

Effect on Driving Performance of Two Visualization Paradigms for Rear-End Collision Avoidance

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Abstract—Driver assistance systems for rear-end collision avoidance support drivers in their response to specific events. However, reaction time can be affected by the way this information is conveyed. The impact of the location of the warning messages conveyed by two systems, one within the following vehicle and the second in the rear part of the leading vehicle is evaluated in a driving simulator study. Both rear-end collision avoidance systems positively affected the parameters that determine the reaction time for responding to a road incident between vehicles: headway, TTC and deceleration rate. Comparative quantitative results regarding the effectiveness of each proposed system are discussed.

I. INTRODUCTION

According to [1] rear-end collisions account for almost thirty percent of the total number of traffic accidents reported in the U.S in 2013. In more than 90% of accidents of this type, the main causes were driver inattention, distraction and/or tailgating [2], an aggressive driving behavior where the driver of the following car intentionally leaves very little space between the two vehicles.

Distance or time gap between vehicles is decisive in being able to react to a road incident. Headway time, or the time drivers have to react to a specific event, is sometimes not sufficient to avoid a crash. Some of the most common advanced driver assistance systems (ADAS) that help estimate a proper distance are forward collision warning (FCW), rear-end collision avoidance and adaptive cruise control (ACC). They constantly collect data regarding the speed of the following and leading vehicles, the following distance, and braking signals [3]. They use on-board sensors or cameras mounted in the front to measure the distance to the leading vehicle, and most of them display to the driver the processed information on an in-vehicle display located in the rear vehicle. If the distance is not sufficient to reduce the risk of a rear end collision, warnings are activated.

A cooperative approach that mimics human communication during a situation in which a vehicle is tailgating another was proposed in [4]. The authors presented an asynchronous collaborative process (i.e. in which the partners involved in the collaboration were not working and communicating concurrently) to increase the driver's visual awareness of the safety distance. The rear driver was visually warned through a message displayed in the rear part of the leading vehicle in an unobtrusive manner when the distance to the



Fig. 1. Message displayed to a tailgating vehicle [4]

vehicle in front became dangerous. Figure 1 depicts the idea. This technology is particularly helpful in situations where tailgating is intentional on the part of the rear driver as the message might remind them to exercise better judgement.

In this paper we evaluate this approach, comparing it with traditional rear-end collision avoidance systems approaches in which the information is presented in an in-vehicle display. In particular, we analyze driver response to and acceptance of the received messages using subjective ratings and driving performance data, based on the following hypotheses:

- H0: The selection between external or in-vehicle methods of conveying information for rear-end collision avoidance systems does not affect driving performance metrics that are relevant to the reaction to a road incident between vehicles.
- H1: The selection between external or in-vehicle methods of conveying information for rear-end collision avoidance systems affects driving performance metrics that are relevant to the reaction to a road incident between vehicles.

The following section presents related work in the area. Section III describes the simulator design and graphical environment to evaluate the proposed systems. Sections IV and V describe the experimental setup and the collection and analysis of data, respectively. Section VI presents the evaluation results and section VII concludes the paper.

II. RELATED WORK

Comparisons of warning output modalities for rear-end collision prevention has been performed in simulated environments in several works. For example, visual and auditory feedback was studied in [5]. The authors in [6] included tactile warnings in a simulated driving environment as they investigated reaction time as a function of warning timing.

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Results showed that the driver reaction time with tactile warnings was significantly shorter than with the other modalities.

More recently, the impact of visual and auditory headway feedback on behavior change was also studied using individual vehicle records and a multivariate linear regression data analysis, in order to find out the effects of certain alternative messages to the current standard *keep your distance* (KYD) on the amount of close and aggressive following [7]. The authors detected significant differences in behavior depending on the messages used to characterize an unsafe distance to the leading vehicle.

Along the same line of research, the authors in [8] proposed two different visualization metaphors to warn drivers through augmented reality using a head-up display (HUD) about an insufficient safety distance. One of the metaphors built upon a variant of the traffic sign C10 that represents the distance in meters of two following vehicles, whereas the other corresponded to the traffic sign that depicted road safety marks. Comparison of these metaphors showed a preference for the metaphor derived from the safety marks and accompanied by warning sounds.

The work [9] studied different visual-acoustical HMI concepts performed in a driving simulator while drivers were engaged in a tertiary task additional to driving. The statistical analyses showed a significant reduction in reaction time when an acoustical speech warning was employed, while no additional reduction was observed when a visual alert for inattentive subjects was used.

In-vehicle human-machine interfaces (HMI) conveyed the headway feedback to the driver in all of these mentioned cases. Even if previous research has studied in-vehicle layout preferences for providing ADAS information and their effect on driving performance [10], [11], the impact of an in-vehicle location compared with an external one for providing feedback on the safety distance and driving response has not been studied. Therefore, in this work we investigate the effect of displaying headway-related information on the leading vehicle versus in the rear vehicle itself as depicted in Figure 2.

III. SIMULATION PLATFORM IMPLEMENTATION

To evaluate the effect of both visualization paradigms on driver response, we performed an experiment using a Unity 3D-based low-fidelity driving simulator that logged data into a SQLite database.

A. City Modeling

Our driving simulator is based on the Unity 3D [12] game development platform. It provides an open source environment which makes it possible to develop and easily modify graphical environments. To test the paradigms, we first created customized scenarios and situations to allow a comparison of different participants facing the same road situation. The urban environment was created within the CityEngine procedural modeling tool [13] using OpenStreetMap data (OSM) [14] and the GeoTIFF data provided by the city of

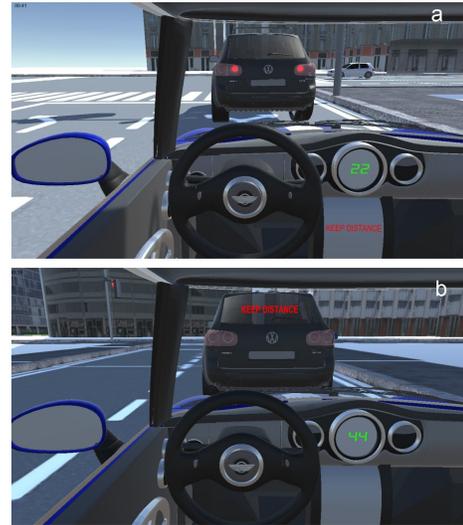


Fig. 2. Visually displayed headway feedback through a) in-vehicle display and b) message displayed on the rear part of the leading vehicle

Vienna [15].

The OSM data obtained was converted to shape and geodatabase files that provided information related to different aggregations of the information in the map. We additionally used an aerial photograph of the section of Vienna we wanted to model, so that it was possible to fill in the gaps of the model and better understand the road layout. In order to create a reasonably sized database of the buildings available in Vienna, we selected a limited section with which to create the buildings' facades.

We first generated street center lines based on the graphs from OSM that represented 2D polygons, adapting the values of the parameters as required. After this, we created the buildings in 3D based on CGA files containing the specific rules for number of floors, floor height and type of roof including color and texture. We also added pertinent elements to create the driving environment (e.g. vegetation, vehicles, etc.). The tree inventory, building models and heights, elevation map data and aerial orthographic map were provided by the open data inventory from the city of Vienna. Figure 3 depicts a section of the urban environment based on the acquired information from the OSM map data.

To create the buildings and road models, we acquired an aerial image that we combined with OSM data. The OSM data proved to be very accurate for the major roads but not reliable enough when it came to bicycle and pedestrian pathways. To reproduce these data, manual work was required.

B. Simulator Design

The urban environment we obtained was then exported to the cross-platform game engine Unity 3D. We selected Unity 3D based on its robustness and online resources with an extensive community. The model that was created in CityEngine was exported as FBX format into Unity, where vehicles and a navigation path were further developed. Furthermore a SQLite database was created to store and

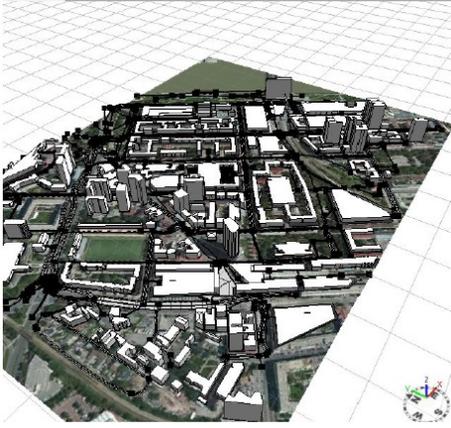


Fig. 3. Architecture model of a section of the city of Vienna

analyze data related to driving performance. The vehicles in the 3D game engine were designed as individual blocks that were capable of colliding with other objects. The inside of the vehicle was designed to provide adequate information to the driver through human machine interfaces similar to those in real vehicles. Therefore, standard controls and displays were added to the cockpit (i.e. speedometer and different in-vehicle screens to provide information). To emulate the traffic scenario from the modeled map, we considered all potential road users. This included vehicles such as cars, trucks, taxi cabs and police vehicles. We additionally included vulnerable road users (VRU) to the road scenarios. Realistic graphics that represented roads, signs and traffic lights completed the graphical interface.

To be able to measure the headway to the leading vehicle at which the warning was shown on the in-vehicle display, we integrated sensors into the front part of the following vehicle. As for the leading-vehicle system, the same method was used except that the distance sensor was built into the vehicle's rear section.

IV. EXPERIMENTAL SETUP

To measure the driver's response to the two rear-end collision avoidance paradigms we defined a tailored urban scenario with speed limits of 50 km/h according to the traffic law. Vehicles in the environment were programmed to drive slowly to encourage tailgating. Each participant was asked to fill in a pre-task questionnaire containing information related to personal data. The participants were given a short explanation about the experimental procedure and purpose and were instructed to drive normally, respecting the traffic laws. During a training session with no data logged, each participant drove through the circuit for 1 minute to get acquainted with the simulator. Figure 5 shows a test subject performing the experiment.

The experiment involved two sets of driving tests: a) one with the headway-related information activated on the in-vehicle display of the rear vehicle; b) the other one with the information displayed on the rear part of the leading vehicle (see Figure 2). In order to test whether the potential benefit

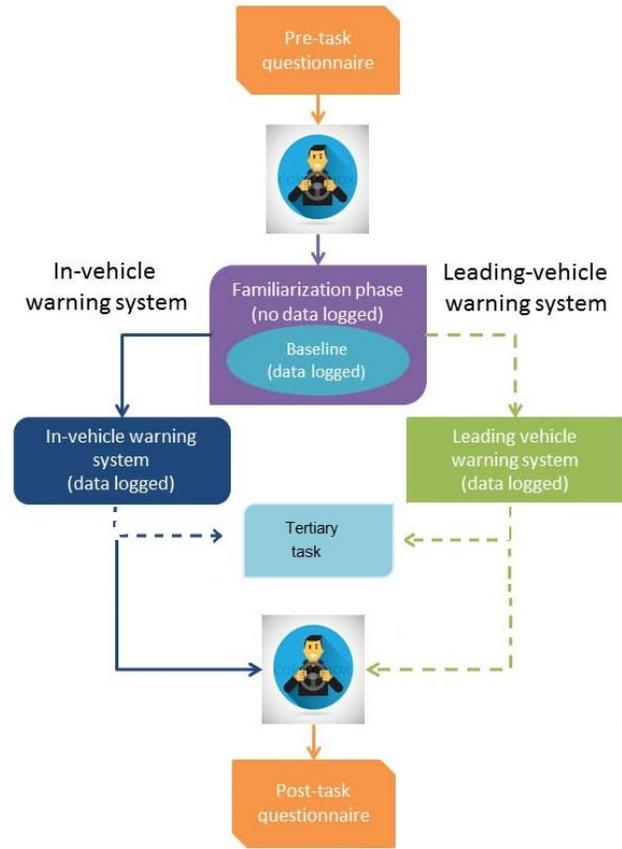


Fig. 4. Flow chart of the experimental procedure to measure driver response to the two rear-end collision avoidance paradigms.

that the systems provided was affected by the performance of an additional task, both sets involved the execution of a tertiary task. It was not the goal of this work to evaluate the effect of the tertiary task on driving while observing ADAS messages. Therefore, we did not perform tests involving a tertiary task while no system was activated. The order of the sets and tertiary task was alternated to avoid bias.

During the first set, each participant drove for a period of four minutes without any system activated, this phase being defined as baseline condition. Next, the participants tested the two different rear-end collision avoidance systems for eight minutes each, while performing a tertiary task for half of that time (4 minutes). The tertiary task consisted of finding specific items in a bag filled with various items that was located on the passenger seat. After completion of the driving task, the participants filled in a post-task questionnaire using a subjective rating system that included 14 items, a 10-point response Likert-type scale and a comment section to provide supplemental information regarding their experience with the system. The flow chart of the experimental procedure can be seen in Figure 4.

V. DATA COLLECTION AND ANALYSIS

We collected data from a sample of 20 test subjects (75% males, 25% females, mean age = 28.5, SD = 6.2) that were



Fig. 5. Participant driving in the simulation platform

previously screened according to the following requirements:

- possessing a valid driver's license for longer than 2 years;
- no health issues that would influence driving;
- no preconditions of motion sickness;
- not having any type of color deficiency in their vision;
- no previous knowledge of the research project.

Information about the time, speed, headway and lateral position (LP) were logged during the runtime of the simulation for every frame and used to calculate the time to collision (TTC) and deceleration change rate (DCR) according to the equations 1 and 2 [16].

$$TTC = \frac{d}{V_f - V_l} \quad (1)$$

where d is the headway, V_f is the speed of the rear vehicle and V_l indicates the speed of the leading vehicle.

$$a = \frac{V_{f-1} - V_f}{t_f} \quad (2)$$

where V_{f-1} is the braking speed of the rear vehicle in the previous frame, V_f is the braking speed of the rear vehicle in the current frame and t_f indicates the frame duration.

The speed variation represents the changes caused by the traffic environment such as a slower vehicle in front. Lateral position variation was calculated as the standard deviation lateral position (SDLP) logging the vehicle position (center of the vehicle) and velocity vector at each frame. The braking activity was calculated through the deceleration change rate within two successive frames, based on the vehicle's speed [17].

To evaluate whether the dependent variable driving performance was affected by the independent variables a) information in the rear vehicle or b) information on the leading

vehicle, we compared the mean values for each of the logged parameters for the different conditions a) and b) and analyzed their statistical significance using a paired t-test. The same test was applied for evaluating the results of the post-task questionnaire. The standard alpha level for significance of .05 was chosen.

In order to measure the effectiveness of the t-test in deciding the deviation from the null hypothesis, a power analysis was performed calculating the value $1 - \beta$ that shows the probability of rejection of the null hypothesis when it is false.

VI. RESULTS

We present in this section the results obtained from our experiment, focusing on statistically significant values. The power of the t-test ranged from 76% to 95%, which indicates a low probability that a false null hypothesis will be mistakenly accepted. Generally speaking, the power analysis demonstrated a low probability of type II error during the experiments. However, the probability of such error in the deceleration change rate was higher during the secondary tasks, the probability of type II error being 52% for the in-vehicle warning system and 55% for the leading-vehicle system.

As shown in Table I activation of the rear-end collision avoidance systems had an impact on the statistically significant differences of the headway, TTC and deceleration change rate parameters. Headway and deceleration change rates when no system was activated were not affected by the display modality. However, in the case of TTC, the differences were only statistically significant for the in-vehicle display system.

As for the impact of the proposed paradigms on driving performance, a higher headway, TTC and deceleration change rate were detected for the in-vehicle display system than for the external display system. However, this difference was only statistically significant for the headway parameter.

Table II depicts driving performance in relation to the activation of the different systems and execution of a tertiary task. A statistically significant decrease of the values could be appreciated in headway and TTC while performing the tertiary task with the in-vehicle system activated. However, the lateral position variation increased with the tertiary task. These tertiary task measurements suggest that the primary task takes a certain capacity of attentional resources and the remaining capacity is then available for secondary and tertiary tasks [18]. Therefore the beneficial effect of using the rear end collision avoidance systems is increasingly mitigated as tasks accrue. Having the message displayed in the rear part of the leading vehicle resulted in only a slightly higher deceleration change rate when performing a tertiary task, suggesting increased brake activity as a result of a compensation for the division of attentional resources. We can conclude that results from our study lead to the rejection of the null hypothesis and acceptance of H1: The selection between external or in-vehicle methods of conveying information for rear-end collision avoidance systems affects

TABLE I
DRIVING PERFORMANCE VALUES DEPENDING ON THE REAR-END
COLLISION AVOIDANCE SYSTEM DISPLAY CONDITION

Metric	Baseline		In-Vehicle Sys- tem		Leading-Vehicle System	
	Mean	SD	Mean	SD	Mean	SD
Velocity (km/h)	31.44	4.85	31.95	3.21	31.34	3.65
Headway (m)	9.87	1.65	12.12	1.71	10.72	1.68
TTC (s)	1.20	0.22	1.46	0.22	1.36	0.25
LP (m)	0.52	0.09	0.50	0.12	0.50	0.07
Deceleration change rate ((km/h)/s)	0.43	0.17	0.62	0.29	0.60	0.28
T-Test ($\alpha=0.05$)						
Metric	Baseline vs. In- Vehicle		Baseline vs. Leading-Vehicle System		In-Vehicle vs. Leading-Vehicle System	
	<i>t</i> (19)	<i>p</i>	<i>t</i> (19)	<i>p</i>	<i>t</i> (19)	<i>p</i>
Velocity (km/h)	-0.41	0.69	0.07	0.94	0.68	0.50
Headway (m)	-4.90	9.93E-05***	-2.32	0.031*	2.87	0.009**
TTC (s)	-5.33	3.81E-05***	-1.88	0.07	1.07	0.29
LP (m)	0.66	0.52	0.44	0.66	-0.19	0.84
Deceleration change rate ((km/h)/s) rate	-2.90	0.009**	-2.35	0.02*	0.30	0.76

TABLE II
DRIVING PERFORMANCE VALUES DEPENDING ON THE REAR-END
COLLISION AVOIDANCE SYSTEM DISPLAY CONDITION WITH AND
WITHOUT TERTIARY TASK

In-Vehicle System Display						
Metric	Without tertiary task		With tertiary task		T-Test ($\alpha=0.05$)	
	Mean	SD	Mean	SD	<i>t</i> (19)	<i>p</i>
Velocity (km/h)	31.95	3.21	32.57	3.02	-0.75	0.46
Headway (m)	12.12	1.71	10.64	1.60	3.87	0.001***
TTC (s)	1.46	0.22	1.29	0.16	3.93	0.0008***
LP (m)	0.50	0.12	0.71	0.25	-3.22	0.004***
Deceleration change rate ((km/h)/s)	0.62	0.29	0.85	0.43	-1.94	0.06
Leading-Vehicle System Display						
Metric	Without tertiary task		With tertiary task		T-Test ($\alpha=0.05$)	
	Mean	SD	Mean	SD	<i>t</i> (19)	<i>p</i>
Velocity (km/h)	31.34	3.65	32.42	3.85	-0.80	0.43
Headway (m)	10.72	1.68	10.92	1.37	-0.52	0.60
TTC (s)	1.36	0.25	1.28	0.15	1.05	0.30
LP (m)	0.50	0.07	0.63	0.07	-6.17	6.16E-06
Deceleration change rate ((km/h)/s)	0.60	0.28	0.81	0.42	-2.26	0.03*

driving performance metrics that are relevant to the reaction to a road incident between vehicles.

Regarding the subjective ratings, the 10-point Likert-type scale ranged from 1 = not at all to 10 = very. Responses related to the realism and ease of adaptation to the simulation environment showed a high score (mean=7.37, SD=2.2). Responses regarding the ease of understanding showed that the “keep distance” message from the leading-vehicle warning system was classified as very clear (mean=9.53, SD=0.94) and not irritating (mean=1.58, SD=2.26), even if the tailgating behavior could be intentional on the part of the rear driver and the proposed technology was intended to remind some tailgaters to correct an aggressive behavior.

Subjective ratings regarding the comparisons between both

systems are shown in Table III. The Likert scale ranged from 1 = very bad to 10 = excellent. Significant statistical differences indicated that the participants gave lower scores for visibility of the warning message with regard to the external warning system. The reason was that the message was only noticed when a certain headway had been reached, and before that point, it was hard to detect the warning message on the leading vehicle’s rear windshield. However, once the external message on the leading-vehicle was visible the test subjects preferred its position over the in-vehicle system. This was due to the fact that the message was conveyed in the field of view of the drivers without having to divert their eyes from the road.

TABLE III
SUBJECTIVE RATINGS REGARDING SELECTED PARAMETERS OF THE
COMPARED REAR-END COLLISION AVOIDANCE SYSTEMS

Parameter	In-Vehicle System Display		Leading-Vehicle System Display		T-Test ($\alpha=0.05$)	
	Mean	SD	Mean	SD	<i>t</i> (19)	<i>p</i>
Visibility	8.25	1.59	5.95	2.09	3.70	0.001***
Position	5.95	3.09	8.30	2.70	2.59	0.018*
Ability to capture driver’s attention	6.20	2.44	7.85	2.43	1.97	0.06
Color contrast	6.60	2.60	7.50	2.54	1.22	0.23
Non annoying	8.50	2.01	8.70	2.11	0.47	0.64

VII. CONCLUSION AND FUTURE WORK

The parameters that determine the reaction time for responding to a road incident between vehicles, headway, TTC and deceleration rate were positively affected by the use of the both rear-end collision avoidance systems proposed. The systems did not have any impact on the velocity and lateral position deviation, parameters both relevant to visual distraction and cognitive load respectively, while performing secondary and tertiary tasks [19], [20].

The message displayed on the in-vehicle system fomented a higher headway than the message displayed on the leading-vehicle system. A possible explanation could be that with the leading-vehicle warning system, drivers needed certain distance between their vehicle and the leading vehicle in order to capture the warning message, in contrast to the in-vehicle system where the “keep distance” message was displayed on the driver’s own dashboard.

The remaining driving performance parameters were not affected by the system evaluated. Results indicated that the execution of a tertiary task while the systems were activated negatively affected the response time to the in-vehicle display information, although it did not affect the response time to the leading-vehicle external system.

Further experiments to study the impact of the presented visualization metaphors in a real world setting will be part of future work.

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