

Evaluation of a generic warning for multiple intersection assistance systems

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Abstract

Intersections are accident hotspots and thus the development of Advanced Driver Assistance Systems (ADAS) is promoted within the scope of research projects like PReVENT INTERSAFE² and Vehicle Infrastructure Integration (VII)³. Many of these future assistance systems follow a common warning scheme already implemented in present ADAS like forward and side collision warning systems. The driver's attention is directed to the source of the threat by presenting a visual/acoustical alert that might be combined with a haptic feedback.

Even with only these two functions implemented in a vehicle, it is a challenge to avoid unwanted side effects due to inconsistent or simultaneous warning messages. Additional intersection assistance systems will increase the demand for integration and prioritization of ADAS information even further.

Introducing a generic warning similar to the "master alert" used in aviation might be an approach to simplify warning management within a car, where multiple warning systems share a common warning scheme. This avoids the need to prioritize different warning systems but also imposes the interpretation of the warning within the current driving context on the driver.

In order to verify that the loss of distinguishability of visual alerts when using a generic warning has no negative effect on driving performance, two video scenario experiments were conducted in a driving simulator. In both experiments, videos of a normal urban traffic environment ending with a critical situation at an intersection were presented. In the first experiment (N=60), the comprehension of the cause of the warning was compared under the two conditions "generic warning" and "specific warnings". In the second experiment (N=40), reaction time was measured by allowing the participants to freeze the video using the brake pedal.

Introduction

A high percentage of all injury accidents occur at intersections (France 30%, Great Britain 60%, Germany 42%, according to Fuerstenberg, 2007). Passive safety systems in vehicles

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² http://www.prevent-ip.org/en/prevent_subprojects/intersection_safety/intersafe/

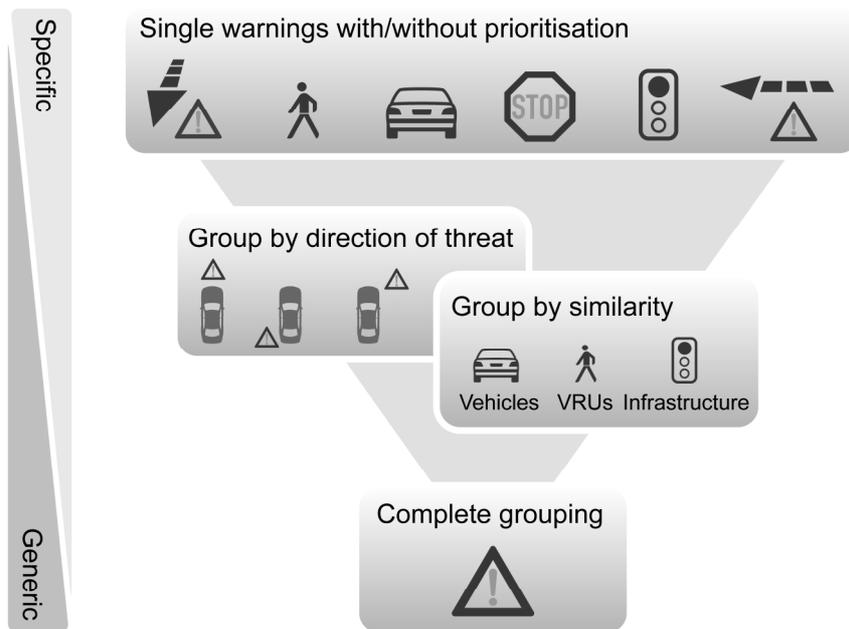
³ <http://www.its.dot.gov/vii/>

have helped to reduce fatalities substantially in the past years. However, to continue this positive trend, there is a need for active safety systems that are able to intervene before a potential crash. Thus, a lot of effort is put into the development of intersection assistance systems (e.g. Fuerstenberg, 2006; Ehmanns et. al., 2005; Meitinger et. al. 2004; Benmimoun, 2005).

A commonly used human machine interface (HMI) is a warning message being presented through one or more sensory channels in case of an imminent critical event. In order to provide a seamless assistance functionality to the driver, integration of multiple warning systems is necessary. Complex traffic situations may require multiple warnings presented simultaneously or in close temporal proximity. Without any further warning management, this could lead to masking of messages or inappropriate or slower driver reactions. Chiang et al. (2006) found such a warning interference effect when presenting a forward and side collision warning in close temporal proximity. The participants were less likely to crash when only the forward collision warning was presented. Apparently the output of the second side collision warning slowed down the participants' reaction to the first warning.

Considering the information processing model by Wickens (1984), simultaneous warnings presented on different sensory channels can be processed more effectively by the driver than messages sharing one modality. Lermer et. al. (2007) show that reactions to an auditory forward collision warning are delayed when a vehicle status warning is presented acoustically at the same time. However a simultaneous side collision warning which is presented via a counter torque on the steering wheel does not slow down the reaction to an acoustical forward collision warning.

Additional intersection assistance systems will increase the demand for integration even further. One approach is to prioritise the different warnings according to their relevance in the current driving context. The complexity of the required prioritisation algorithm is a challenge considering the huge amount of scenarios and situations which need to be covered.



VRU: Vulnerable Road User

Figure 1: Warnings integration strategies

Another way of dealing with the increasing number of driver assistance systems is to group multiple warnings so that different warning systems share a common warning message. Figure 1 shows a spectrum of possible grouping strategies. Using one unique warning message for every warning system in the vehicle leads to the least integrated solution (top row in the figure). The other extreme is to group all warnings in the vehicle, which would result in a “master alert”. Many other “mixed” approaches lie between these two extremes (only two possibilities are shown in the figure). The grouping strategy has to be considered for every sensor modality separately. E.g. the auditory part of a warning message could be grouped according to the direction of the threat and combined with a visual “master alert”.

The use of a generic warning might be an approach to simplify warning management within a car because multiple warning systems share a common warning scheme. This avoids the need to prioritize different warning systems, but also imposes the interpretation of the warning within the current driving context on the driver. Cummings et al. (2007) investigated a master alarm warning scheme for several collision event types: frontal collision warnings, left and right lane departure warnings, and warnings for a fast-approaching following vehicle. The results show that the master alarm did not negatively influence the driving performance or the reaction times. This indicates that the drivers concentrate more on the surroundings of the vehicle in order to identify the cause of the alarm.

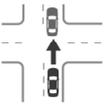
On the one hand, replacing multiple warnings by one single generic warning message might be a valid approach to integrate different warning systems within a vehicle. But on the other hand, it could also worsen comprehension and in consequence lead to longer reaction times or inappropriate reactions.

Two experiments were conducted in a driving simulator to evaluate the use of a *visual* master alarm in comparison to specific *visual* warnings with regard to intersection assistance scenarios. Evaluation of grouping approaches for haptic or auditory warning messages or “mixed” integration solutions is object of further research.

Concepts and Hypothesis

For this study six representative intersection assistance systems were selected. Table 1 shows the systems, the corresponding specific warning icons and the icon used for the generic warning message.

Table 1: Icons used for the various warning systems

Situation description	Warning icon
 Forward collision warning (FCW)	
 Left/right cross traffic collision warning (CTW)	
 Oncoming traffic warning (OTW)	
 Pedestrian warning (PW)	
 Red traffic light warning (TLW)	
 Stop sign warning (SW)	
Generic warning (GW)	

The forward collision warning icon is used in BMW series-production cars. The left/right cross traffic collision warning and oncoming traffic warning icons were originally presented in Fuerstenberg (2007) and further simplified for this experiment. Pedestrian, red traffic light and stop sign warning use standard symbols. The generic master warning does not provide any information as to the cause of the alarm. Also, no action is proposed to the driver (e.g. brake or steering).

The experiments were performed in order to answer the question if replacing the various system specific icons by a generic icon leads to worse driving performance, i.e. reaction. Two hypotheses were formulated and evaluated separately in two similar experiments:

1. "Comprehension"

The driver needs specific symbols in case of a critical situation to understand the reason for the warning.

2. "Reaction"

The driver reacts faster and more appropriately when a specific warning is presented.

The visual warning was combined in all cases with a standard auditory warning which is used for forward collision warning in BMW series-production cars.

Method

Evaluating active safety systems or warning strategies in real world tests (Benmimoun et. al., 2007; Klanner et. al., 2008) is very expensive in terms of time and money. As the drivers must never be put at risk, these experiments are often limited to a few scenarios. Even creating adequate driving simulator scenarios is a complex task. Regarding the number of events relative to the mileage, an accident is fortunately a very rare event. Therefore, reproducing normal urban traffic in a driving simulator will not lead to critical situations in a statistically relevant amount. Unnatural and uncooperative behaviour of simulated vehicles and secondary tasks are used to force participants into hazardous situations. But still, due to different styles of driving, not all designed scenarios will lead to an utilizable warning event. Particularly experiments focusing on the integration of multiple warning systems face the problem of presenting an unnaturally large amount of messages in a very short period of time. Repetitions of a scenario within one single simulator session would cause anticipation and learning effects. As a result, driving performance (e.g. reaction times) would be much better than compared to an unexpected event in a real traffic environment. A complete between-subjects design can be used to avoid these negative side effects. Depending on the number of independent variables under investigation, the number of required participants reaches an impractical level. Even disregarding this fact, a between-subjects design requires accurately comparable scenarios. Otherwise, variations in the style of driving and the resulting large standard deviation of the reaction time distribution make it impossible to verify smaller effects.

To address some of the mentioned disadvantages, two video scenario experiments were conducted in a fixed-base driving simulator to evaluate the different warning strategies. Artificial video sequences of hazardous situations were designed and iteratively improved during the development process. By using video sequences no logic or trigger programming is necessary to deal with different ways of driving. These predefined sequences ensure a high reproducibility which is required for a between-subjects design.

Experiment 1

The first experiment was designed to examine the "comprehension" hypothesis. This hypothesis questions whether a specific warning icon is beneficial for the drivers' understanding of the situation and the warning itself. Therefore, the experiment was designed to determine the understanding of the warning by giving the participants the chance to verbally express their opinion regarding the reason of the warning.

Material and Design

For both experiments a static driving simulator was used which was equipped with five plasma displays which offered a field of view of approximately 180° (see Figure 2). The warning icons were presented in a head-up display and in a freely programmable instrument cluster display.



Figure 2: Static driving simulator with plasma screens and mock-up

The first independent variable in the experiment was the type of HMI. The four factor levels (1) “No warning”, (2) “Auditory warning only”, (3) “Auditory and specific visual warning” and (4) “Auditory and generic visual warning” were used. However, in the analysis, only the last two conditions were included as they represent the specific and generic visual warning of interest.

The auditory warning was equal for factor levels (2), (3) and (4) as the experimental focus was on comparison of different visual warning strategies.

The second independent variable in the experimental design was the type of warning situation. Four different scenario types were used:

- The warning-cause is easily detectable at the point in time when the warning occurs. The driver does not need any additional information but the view through the windscreen to assess the situation. Therefore, the expected influence of a specific warning icon is very low in these situations.
- The warning-cause is difficult to detect (see Figure 3). The reduction of perceivable cues in the vehicle environment might force the driver to take additional information into account which is given by in-vehicle warning systems in order to understand the reason for the warning.
- A secondary event in the scene complicates the detection of the cause of the warning (see Figure 3). There are two potentially hazardous objects in the scene but only one justifies a warning. The in-vehicle warning system might be able to influence the driver’s interpretation of the situation.
- An incorrect warning icon is presented in a hazardous situation. A warning is justifiable but the icon does not match the cause of the warning (only relevant under the specific warning condition). This condition was introduced to reveal potential negative effects of specific warning icons. Presenting a wrong specific warning might be worse than presenting an uninformative generic warning.

Table 2 shows representative situation descriptions for the Cross Traffic Warning System.



Figure 3: Simulation screen shot for Situation “Difficult to detect” (1) and “Secondary event” (2)

Table 2: Example scenario descriptions for Cross Traffic Warning system

Warning scenario type	Scenario description
Easy to detect	Driver does not perceive cross traffic on a rural intersection. Slight line-of-sight obstruction.
Difficult to detect	Driver does not give way to cross traffic from right crossroad. Massive line-of-sight obstruction by buildings.
Secondary event	Driver waits at a priority road for an adequate gap in the crossing traffic. After accelerating he does not detect a pedestrian who started crossing the side road a few seconds earlier.
Incorrect warning	Driver violates the right of way to crossing traffic. In the specific icon condition, a stop sign warning icon is presented.

Finally, the third independent variable represented the various warning reasons respectively the warning systems listed in Table 1.

A between-subjects design for the factor “HMI type” was used and a within-subjects design for the factors “scenario type” and “warning system”. Therefore twenty-four video sequences for each warning system and scenario type needed to be designed. However, due to technical problems, the secondary event scenario was missing for the pedestrian warning condition.

The twenty-three videos were presented in randomized order to every participant with regard to order effects. Additionally, the HMI type was changed randomly for every video to avoid habituation effects. The HMI type was permuted across every group of four participants in such a way that for every video, every HMI type was presented exactly once (see Figure 4).

The dependent variable was the correctness of the articulated warning reason.

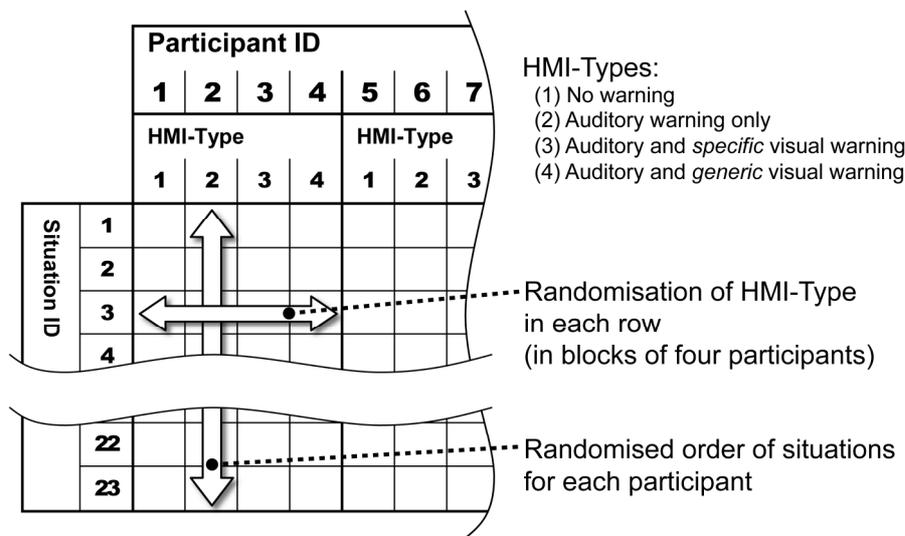


Figure 4: Randomization scheme for first experiment

Procedure

Driving experience, vehicle miles travelled per year, previous simulator experience and standard demographic data was collected using a short questionnaire. After taking seat in the driving simulator, the participants were informed that they would see various recorded video sequences of short drives through an urban environment. The participants were asked to put themselves in the position of a driving instructor (while being seated in the driver's seat), where they are supervising a learner who is likely to make driving mistakes. Additionally, they could benefit from a warning system which is installed in the vehicle (no details were given on the type of warning system). They were told that the warning system may also give nuisance alarms.

As this experiment was designed to test the timely comprehension of a warning, the videos were all faded out approximately one second after the warning was presented. The fade-out was used as the participants should not have had a chance to continue visually analysing the scene. The warning was timed in such a way that the critical event (e.g. impact) would have happened roughly three seconds after the warning occurred. Under the "no warning" condition, the warning message was omitted. The participants were asked to articulate their understanding of the reason for the warning as fast as possible after the warning (after the fade out in the case of the baseline). They were told that there are no wrong answers and that they should answer as spontaneously as possible. Accordingly, no feedback was given on the correctness of the response. All answers were recorded as WAV files. The recording was started simultaneously with the output of the warning message. In the case of the baseline, the recording was started with the imaginary warning point in time (which exists as all video sequences were combined with all HMI types). To avoid anticipation of the occurrence of the critical events, the duration of the video sequences varied between 10 and 60 seconds.

Participants

In order to have fifteen events for each HMI type/scenario combination, sixty participants, fifteen female and forty-five male, were invited to participate in the experiment. The average age was 29.4 years (S.D. = 7.7). Thirty-one participants had no prior driving simulator experience, thirteen participants had attended at least one or two prior simulator experiments and the rest had attended three or more prior experiments. Thirty-three participants were driving more than ten thousand kilometres per year. All participants were full, temporary or external employees of BMW Group and they did not receive an incentive for participation (twenty-six interns/master students engineering, fourteen employees engineering, seven employees finance, thirteen employees other departments). The unequal gender distribution of the sample mainly reflects the composition of the BMW research and development department. Recruitment of external participants was not possible for this experiment. No other inclusion or exclusion criteria were used.

Results

The responses (1380 sound recordings, sixty participants multiplied by twenty-three recordings each) were manually classified as correct or incorrect with respect to the corresponding scenarios. Thirty of them were excluded due to invalid answers (e.g. no answer within given time frame, incomprehensible or meaningless utterances). The thirty missing values were randomly distributed over the whole sample.

Table 3 shows the number of participants who named the correct reason for the warning (respectively the video fade out for the “no warning” HMI type). As an example only the data for the condition “Difficult to detect” is presented here. The maximum possible number of correct responses is fifteen. Generally, the experimental setup led to a very low number of false responses even in the “no warning” condition (e.g. Forward Collision Warning, FCW or Cross Traffic Warning, CTW). Apparently the scenarios were not complex enough and/or the participants’ mental and visual workload was too low. Increasing the situation complexity was hardly possible using the BMW driving simulator environment. Therefore, a secondary task was used in the second experiment to artificially increase the distraction from the road scene.

Table 3: Number of correct responses for scenario type “Difficult to detect” under the four HMI type conditions

		Warning type			
		No Warning	Auditory only	Auditory and <i>generic</i> visual	Auditory and <i>specific</i> visual
Warning system	FCW	15	15	15	15
	CTW	14	13	15	15
	OTW	14	12	13	10
	PW	2	1	2	9
	TLW	8	5	6	13
	SW	5	2	2	7

The exact Fisher test was used to compare the number of correct responses for each condition. Table 4 shows the test results for the comparison between the conditions “generic icon” and “specific icon” for all scenario types. None of the “easy to detect”-scenarios showed a significant difference between the number of correct answers. This is not very surprising, as the warning-cause was visible at the point in time when the warning message was displayed. In two of the “difficult to detect” scenarios, however, significantly more correct answers were given under the “specific warning icon” condition. It seems that the participants used the additional visual information given to interpret the situation. This fact is substantiated by the significant difference in the TLW “incorrect warning” situation: participants tended to misinterpret the situation by taking the wrong warning icon into account. In a worst case scenario this incorrect system message could lead to a delayed reaction to the real threat.

Table 4: p-values for Exact Fisher Test comparing HMI type "generic icon" and "specific icon"

		Scenario type			
		Easy to detect	Difficult to detect	Incorrect warning	Secondary event
Warning system	FCW	1.000	1.000	1.000	1.000
	CTW	1.000	.483	.598	.139
	OTW	1.000	.390	1.000	.102
	PW	1.000	.021*	1.000	(n/a)
	TLW	1.000	.021*	.041**	.025*
	SW	1.000	.109	.700	.272

* Significantly more correct responses under the *specific* icon condition

** Significantly more correct responses under the *generic* icon condition

Experiment 2

The second experiment addressed the reaction time hypothesis. While maintaining the video scenario experimental setup, the task was to find a method of measuring reaction times. The idea was to allow the participants to interact with the simulation by pressing the brake pedal.

Design

The first independent variable, the HMI type, was reduced to (1) “Auditory and *generic* warning icon” and (2) “Auditory and *specific* warning icon”.

The main intention behind the reduction of HMI types was to lower the number of required participants by focusing on the most interesting HMI type conditions.

The levels of the independent variable “scenario type” were changed in comparison to the first experiment. Four different scenario types were used:

- Difficult to detect
The warning is appropriate in the respective situations but the warning-cause is difficult to detect in the scene.
- Correct warning, secondary event
A hazardous situation occurs and a warning message is displayed. The warning is appropriate to the respective situations. There is a secondary event which requires the drivers’ attention.
- False positive (“false alarm”)
A warning message is displayed although there is no critical situation.
- False negative (“miss”)
No warning message is displayed even though there is a reason for doing so.

For each of the six warning systems four video sequences were recorded (in contrast to the first experiment, all 24 scenarios were implemented). Most of the scenes were reused from the first experiment with only slight changes. Introducing the false negative and positive event types should avoid skill based reactions of the participants. The number of correct (brake) responses and the reaction times for the false positive messages are not part of the analysis presented.

The dependent variable was reaction time (not applicable to the “false positive” condition). It was determined by measuring the elapsed time between the onset of the warning message and the beginning of a brake reaction. Again, an in-between design was applied using two groups for the two different HMI types. The scenes were presented in randomized order (see Figure 5). In contrast to the first experiment, the HMI type was kept constant for one participant. A baseline reaction time measurement was performed to detect potential predisposed reaction time differences between the two treatment groups.

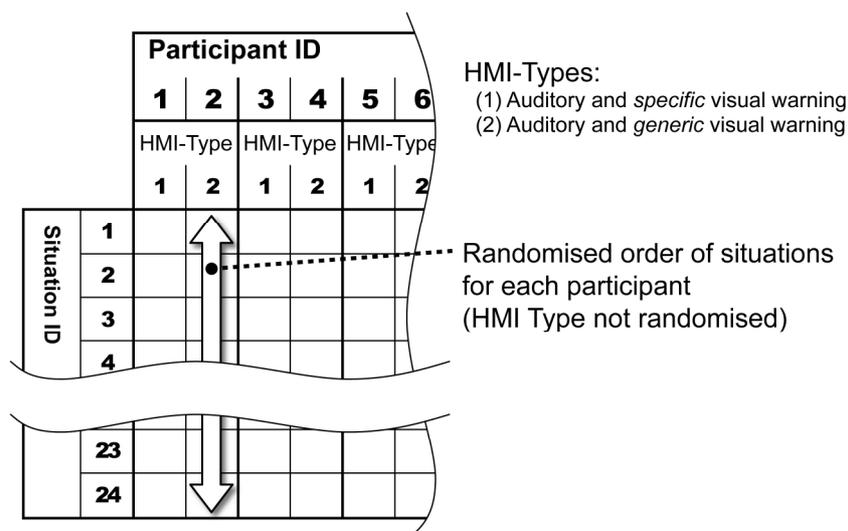


Figure 5: Randomization scheme for second experiment

Procedure

Just like in the first experiment, the participants were asked to put themselves in the position of a driving instructor who should avoid potential driving mistakes of a learner. This time they

were instructed to press the brake pedal whenever they judged a situation to be a potentially hazardous. The participants were informed that a warning system would be assisting them. However, the warning system might warn even though no critical event is happening, and it might also miss a critical situation, thus, omitting a warning. A quick but well judged response was demanded from the participants. Whenever the brake pedal was pressed and the brake pressure exceeded a certain threshold, the video was frozen immediately. This represents a slight change with regard to the first experiment, where the videos were faded out. In this experiment the experimenter needed to have the possibility to easily resume the video in case of a false brake reaction. Multiple less hazardous non-warning situations were inserted in the videos to force the participants to decide on pressing the brake pedal or not. The investigator was able to continue the video in case the brake reaction was performed without a hazardous situation being imminent. In the first experiment, the number of correct answers was generally very high; even under the “no warning” condition. Thus, while viewing the video scenes, the participants were asked to perform a secondary task in the second experiment. The idea behind this measure was to simulate a distraction pattern like it is caused by in-vehicle information systems like navigation systems or entertainment functions. Returning the driver’s attention to the road is one major use-case for in-vehicle warning systems. A Critical Tracking Task (Jex, 1988) implementation by Dynamic Research (see Figure 6) was used to simulate a realistic and adjustable distraction pattern. The task was presented in the mock-up’s central information display (normally used for BMW iDrive menu). The participants need to keep a horizontal line in the centre of the screen by using the up and down arrow keys on a keypad. A disturbance function is used to move the line away from the centre position. In this experiment a CTT-lambda value of 0.8 was used.

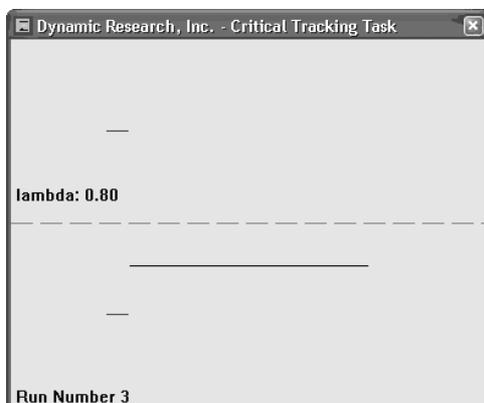


Figure 6: Screenshot of Critical Tracking Task

Participants

To achieve reasonable reaction time distributions, the number of participants per treatment group was increased from fifteen to twenty for this experiment. At the same time, the number of factor levels was reduced to a number of two. Therefore, forty participants (three female, thirty-seven male) participated in the second experiment (average age 29.5 years, S.D.=7.6). Twenty-eight participants had no prior driving simulator experience, eight participants had attended at least one or two prior simulator experiments and the rest had attended three or more prior experiments. Thirty participants were driving more than ten thousand kilometres per year. Only BMW Group employees were invited, hence the unbalanced gender

distribution. Due to the similarity of the used scenarios, only persons who did not participate in the first experiment were invited. No other inclusion or exclusion criteria were applied.

Results

Event protocols were recorded for each scenario and automatically evaluated after the experiment using a custom software tool. The baseline reaction time measurement showed no significant difference for the two treatment groups (generic vs. specific). The reaction times for the false positive warning scenarios were not used for further analysis (there were only very few reactions to these warning events). The remaining average reaction times are shown in Table 4. The reaction times for the “no warning” scenario type originate from both the generic and specific warning icon condition. Due to the experimental design, comparison of reaction times is only possible within one scenario type as the implemented traffic scenarios are not the same.

Table 4: Mean of reaction times in seconds and standard deviation

		Scenario type				
		No warning/miss	Difficult to detect		Secondary event	
			Generic warning	Specific warning	Generic warning	Specific warning
Warning system	FCW	0.75 (0.4)	1.5 (0.4)	1.4 (0.4)	1.0 (0.3)	1.1 (0.3)
	CTW	1.3 (0.3)	0.9 (0.3)**	1.2 (0.5)	1.4 (0.2)	1.4 (0.3)
	OTW	1.4 (0.5)	1.9 (0.3)	2.1 (0.3)	1.5 (0.7)	1.9 (0.7)
	PW	1.77 (0.8)	0.9 (0.4)	0.7 (0.3)	1.5 (0.4)	1.4 (0.5)
	TLW	1.6 (0.8)	1.7 (0.5)	1.3 (0.5)*	1.1 (0.4)	1.0 (0.4)
	SW	1.81 (0.3)	(not enough samples)		1.4 (0.3)	1.5 (0.3)

* Significantly shorter reaction times under the *specific* icon condition

** Significantly shorter reaction times under the *generic* icon condition

In the red traffic light warning scenario (TLW) “difficult to detect” a Kolmogorov-Smirnov test showed significant faster reaction times ($p=.037$) under the condition “specific warning icon” than under the condition “generic warning icon”. The non parametric test was used as the reaction times were not normally distributed. In the respective scenario the traffic light was occluded by a truck until approximately one second after the warning message was displayed. The difference in the mean reaction times indicates that the drivers used the specific traffic light warning icon to interpret the situation and execute a brake reaction.

However, in all other scenarios the display of a specific warning icon did not show a significant positive effect with respect to reaction times. In the cross traffic warning scenario (CTW) “difficult to detect” a t-test (under this condition, the data was normally distributed) even showed significantly slower reaction times ($p=.026$) under the condition “specific warning icon”.

Discussion

The comprehension test experiment showed a significant influence of the warning icon, especially for the traffic light and pedestrian warning scenarios. Both warning systems use very simple and intuitively understandable icons. This might lead to better recognition performance during a hazardous event and explain the missing influence of the other warning icons. By trend, the number of correct answers under the “difficult to detect” scenarios were lower than under the other conditions, which indicates a coherent influence of the situation complexity. Specific warning icons might be valuable for the driver, especially in situations where the cause of the warning is not directly perceivable. For instance, car-2-car communication systems are likely to detect objects which are not visible to the driver due to line-of-sight obstruction.

Despite these effects, both experiments revealed limited differences between the two visual warning strategies. This could be an artefact of the selected experimental setup. The design of the first experiment led to relatively high numbers of correct answers (see Table 3). Even under the “no warning” condition, almost no participants gave wrong answers. This is a disadvantageous precondition, as there is only little room for improvement of comprehension by adding a warning output. Even though the traffic situations were implemented as complex as technically possible, it seems that the participants’ visual and mental workload was not high enough to cause misinterpretations by just watching the videos. Therefore, in the second experiment a secondary task was added, to visually distract the participants and simulate the operation of in-vehicle information systems like entertainment functions. However, the impact of the secondary task is marginal. The reaction times for the “no warning” scenarios in the second experiment were not noticeably higher than for the other scenarios (see Table 4). A significance test is not possible here as the traffic scenarios do not exactly match by experimental design. A higher level of distraction should cause longer reaction times if no warning is presented. Apparently, the participants prioritised the secondary task with respect to the traffic situation. Forcing the participants into a secondary task right before a warning occurs seems to be the only solution.

The video scenario technique used in this experiment might suffer a lack of validity, but conducting a simulator experiment with participants driving on their own seems to be impracticable considering the high number of scenarios required. The participants would change their driving behaviour after a few warnings, thus making it complicated to trigger the traffic situations. Measuring reaction times using video scenarios is an interesting alternative,

in terms of time, money and reproducibility. Even though it creates reasonable reaction time distributions with respect to the scenarios, further research is needed to prove the validity of that method. Otherwise no clear statement about the potential advantages or disadvantages of a single generic warning replacing multiple specific warnings is possible.

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