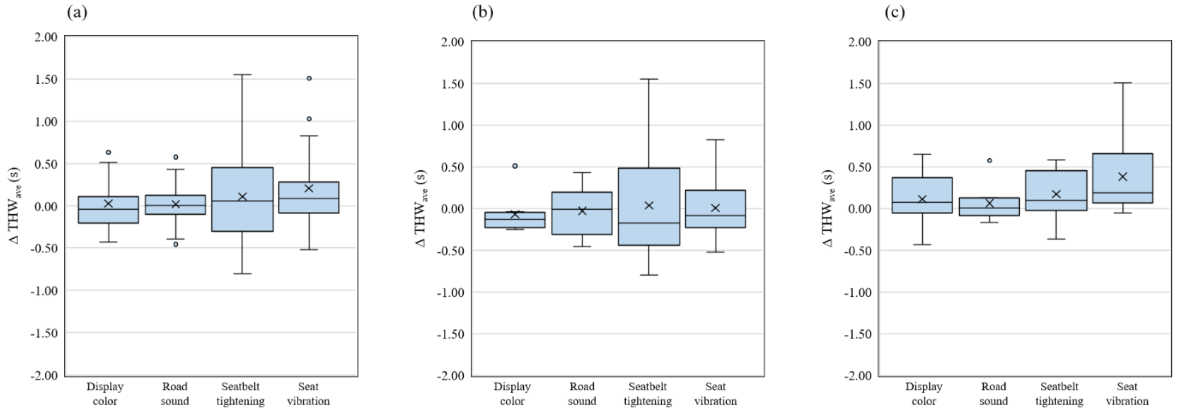

Figure 7. Comparison of ΔTHW_{ave} of (a) all participants, (b) non-aggressive participants, and (c) aggressive participants.

Subjective Ratings of HMI Acceptance

To evaluate system acceptance, based on the analysis method that Van der Laan et al. have reported [12], the average scores of five questions for subjective usefulness and four questions for affective satisfaction were calculated. Figure 8 shows the average scores of all participants on two dimensions, a usefulness scale and a satisfaction scale. Here, the error bars indicate the standard deviations between participants and there is no plot for the baseline condition in the motivated tailgating scenario due to no HMI activation. In the distracted driving scenario, the usefulness scores of the display color, road sound, seatbelt tightening, and seat vibration HMIs were significantly higher than the neutral score (zero), i.e., they were evaluated positive (display color: t(16) = 8.95, p < .01, road sound: t(16) = 2.69, p < .01, seatbelt tightening: t(16) = 17.42, p < .01, seat vibration: t(16) = 11.30, p < .01). The satisfaction scores of the baseline condition and the display color HMI were significantly higher than zero (baseline: t(16) = 6.01, p < .01, display color: t(16) = 2.78, p < .01), whereas the score of the road sound HMI was significantly lower than zero (t(16) = 2.79, p < .01).

In the motivated tailgating scenario, the usefulness scores of the display color, seatbelt tightening, and seat vibration HMIs were significantly higher than zero (display color: t(16) = 2.23, p < .05, seatbelt tightening: t(16) =5.59, p < .01, seat vibration: t(16) = 6.34, p < .01). The satisfaction scores of all HMIs were not higher than zero, whereas the scores of the road sound and seat vibration HMIs were significantly lower than zero (road sound: t(16) = 2.47, p < .05, seat vibration: t(16) = 1.98, p < .05) and were thus evaluated negative

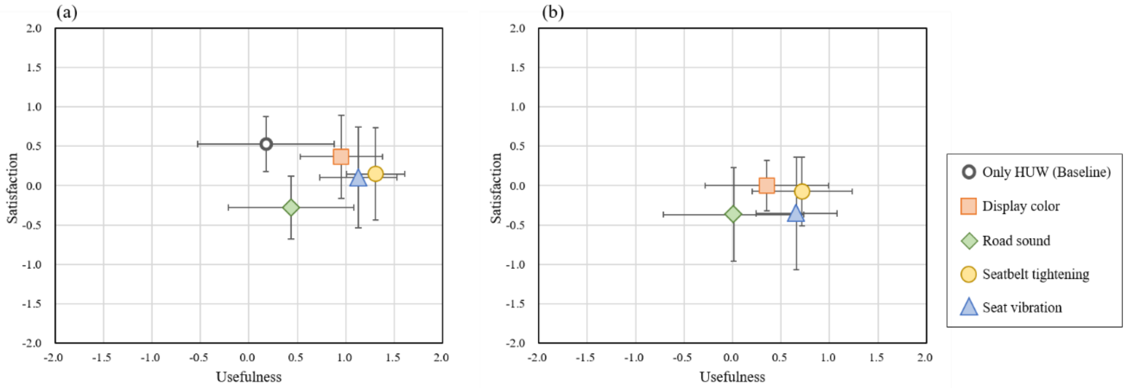

Figure 8. Subjective ratings of HMI acceptance in (a) distracted driving scenario and (b) motivated tailgating scenario.

DISCUSSION

The results demonstrate that, compared to the existing FCW, all HMIs that we proposed reduced participant reaction times to the hazardous event and the situation, accordingly, became safer in the distracted driving scenario. In this scenario, the participants were not able to directly watch the leading vehicle beginning to decelerate because of the secondary task. The proposed system has the features of early signal onset and conveying the degree of front risk. It is considered that, compared to the existing FCW, these features led the participants to become aware of the increased front risk and respond to it sooner. In particular, because the deceleration of the leading vehicle was rapid and the collision risk largely increased in this scenario, the change of stimuli from HMIs seemed to be easy to perceive.

The reaction time with the road sound HMI was longer than that with the other three HMIs (display color, seatbelt tightening, and seat vibration) and both the subjective usefulness and affective satisfaction were negative on average. For the prototype of sound source, not the beep sound but the natural road sound that the driver hears in daily driving was used to avoid annoyance. In this experiment, the participants heard both the environmental sounds of the simulator and the auditory stimulus through the headphones and it seemed that they were difficult to distinguish. However, this issue can be caused by in-vehicle sounds or environmental sounds during actual driving. It is noteworthy that the display color HMI was perceived as both useful and satisfying.

In the motivated tailgating scenario, compared to the baseline condition, only the seat vibration HMI significantly encouraged the aggressive participants to drive farther away from the leading vehicle. In this scenario, the deceleration of the leading vehicle was small and the inter-vehicular distance gradually decreased. Because the stimulus of seat vibration HMI was output in a steady rhythm all the time while driving and the interval between stimuli was changed once TCPA fell below the threshold, the participants were able to notice the start of risk increasing more clearly and respond to the increased risk sooner compared to the other HMIs. However, some participants were sensitive to the stimulus of seat vibration HMI and the average score of affective satisfaction was negative. In fact, a participant commented, “The vibration from the seat is uncomfortable for me.” These results suggest that this scenario requires both ease of perceiving the starting point of stimulus changing and subjective acceptance, whereas there was no HMI that achieved a good balance of them on its own.

One possible reason why HMIs other than the seat vibration HMI did not achieve significant effects on safe driving in the motivated tailgating scenario is that each driving time (4 minutes) was too short to evaluate such an effect. As mentioned above, besides the small deceleration of the leading vehicle, the degree and frequency of approaching the leading vehicle depended on not only HMI effect but also individual participants in this scenario. ΔTHW_{ave} was calculated for every participant to evaluate the effect of each HMI on driving safety and this quantitative measurement showed consequences of the iterative interaction between HMI activation and participant reaction during a drive. Therefore, a long-term evaluation is considered necessary to determine whether the system has an effect on driving behavior in such a situation with lower criticality. Furthermore, HMIs can be improved to have signal onset at a degree that is not perceived as annoying even in situations with lower criticality. For instance, an HMI that is activated all the time while driving can give information on current status or a small change of risk to the driver. To focus on these issues, our research group has reported another study for long-term system evaluation on a public road [13].

From the results in the distracted driving scenario, the display color HMI seems to be the most balanced HMI between the effects on driving safety and subjective acceptance. In prototyping the display color HMI, we designed the stimulus to be perceivable in the peripheral visual field while driving. However, in cases of severely inattentive driving or drowsy driving, it is not guaranteed that a driver will always perceive such a visual stimulus. On the other hand, the seatbelt tightening and seat vibration HMIs also showed a good balance of the effect on driving safety and subjective acceptance although their satisfaction scores were not necessarily positive. Especially concerning the seatbelt tightening, a participant commented, “When I pressed the brake pedal, releasing of the tension was too late,” which may explain the low score of satisfaction. In this study, we set the thresholds for both start and stop of all HMIs to 4 seconds of TCPA. In consequence, the stimulus stopped too late after the participant started to decelerate the subject vehicle and this time gap is considered to partially lead to low scores of subjective ratings. A promising approach for this issue is to adapt the HMI stop threshold to driving behavior and driver’s attention through combination with not only driving data but also driver’s gaze data from a driver monitor camera. To minimize the gap between HMI activation and driver’s risk perception, once the situation is improved by the driver’s appropriate attention or averting action, the system should stop the stimulus immediately.

Furthermore, the multimodal effect using multiple HMIs is another interesting investigation topic. Although the stimulus strength of each HMI changes depending on the risk level in our concept, the participant may have differently perceived each HMI that utilizes different modality [14]. If we apply multiple HMIs and assign their roles according to the risk level, the information may become more subjectively relevant to the effect of averting front collision risks.

CONCLUSIONS

In this study, we have proposed a new system that assesses potentially hazardous situations in real time and continuously outputs signals with a strength that depends on the risk level. A driving simulator experiment was carried out to investigate the effects of the proposed system on driving behavior and user acceptance. The results indicate that the proposed system reduced driver reaction times to a developing front collision risk and the situation accordingly became safer compared to a classical FCW in a driving situation with high or medium collision risk. A peripheral visual stimulus that changes the color brightness on the meter display showed high system acceptance in such a driving situation. Future work should aim to achieve more balanced HMI candidates in terms of driving safety and system acceptance in driving situations with lower criticality. We expect further insights from long-term evaluations in which drivers would have more opportunity to become accustomed to the added information sources.

REFERENCES

[1] Cicchino, J. (2017). Effectiveness of Forward Collision Warning and Autonomous Emergency Braking Systems in Reducing Front-to-rear Crash Rates. Accident Analysis & Prevention, 99(A): 142-152

[2] Yue, L., Abdel-Aty, M., Wu, Y., Ugan, J., and Yuan, C. (2021). Effects of Forward Collision Warning Technology in Different Pre-crash Scenarios. Transportation Research Part F: Traffic Psychology and Behaviour, 76: 336-352

[3] Krüger, M. (2022). An Enactive Approach to Perceptual Augmentation in Mobility. Munich: Ludwig-Maximilians-Universität Munich.

[4] Breznitz, S. (1984). Cry Wolf: The Psychology of False Alarms. Psychology Press.

[5] Getty, D. J., Swets J. A., Pickett, R. M., and Gonthier, D. (1995). System Operator Response to Warnings of Danger: A Laboratory Investigation of the Effects of the Predictive Value of a Warning on Human Response Time. Journal of Experimental Psychology: Applied, 1(1): 19-33

[6] Jamson, A. H., Lai, F., and Carsten, O. (2008). Potential Benefits of an Adaptive Forward Collision Warning System. Transportation Research Part C: Emerging Technologies, 16(4): 471-484

[7] Sorkin, R. D., Kantowitz, B. H., and Kantowitz, S. C. (1988). Likelihood Alarm Displays. Human Factors, 30(4): 445–459

[8] Lerner, N., Singer, J., Huey, R., Brown, T., Marshall, D., Chrysler, S., Schmitt, R., Baldwin, C. L., Eisert, J. L., Lewis, B., Bakker, A. I., and Chiang, D. P. (2015). Driver-vehicle Interfaces for Advanced Crash Warning Systems: Research on Evaluation Methods and Warning Signals. (Report No. DOT HS 812 208). Washington, DC: National Highway Traffic Safety Administration.

[9] Wang, J. H. and Song, M. (2011). Assessing Drivers' Tailgating Behavior and The Effect of Advisory Signs in Mitigating Tailgating. In Proceedings of the 6th International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design, Transportation Research Board, Olympic Valley - Lake Tahoe, California, U.S., 583-589

[10] Imazu, H. (2006). Ships Collision and Measures for Safety. Journal of Japan Society for Safety Engineering, 45(6): 1-10

[11] Mattes, S. and Hallén, A. (2009). Surrogate Distraction Measurement Techniques: The Lane Change Test. In M.A. Regan, J.D. Lee, & K.L. Young (Eds.), Driver Distraction. Theory, Effects, and Mitigation (pp. 107-122). Boca Raton, FL: CRC Press.

[12] Van der Laan, J. D., Heino, A., and De Waard, D. (1997). A Simple Procedure for The Assessment of

Acceptance of Advanced Transport Telematics. Transportation Research – Part C: Emerging Technologies, 5(1): 1-10

[13] Krüger, M., Krüger, V., and Mukai, T. (2023). Real-vehicle Long-term Evaluation of Interfaces for Augmenting a Driver's Ability to Anticipate Front Risks. In Papers of the 27th International Technical Conference on the Enhanced Safety of Vehicles (ESV) (Paper Number 23-0307)

[14] Stevens, S. S. (1957). On the Psychophysical Law. Psychological Review, 64(3): 153-181