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Specificity and timing of advisory warnings based on cooperative perception

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Summary

Future perception and communication technologies provide the possibility of assisting drivers by so-called advisory warnings in potentially dangerous driving situations. The effectiveness of such advisory warnings will possibly depend on (1) timing (i.e., time left for avoiding the collision, when the driver is warned) and (2) the specificity of the warnings (i.e., warning content, for example information about the direction from which a hazard is imminent). Using a fixed-based driving simulator, n=21 participants encountered three different conflict situations: a longitudinal (pedestrian entering the road between parked cars), a crossing-path (crossing cyclist at an intersection) and a turning vehicle scenario (vehicle turning at an intersection and taking the driver´s right of way). Advisory warnings about upcoming conflicts were provided via Head-Up Display and accompanied by an unobtrusive acoustic signal. Warning timing (latest possible warning timing t_0 vs. two seconds before t_{0+2s}) and warning specificity (depiction of type and/or heading of road user vs. no depiction) were varied. Effects on driving behavior and situation criticality were strongly dependent on warning timing, with early warnings (t_{0+2s}) being more effective than late warnings (t_0). In comparison to warning timing, the effects of warning specificity were of minor importance to driving behavior, but had a great impact on ratings of usefulness.

1 Introduction

Advanced driver assistance systems (ADAS) are widely established in upper class and even middle class vehicles. ADAS aim at providing assistance to the driver in order to ameliorate driver safety (e.g., autonomous braking systems) and comfort (e.g., traffic sign recognition). At present, ADAS are largely based on machine perception via on board sensors and are thus covering only a limited number of driving situations. Recently, the scope of driver assistance systems is widened by means of inter-vehicle communication technologies (so called C2X-communication).

The present study has been carried out as a part of the research project Ko-PER ("Cooperative Perception"). The aim of Ko-PER was the development of cooperative sensor and perception systems to provide road users with a comprehensive view of the traffic around them. By cooperative perception, information about possible critical driving situations can be passed to road users timely and preventive driver assistance can be provided. The benefit of cooperative perception consists mainly in the possibility of assisting the driver at an early stage of an impending conflict situation. In Figure 1, the time-line on the bottom shows the remaining time before a possible collision. This remaining time determines the assistance strategy.

- If the remaining time is too short for the driver to react and stop the vehicle by himself, only autonomous braking or steering could avert the conflict.
- If there is enough time remaining for the driver to react, an "imminent crash warning" can be provided. The goal of such an imminent warning is traditionally to provoke an immediate driver reaction and is thus given as late as possible.

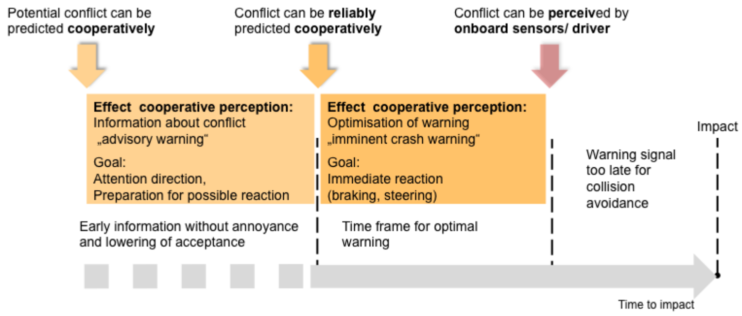


Figure 1: Framework of possible extensions of driver assistance based on cooperative perception (Neukum, 2011).

The main benefit of cooperative perception is to be found in the timeframe before on-board sensors are able to detect potential conflict situations. In this case, a so-called "advisory warning" about the impending conflict can be provided to the driver. The goal of such an advisory warning is to (re)direct the driver´s attention and to prepare the driver for a possible reaction if the dangerous situation prevails. Within the research project Ko-PER, critical aspects of the human-machine-interface (HMI) for such advisory warnings have been investigated.

1.1 Background and aim of the study

In this study, two HMI-design requirements of advisory warnings are investigated. Firstly, driver assistance should be provided as late as possible before an impending collision in order to maximise their reliability (the later the assistance is provided, the more reliable it is). Secondly, cognitively overloading the driver by too complex warnings should be avoided. Therefore, this study investigates the minimum time frame as well as the minimum information content being displayed for effective advisory warnings. In contrast to imminent crash warnings, there is little research pertaining to the design of advisory warnings to date. Nevertheless, guidelines and lessons learned from the literature about imminent crash warnings can be of great importance for the design of advisory warnings. Thus, important design considerations of driver warning systems are briefly reviewed in this section.

Modality: Guidelines dealing with the modality of advisory warnings can be summarized as follows (e.g., Dingus, Jahns, Horowitz, & Knipling, 1998; Green, Levison, Paelke, & Serafin, 1993): Visual displays should be preferably used in advisory warnings. Obtrusive acoustic signals (warning tone or speech signals) should be avoided and preferably be used in imminent crash warnings. An announcing but unobtrusive tone could ameliorate the effectiveness.

Timing: In the case of imminent crash warnings, a time frame of 700-1500ms before the impending crash is seen as suitable (see reviews by Lenné & Triggs, 2009 or Spence & Ho, 2008). Through cooperative perception, the time frame before imminent warnings (> 1500ms) is accessible for assisting the driver. Naujoks and Neukum (2014) demonstrated that providing advisory warnings 1-2 seconds before the latest possible warning timing to be effective in several protoypical conflict scenarios.

Specificity: Besides timing, one major issue in the design of driver warnings is the specificity of the warning signal. Therefore, two different types of warning specificity are investigated in this study: so-called “conflict specificity” (depiction of the type of road user, the driver is warned about) and “direction specificity” (depiction of the direction of the hazard). With regard to conflict-specificity of warnings, most studies do not show a positive effect on driver reactions (particularly on driver reaction times) in comparison to unspecific warnings (Ho & Cummings, 2005; Thoma, Lindberg & Klinker, 2009). It is thus questionable, if the depiction of the type of the potential threat has an advantage over the mere information that a conflict situation is imminent. Findings on the impact of direction-specificity of warnings are also mixed. Evidence of faster driver reactions following direction-specific warnings (Spence & Ho, 2008) as well as studies finding no such difference in comparison to unspecific warnings can be found (Lee, Gore, & Campbell, 1999; Bliss & Acton, 2003).

Research Needs: Most research is investigating different HMI-issues separately from one another. It is consequently hard to decide, which of the above mentioned aspects (modality, timing and specificity) is most influential and how they interact with one another to influence driver reactions in impending collision situations. In order to assess the relative impact of timing and specificity of advisory warnings, these two factors are systematically varied and their impact on effectiveness and acceptance is observed in a driving-simulator study. Modality of driver information is designed in accordance with the cited literature on advisory warnings.

2 Method

Sample: The sample consisted of N = 21 participants (7 female and 14 male) from the WIVW driver panel. Prior to the participation, all drivers had taken part in extensive driving simulator training. At the time they took part in the study, the participants´ mean age was 32 years (sd = 7, min = 24, max = 50) with mean driving experience of 13 years (sd = 7, min = 6, max = 32). On the average, the participants had a mileage of 16,100km within the last year (sd = 12,946, min = 2,000, max = 60,000).

Human-machine-interface: In the present simulator study, drivers encountered different critical driving situations that were completed with assistance through advisory warnings. Specifically, visual-auditory advisory warnings about upcoming conflicts were presented to the drivers in a simulated Head-Up Display (HUD) together with an unobtrusive tone (500 Hz, sinus). Conflict- and direction-specificity of the advisory warnings was varied independently. Table 1 shows the different HMI-versions used in this study. The corresponding conflict situation is a cyclist passing an upcoming intersection from the left. The drivers triggered the presentation of the advisory warnings: If a predefined Time-to-arrival (TTA) threshold to the respective conflict point was exceeded, the driver assistance was activated. Warning timing was varied in two steps: drivers were either warned at the latest possible warning timing (t_0) to avoid the collision or two seconds before that timing (t_{0+2s}). The latest possible warning timing was defined as the point in time when the driver has 1 second left until he has to decelerate with a constant deceleration of -8m/s² to avert the collision. The resulting thresholds for the information presentation with a speed of 50km/h are:

$$t_0\text{: } TTA_{activation} = 1.87s,\ t_{0+2s}\text{: } TTA_{activation} = 3.87s.$$

specificity		conflict-specificity	
		unspecific	specific
direction-specificity	un-specific		
	specific		

Table 1: HMI-versions with varying specificity.

Driving situations and study design: The drivers encountered three different driving scenarios with different types of road users and different conflict locations (see Table 2). A within-subject design was chosen: The study consisted of a longer ride in a fixed-base driving simulator with the target situations occurring occasionally together with non-critical driving situations. Direction specificity, conflict specificity and warning timing were varied independently, resulting in a 2x2x2-experimental design. In order to control order effects of the various HMI-Versions, four different permutations of the situation sequence were created. The study was carried out in the static driving simulator of the Wuerzburg Institute for Traffic Sciences (WIVW).

Dependent variables: During the simulator ride, participants were asked to answers questions concerning the usefulness of the driver assistance (see Table 3). The questions were to be answered after each test situation. Objective data of the driver brake reaction (maximum brake pedal activation) and the time left to avoid the collision (minimum Time-to-arrival) were recorded with a sampling rate of 100hz.

Scenario	direction specificity			
	no		yes	
	conflict specificity			
	no	yes	no	yes
Turning vehicle takes right of way				
				
Pedestrian enters the road between parked cars				
				
Crossing cyclist takes right of way				
				

Table 2: Investigated driving scenarios and HMI-Versions.

Measure	Description	Scale/Unit
	Rating items	
Information usefuleness	How useful was the information?	0-15
	Brake reaction	
Maximum brake pedal activation	Maximum of brake pedal pressure while decelerating	[% of possible maximum brake pedal pressure]
Time-to-arrival (TTA)	Time left until subject vehicle would collide with crossing road user if velocity remains constant	[s]

Table 3: Overview of the collected measures.

3 Results

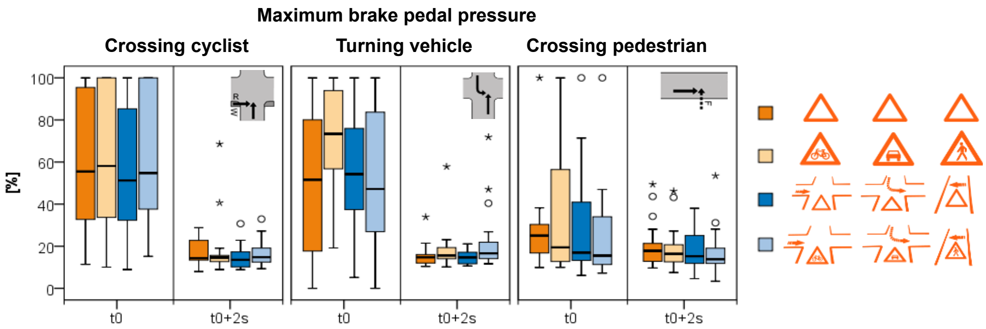
Table 4 shows the number of drivers that fell short of the predefined TTA-thresholds for the activation of the advisory warnings. Only in these trails, warnings were provided to the drivers. It becomes apparent that most of the drivers activate the driver assistance at the warning timing of t_{0+2s}. In contrast, late driver warnings (t_0) are only presented to half of the drivers in the pedestrian scenario. Only drives in which the drivers had been assisted are included in the following analysis. 2x2x2 repeated measures analysis of variance is conducted in order to evaluate the influence of the experimental measures on the dependent variables.

Szenario	Timing	MMI			
		direction unspecific, conflict unspecific	direction unspecific, conflict specific	direction specific, conflict unspecific	direction specific, conflict specific
Turning vehicle takes right of way	t_0	20	17	18	19
	t_{0+2s}	21	21	21	21
Pedestrian enters the road between parked cars	t_0	11	14	12	11
	t_{0+2s}	21	20	21	21
Crossing cyclist takes right of way	t_0	20	20	21	19
	t_{0+2s}	21	21	21	21

Table 4: Number of drivers that fell short of the TTA-thresholds for the activation of the driver assistance.

Maximum brake pedal pressure: A large main effect of warning timing on the maximum brake pedal pressure can be found in all the investigated scenarios (see Figure 2): If drivers are warned timely about the upcoming conflict situation (t_{0+2s}), they brake less intensively as with late warning timing (t_0). For example, in the crossing cyclist scenario, the participants brake on the average with 60.34% of the maximum possible brake pressure at t_0, whereas they brake with only 16.56% of the maximum possible brake pressure if they are assisted at t_{0+2s}. The same results can be found with regard to the turning vehicle scenario and the pedestrian scenario. As only few drivers activate the advisory warnings at t_0 in the pedestrian scenario, the timing effect is shown only by a comparison of the confidence intervals of t_0 and t_{0+2s} (m_{t0}=28.91%, $CI_{95\%}$[23.54; 34.27]; m_{t0+2s}=18.47%, $CI_{95\%}$[16.29; 20.65])[1]. In spite of the turning vehicle scenario, the specificity of the advisory warnings shows no clear influence (main effect or interaction effect) on the maximum brake pressure. Only in the turning vehicle scenario, drivers brake more intensively in the approach to the conflict point if the warning contains an indication of the type of conflict.

[1] The effects of specificity in the pedestrian scenario are compared using the data from the t_{0+2s} condition.

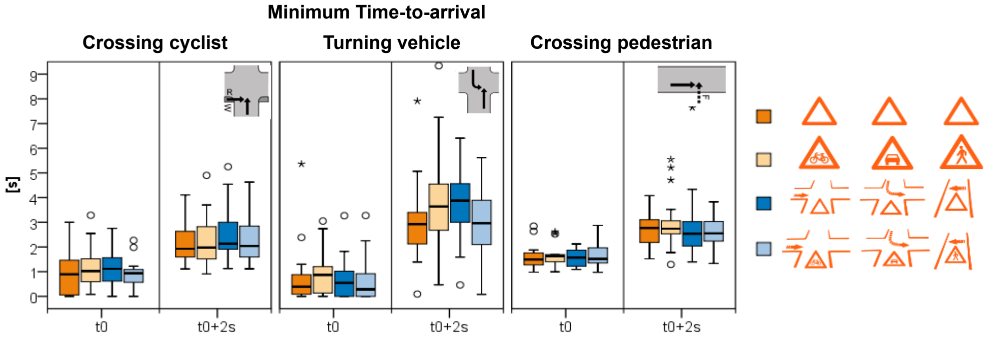


Scenario	Effect	F	df	p	η^2
Crossing cyclist takes right of way	Conflict specificity	1.53	1.18	.232	.08
	Direction specificity	0.73	1.18	.403	.04
	Timing	*55.75*	*1.18*	*.000*	*.76*
Turning vehicle takes right of way	*Conflict specificity*	*4.66*	*1.16*	*.046*	*.23*
	Direction specificity	0.58	1.16	.403	.04
	Timing	*43.08*	*1.16*	*.000*	*.73*
Pedestrian enters road between parked cars	Conflict specificity	1.25	1.19	.278	.07
	Direction specificity	1.43	1.19	.247	.07

Figure 2: Results maximum brake pedal pressure. Interaction effects are only reported if they are siginficant.

Minimum Time-to-arrival: Warning timing has also a large effect on situation criticality as measured by TTA_{min}-values. (see Figure 3): In all investigated scenarios, TTA_{min}-values are higher (indicating safer situations) when advisory warnings about the upcoming conflict situation are presented at t_{0+2s} than with advisory warnings presented at t_0. In the case of the crossing cyclist, TTA_{min}-values rise from m_{t0}= 1.06s to m_{t0+2S}= 2.25s. The same pattern of results can be found for the turning vehicle scenario (m_{t0}=0.97s, m_{t0+2s}=3.22, and the pedestrian scenario (m_{t0}=1.66s, $CI_{95\%}$[1.51; 1.81]; m_{t0+2s}= 2.75s, $CI_{95\%}$[2.53; 2.98]).

An impact of the advisory warnings' conflict-specificity (depiction of the type of road user) is not found in any of the scenarios. In contrast, there is a significant main effect of the advisory warnings' direction-specificity in the scenario with crossing cyclist and a significant interaction of warning timing and direction-specificity in the turning vehicle scenario (see Figure 3). TTA_{min}-values to the crossing cyclist are larger (indicating safer situations) if the warning contains information about the direction from which the cyclist is entering the intersection ($m_{direction\ unspecific}$=1.55s; $m_{direction\ specific}$=1.76s). In the turning vehicle scenario, direction-specific warnings also lead to larger TTA_{min}-values, but only if the advisory warnings are provided timely at t_{0+2s} ($m_{direction\ unspecific}$=3.25s; $m_{direction\ specific}$=3.59s).



Scenario	Effect	F	df	p	η^2
Crossing cyclist takes right of way	Conflict specificity	0.94	1.18	.763	.01
	Direction specificity	*4.36*	*1.18*	*.052*	.36
	Timing	*25.71*	*1.18*	*.000*	*.60*
Turning vehicle takes right of way	Conflict specificity	0.02	1.11[2]	.896	.00
	Direction specificity	0.10	1.11	.843	.01
	Timing	*49.22*	*1.11*	*.000*	.82
	*Timing*direction specificity*	*5.99*	*1.11*	*.026*	.27
Pedestrian enters road between parked cars	Conflict specificity	0.88	1.19	.361	.05
	Direction specificity	3.32	1.19	.089	.16

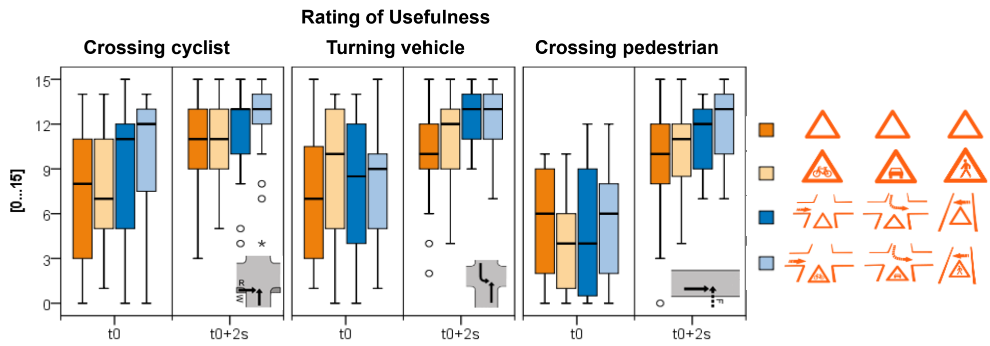
Figure 3: Results maximum brake pedal pressure. Interaction effects are only reported if they are siginficant.

Usefulnes-ratings: In line with the objective data on driver brake reactions and situation criticality, a main effect of warning timing on the usefulness ratings is found. Drivers rate advisory warnings at t_{0+2s} more useful than warnings at the latest possible warning timing t_0 (see Figure 4). For example, if drivers are warned timely (at t_{0+2s}) about the impending conflict situation with the crossing cyclist, they rate the advisory warnings as more useful (m_{t0+2s}= 11.46) than if they are provided at t_0 (m_{t0}= 8.50). The same pattern of results is found in the turning vehicle scenario (m_{t0+2s}=11.59, m_{t0}=7.93) and the crossing pedestrian scenario (m_{t0+2s} =10.05, $CI_{95\%}$[9.16, 10.05]; m_{t0}=4.84, $CI_{95\%}$[3.64, 6.04]).

Furthermore, there is a main effect of the warnings' direction-specificity on the usefulness ratings. Direction-specific advisory warnings are rated as more useful as direction-unspecific warnings in the investigated scenarios with crossing cyclist ($m_{direction\ unspecific}$=9.16; $m_{direction\ specific}$=10.80) and crossing pedestrian ($m_{direction\ specific}$=10.28; $m_{direction\ unspecific}$ = 9.50). In the turning vehicle scenario, a significant interaction of warning timing and direction specificity is found: direction specific advisory warnings are rated as more useful only when drivers are informed at t_{0+2s} ($m_{direction\ specific}$=10.37; $m_{direction\ unspecific}$ = 11.90), not at t_0. There is no

[2] Five drivers brake so early in the approach to the conflict point that their velocity is close to standstill when the turning vehicle enters the conflict zone. In thesese cases, the TTA_{min}-values cannot be determined.

significant effect of conflict specificity on the usefulness ratings in any of the investigated scenarios.



Scenario	Effect	F	df	p	η^2
Crossing cyclist takes right of way	Conflict specificity	1.29	18.1	.271	.07
	Direction specificity	*10.19*	*18.1*	*.050*	*.36*
	Timing	*19.57*	*18.1*	*.000*	*.52*
Turning vehicle takes right of way	Conflict specificity	4.22	15.1[3]	.058	.22
	Direction specificity	1.09	15.1	.313	.07
	Timing	*20.12*	*15.1*	*.000*	*.57*
	*Timing*direction specificity*	*5.13*	*15.1*	*.039*	*.25*
Pedestrian enters road between parked cars	Conflict specificity	2.75	19.1	.113	.13
	Direction specificity	*5.40*	*19.1*	*.031*	*.21*

Figure 4: Usefulness rating. Interaction effects are only reported if they are siginficant.

4 Conclusions

The results of the study show, that the advisory warning timing is more important than the warning specificity. Provided that the advisory warnings about an impending traffic conflict are given in a timely manner, drivers react independently of the warning specificity with a moderate brake reaction. Because of the resulting speed reduction in the approach to the given conflict point, the objective (by means of TTA_{min}-values) situation criticality is significantly lower as with late advisory warnings. In conflict situations at intersections (crossing cyclist and turning vehicle), an additional positive effect on driver behaviour could be shown if the hazard direction is displayed to the drivers. The drivers' usefulness ratings also show a clear favour of direction-specific advisory warnings in comparison to unspecific warnings. On the basis of the present study, it can be recommended to include information about the direction of a road hazard into advisory warnings. Especially in the case of intersection conflicts, there should be a positive effect on the acceptance of such advisory warnings.

[3] Because of one missing rating, only 16 ratings are included in the analysis.

Positive effects of direction specific advisory warnings on effectiveness were also present, however, compared to the effect of warning timing they seem to be of minor importance.

There are some possible limitations of this study. Firstly, it must be emphasized that our findings apply to the implemented human-machine-interface (discrete visual-auditory advisory warnings presented in a HUD). Secondly, carry-over effects (e.g., practice or fatigue) may have influenced the study results due to the within-subject design. These effects were taken into account by presenting the test situations in randomized order. Thirdly, the results may be limited to the simulation environment. However, relative validity (i.e., the assumption that the effect found in the simulation environment will also be present in every-day driving) rather than absolute validity (i.e., transfer of exact values to everyday driving) may be assumed regarding the simulation environment used in the study.

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