Investigating Safety Services on the Motorway: the Role of Realistic Visualization

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ABSTRACT

Today's in-car information systems are undergoing an evolution towards realistic visualization as well as to real-time telematics services. In a road study with 31 participants we explored the communication of safety information to the driver. We compared three presentation styles: audio-only, audiovisual with a conventional map, and audiovisual with augmented reality. The participants drove on a motorway route and were confronted with recommendations for route following, speed limitation, lane utilization, unexpected route change, and emergency stops. We found significant differences between these safety scenarios in terms of driving performance, eye glances and subjective preference. Comparing the presentation styles, we found that following such recommendations was highly efficient in the audio-only mode. Additional visual information did not significantly increase driving performance. As our subjective preference data also shows, augmented reality does not necessarily create an added value when following safety-related traffic recommendations. However, additional visual information did not interfere with safe driving. Importantly, we did not find evidence for a higher distraction potential by augmented reality; drivers even looked slightly less frequently on the human-machine interface screen in the augmented reality mode than with conventional maps.

Author Keywords

User studies, Telematics, Realistic Visualization

ACM Classification Keywords

H.5.1. Information Interfaces and Presentation: Multimedia Information Systems—Artificial, augmented, and virtual realities; H.5.2. Information Interfaces and Presentation: User Interfaces—GUI

1. INTRODUCTION

Automotive information systems, including on-board driver assistance units, portable navigation devices, and mobile phones, have become widely used by drivers. Some of the most spectacular advances are related to the visual presentation on the human-machine interface (HMI). For example, navigation device manufacturers are offering popular 'reality view' features, which provide recommendations for changing lanes in preparation for taking highway exits as well as high quality images of the exits.

Up to now, such realistic visualizations have mostly been applied to navigation, but with emerging co-operative vehicle-to-

infrastructure or vehicle-to-vehicle communications technology ([6],[20]), they will also become relevant for delivering Real-Time Safety-Related services. Better instructions on how to act with regard to urgent dangerous incidents might be possible. For example, an advanced HMI of such a co-operative service could involve 'augmented reality' (AR): the overlay of arrows and icons over the virtual representation of the scene ahead of the driver, to indicate a lane change and a stop in the emergency lane.

However, the impact of different levels of visual information and warnings on driving has not been fully explored. AR presentations with quasi-realistic images of the outside reality might be recognized more quickly, but on the other hand the wealth of details might hamper the identification of the task-relevant information. We argue that the effects of realistic visualizations on usability and user experience should be fully understood to ensure the safe usage of advanced co-operative telematics services. In order to achieve this, systematic and reflective user-oriented research is needed.

In this paper, we report on a road-based field experiment that sets out to understand to what extent visual information on the HMI is useful to communicate realtime safety services to the driver, taking audio-only as a baseline. We are aiming to provide guidelines for the user interface design of motorway vehicle-to-infrastructure services, which will presumably be rolled out in several European countries on a large scale within the next few years [6]. In the following, we introduce the field of safety-related traffic services, and we summarize the research state with regard to the suitability of visual presentation at the HMI.

1.1 Safety-related traffic telematics

Realtime safety-related traffic telematics systems are expected to improve the reliability and efficiency of navigation services, for example by calculating routes based on accurate congestion information. But qualitatively new service types are also targeted, such as urgent incident warnings, dynamic roadwork information, or lane utilization. The necessary infrastructure for the transmission of safety-relevant messages from the road to the car and vice versa will in many countries be rolled out first on the motorway, and then later in the cities. Thus, it is of most immediate interest to understand the user interface requirements for the motorway context.

Table 1 classifies typical traffic services that will be implemented on motorways (compare [3]). The information provided in these services varies in the level of demand on the user. During normal route following, the information by the HMI must be monitored from time to time, but acute reactions are typically not necessary. However, when the system calculates a detour to bypass a congestion, the driver needs to be notified and given detailed instructions on how to change directions.

The highest demand level is given in case of an emergency stop. Here, the driver needs to be quickly notified and provided with comprehensible information on what to do next. The key challenge here is that the required actions can be quite unfamiliar. For example, drivers may be asked to stop before the tunnel in the emergency lane. When designing the user interface for such systems, a basic question could be whether or not the visualization capabilities of today's in-car information systems should be exploited.

**Table 1: Safety services
enabled by upcoming vehicle-to-infrastructure systems**

Recommendation type	Demand	Description
Normal route following ("Normal")	Low	Following the directions on the HMI.
Speed limitation ("Speed")	Low	A new speed limitation is recommended.
Lane utilization ("Lane")	Medium	The system instructs the driver to use a specific lane.
Unexpected route change ("Route")	Medium	A new route is recommended, requiring the driver to react and leave the highway.
Emergency stop ("Emergency")	High	Due to an urgent safety hazard, the system instructs the driver to stop on the emergency lane at a certain position.

1.2 Suitability of visual presentation

There is considerable research evidence suggesting audio as a highly suitable presentation modality for in-car navigation systems (see e.g. [1],[13],[10]), provided that quality principles and standards are followed (compare [7]). The most important advantage of audio as compared to visual presentations is of course that visual attention remains on the road. Audio may even be more recommendable for the communication of urgent safety-related information, as messages via the auditory channel inherently attract attention ([18], [11]).

However, long and complex auditory messages impose high workload on the driver, which may lead to phenomena like inattentional blindness [16] and related dangerous driving situations [8]. To relax requirements for working memory, it is often recommended to additionally present visual information. Especially in the case of unusual safety recommendations, such as emergency stops, detailed visual information may be important for drivers to reassure themselves about where exactly to stop the car.

Furthermore, it is simply a reality that the vast majority of drivers want to have a graphical display and often keep auditory information disabled. Even if visual safety recommendations are suspected to be distractive, the strategy of suddenly switching off the screen display for audio-only presentations might even cause more confusion and further destabilize the driving situation.

For in-car information systems, it thus appears that presenting visual in addition to auditory information is the best choice, as drivers could gain from the advantages of both modalities ([19],[1]). However, as most research evidence comes from simulator-based research of navigation aids, this general recommendation needs to be validated by more naturalistic experimentation. We especially need to clarify whether the requirements for visual information depend on the type of safety scenario.

1.3 Suitability of realistic visualization

Augmented reality representations provide a 1:1 picture of the driver's view, which is qualitatively different from conventional schematic map displays. Arrows and icons are exactly overlaid over this representation to aid in tasks such as lane-changes or speed adaptation. The main goal of realistic visualizations is to reduce the amount of abstract symbolization. This way, map use is reduced to "looking rather than reading" [15].

In a driving context, realistic views could potentially make visual processing easier and enable better concentration on the driving task. Departing from earlier results in cognitive psychology [5] one might argue that as the representation (of the road situation) becomes more realistic, the mapping to the real situation based on perceptual features becomes easier. Furthermore, a higher realism of visualizations may possibly result in higher usage satisfaction and appeal to customers than standard visualizations.

However, realistic visualizations in cars could also cause problematic situations on the road. First, it could be more time-consuming to identify relevant information in realistic displays, which would limit a faster mapping between virtual and real environment. Furthermore, it is not clear which features of realistic views really help the user to match with the real road situation. Many features could as well just be "eye candy", i.e. visual entertainment that would not provide a benefit but only distract from the primary driving task.

In a simulator experiment, Kim and Dey found that for older drivers an augmented reality display of city navigation information on the windscreen (head-up display, HUD) provided better support for drivers than a conventional personal navigation device with a bird's eye view map [12]. Furthermore, in a car simulation study on city wayfinding, Medenica et al. [14] showed that an AR HUD presentation required less time looking away from the road, and resulted in lower subjective workload ratings, than an HDD featuring a presentation similar to Google Street View.

While these study results provide important background evidence on the suitability of realistic visualizations in the car, these can only partially be used as guidance for our targeted application context of realtime safety services on the motorway. As our focus is on vehicle-to-infrastructure services to be rolled out in the near future, we expect that they will mostly be used with HDD-based in-car information systems.

A study which is more closely related to our application context compared the presentation of highway-based safety services on HDD-only versions of AR with conventional map displays [7]. The AR version had a positive impact on user-perceived safety, but there was no significant increase in driving performance compared to the conventional map alternative. However, as almost all of the above findings come from simulator experiments, validity for real road usage still needs to be strengthened by road experiments and field studies.

2. RESEARCH QUESTIONS

In the context of safety-related traffic telematics, when users are to follow specific prescriptive HMI recommendations, the following generic HMI design questions are relevant:

1. Should real-time safety recommendations only be presented auditorily, or also visually?
2. When safety recommendations are presented visually, should the outside world be represented by a conventional map or by augmented reality?
3. Are different presentation styles (audio-only, conventional map, augmented reality) recommendable for different safety scenarios (see Table 1)?

The focus of attention when analyzing these aspects is on primary driving performance, secondary driving performance (accuracy of following HMI recommendations), on eye-glance behavior, and on user experience.

3. METHOD

To answer the above questions, we conducted a road study, which is now described. After a description of the sample, we lay out the test method according to the subsequent phases of the study, i.e. the briefing phase, the road test phase, and the debriefing phase.

3.1 Participants

The study was completed by 31 participants, receiving a voucher for a consumer electronics store as an incentive for participation. Participants were recruited via public announcements and the institute's test person database. Participants' age ranged between 20 and 65, whereas the mean age was 32. There were 11 female and 20 male participants. A larger number of male participants was accepted, as statistics indicate a higher share of drivers among males as compared to females [2].

To minimize the risk of accidents, only experienced drivers were admitted to the experiment, who were in possession of a driver's license for two years and who drove at least two hours per week and several times per month on a highway. In order to control for the influence of experience with navigation devices, we aimed for an equal distribution: 15 participants stated to have no prior experience with navigation devices. 8 were regular and 8 sporadic users of navigation devices.

3.2 Safety scenarios

The test users were exposed to four types of safety-related scenarios as specified in Table 1: unexpected route change, speed limitation, lane utilization, and emergency stop. Participants drove along the motorway using a normal route following service, which was at a certain time interrupted to present the respective safety recommendation.

In each safety instruction, the following information was subsequently provided via audio (speech in quotes, translated from German, example for unexpected route change): (1) an alert by a well-audible non-speech sound and verbally by "Attention!", (2) a distance indication "in 300m", (3) the driving recommendation "Turn right", and (4) the underlying safety information "due to a congestion". Such an audio message had a duration of about 4 – 5 seconds. The key information (2) and (3) was then repeated after 2 seconds.

To mirror the realtime character of a future V2I system, the necessary time to react given by the HMI instruction was on purpose relatively short: drivers were to change the lane within the next 200 meters, to change the route in the next 300 meters, and to make an emergency stop within the next 500 meters. The lane utilization scenario actually included two subsequent lane change recommendations, in order to result in at least one lane change in case the participant is already driving in the recommended lane.

3.3 Presentation styles

The second independent variable was the presentation style, and according to the research questions it had three factor steps: audio-only ("Audio"), conventional map ("Map"), and augmented reality ("AR"). Figure 1 shows how the experimental presentation styles and the safety scenarios were reflected in the in-car presentation prototype developed for the study.

Presentation style	
A. Audio-only: ("Audio")	Audio instructions (sound + speech)
B. Conventional map: ("Map")	+ Audio instructions (sound + speech)
C. Augmented Reality: ("AR")	+ Audio instructions (sound + speech)

Figure 1: Experimental HMI presentation styles

The PC-based in-car application prototype mimicked a future car information system with integrated navigation and safety services (see a description of the system and its underlying prototyping platform in [17]). A 12" HDD screen setup comparable to that of a high-end large-screen OEM in-car information system was used for the experiment, to exclude potential effects of device miniaturization in smartphones or small PNDs.

In the audio-only user presentation mode, the screen was black, and its loudspeaker provided high-quality synthetic speech instructions, following the scheme presented in the previous section. The two visual presentation provided the same audio instructions as in the "Audio" condition and additionally featured a split-screen design, which was based on a recently positively validated realtime safety information system from the EU-funded research project COOPERS [3]. The split-screen featured the spatial representation of the outside world (Map or AR) on the left side and the messages boxes on the right side.

The spatial representation of the outside world was either realized by a conventional map or by augmented reality. The message boxes were consistent for both visual experimental presentation styles, and they provided special safety-related information. Specifically, we had 1-3-message boxes with currently valid safety information and warnings at the bottom, and the resulting

driving recommendations on the top (including icon and distance indications). The driving recommendations in non-critical situations displayed standard route directions, and in case of a safety issue they provided one of the four safety recommendation types: speed limitation, lane utilization, route change, or emergency stop.

The augmented reality mode was implemented by overlaying an arrow over a front view video stream of a live webcam (see Figure 1). While informal feasibility tests of an automatic approach of overlaying of the route trajectory of the map route over the live video were moderately successful, accuracy limitations did not allow for application in our experiment. To simulate a reliable "system behavior" that could be expected for future AR systems enhanced by computer vision algorithms, we therefore chose a wizard-of-oz approach, where a human operator manipulated the route trajectory manually in realtime.

The operator was a researcher in a back seat using a trackball device for manipulating the trajectory overlay. The researcher was trained to manipulate the overlay in about 10 pre-test drives on the test route within a one-month period prior to the experiment. Due to the custom-developed software and the trained operator, behavior of the AR presentation was smooth, which was also substantiated by the fact that none of the subjects experienced any confusion by the AR overlay or mentioned any related inaccuracy.

3.4 Experimental design

Main experiment

The study is a 2-factors (presentation style *x* scenario type) mixed design, with 'presentation style' as a between-group factor and 'scenario type' as a within-group factor. We wanted to have at least 3 data points per experimental condition in each test drive, in order to gain more valid results in the behavioral analysis. Thus, a full combination of both factors in a within-subjects design (3 presentation style *x* 4 Scenario type *x* 3 data points = 36 test situations) would not have been feasible. However, with only presentation style as a between-subjects factor, 4 scenario types *x* 3 points = 12 test situations were manageable within a driving course of 45-60 min.

Participants were randomly assigned into three groups, each experiencing one presentation style. Participants were equally distributed between groups in terms of gender and age, but regarding experience with navigation systems, the share of experienced participants was higher with the audio group (70%) than with the AR group (50%) and the conventional map group (36%). However, this unequal distribution resulting from the randomized allocation of participants to groups was preferred to utilizing an otherwise necessary quasi-experimental design.

Comparison phase

To allow for subjective comparison between the visualization styles within each test, each participant was also confronted with the two other visualization styles after the main experiment. The order of presentations was systematically varied among the participants, in order to prevent systematical bias through preference, learning or fatigue effects.

3.5 Procedure and test route

During the test drives, the participants were accompanied by two researchers: an experimenter and an operator. The same two researchers accompanied each participant in order to attain internal consistency. The experimenter managed the test procedure, handed in the materials, provided instructions and coded some aspects of driving behavior. The operator managed

the test instrumentation and realized the WOZ behavior in the AR test conditions.

In the briefing phase, test users were informed about the test procedure and signed consent forms, which were necessary due to special permits to stop in the highway emergency lane. The participants then drove along a pre-defined route, which was a roundtrip along several highways in the Vienna metropolitan area (Figure 2). Driving the route was subdivided into sections for the training and reference phase, three main experiment phases and a comparison phase. The route length was about 55 km, with an averaged test driving time of 45 – 60 minutes.

The training and reference phase enabled the driver to get familiarized with the test car and the driving tasks encountered in the experiment. Here the driver was not exposed to the HMI.

Figure 2: Test route

The main experiment was composed of three phases where each of the four safety recommendations was presented once by the HMI. By allocating the scenario types over these three phases, presentation of each scenario type was stretched over the whole length of the test drive, thereby preventing systematic experimental order biases.

Furthermore, the order of the safety scenarios was varied throughout the phases, to avoid systematic experimental biases.
There was always a "normal" driving situation of approximately 4.5 km on average before a critical moment, in which a safety recommendation was presented. With this setup, we aimed to simulate normal driving and avoid the pure succession of unusual critical situations: the driver could "fall back" into a typical driving situation, and would then be confronted with a special situation. Furthermore, this setup should help the driver to reserve sufficient mental resources for the safety-critical moments.

The final driving section was to enable the comparison phase described above, in which the driver was briefly confronted with the other two alternatives, in order to gather overall comparative feedback. After the drive, the participants were interviewed about the presentation style they experienced in the main test phase.

3.6 Measures

Three cameras were used to capture the driving situation, specifically the road ahead, the HMI display, and the driver's face. These video signals were integrated via a quadsplitter and recorded with two microphone signals on a video recorder. These were used to support data analysis with regard to the measures below.

Primary driving task performance: Directly after each critical situation, the experimenter provided a rating on a 7-point scale with regard to safe driving (no abrupt braking maneuvers, no drastic tempo changes, distance keeping). The experimenter

(always the same person) was an experimental psychologist, and had been thoroughly trained during 10 test drives, in order to ensure reliability of test results.

Secondary driving performance: The experimenter also qualified the fulfillment of the safety recommendation, by coding correctness of task fulfillment (0=no; 1=yes; 2=yes, but only with a hint by experimenter), and correct location of task accomplishment (1=correct location; otherwise=distance in meters). From the combination of these categories, an ordinal 7-point scale was derived (see Table 2).

Table 2: Coding scheme for secondary driving performance (safety recommendation fulfillment)

7	Fulfillment = 1, Distance=1
6	Fulfillment = 1, Distance < 100m
5	Fulfillment = 1, Distance > 100m
4	Fulfillment = 2, Distance = 1
3	Fulfillment = 2, Distance < 100m
2	Fulfillment = 2, Distance > 100m
1	Fulfillment = 0, Distance irrelevant

Eye glance behavior: The drivers' facial videos were analyzed to investigate glance behavior for the normal and each of the four critical situations. Eye glances were captured by manually analyzing the videos of the driver's face by two independent coders, adopting the methodology of Jensen et al [10]. Glances to the HMI were counted according to the following classification: 1) short glances of max 0.5 seconds, 2) medium glances of 0.5 to 2 seconds, and 3) long glances of more than 2 seconds.

Subjective preference: After the test, the participants were asked to provide an overall subjective rating of system usability. Furthermore, they provided comparative ratings with regard to different presentation styles and safety scenarios. For that purpose they were provided with an overview sheet containing all 15 possible combinations and asked to rank them with regard to the degree to which the presentation style supported the user in following the provided driving instructions.

Furthermore, for each screenshot, participants indicated the degree to which they felt supported by information provided by the visual outside world representation (left screen side), the visual driving recommendations and safety messages (right side), and the audio messages. Finally, persons were handed out the incentive, the test session was closed. Each individual test had an overall duration of about 2 hours.

4. RESULTS

The presentation of the results follows the three research questions. Data of all 31 participants could be included in the analysis. However, we could not investigate eye glances for 14 of the 372 test situations (4 safety scenario types *x* 3 phases *x* 31 participants), due to insufficient video picture quality. Furthermore, for one participant we could not obtain primary performance data.

Inferential statistical verification was done by means of 2-factorial ANOVAs for analyzing main and interaction effects. In case of a rejected sphericity assumption, the degrees of freedom were corrected by means of a Greenhouse & Greenhouse estimate. For pairwise comparisons we calculated non-parametric tests (Mann-Whitney-U-test for independent samples, and Wilcoxon-Z-test for dependent samples). In case of necessity of several pairwise

comparisons, Bonferroni corrections of the p-level were applied, to avoid overtesting biases. Errorbars in graphs represent a 95% confidence interval. Note that we did not find significant effects of demographic variables or experience with a navigation device, thus related analyses are not reported below.

4.1 Overall results

Throughout the test, the experimenter ratings for primary and secondary driving performance were very high for all presentation styles (M=6.65, SD=0.65; M=6.34, SD=1.24, on a 7-point rating scale). Furthermore, overall subjective preference data was quite favorable: subjects provided relatively high ratings for system comprehensibility (M=6.0, SD=1.283). This also suggests that results are less likely biased by potential usability or acceptance problems.

The absolute number of eye glances on the HMI was actually lower than may have been expected: for AR and Map glances on average ranged between 0.5 and 1.1 per 10 seconds. Interestingly, long glances, which are known to be particularly dangerous, were almost non-existent (see Figure 3).

4.2 Audio vs. visual presentation

Primary driving performance: The experimenter ratings were very high for all presentation styles Audio (M=6.65, SD=0.64), Map (M=6.54, SD=0.76), and AR (M=6.76, SD=0.51). A two-factorial variance analysis (mixed design) did not result in a significant mean effect of the presentation style, $F (2, 27)=0.562$, $p>0.05$, i.e. no difference was detectable between audio-only and the two audiovisual presentation styles (conventional map and AR).

Secondary driving performance: Observer ratings for secondary driving performance, i.e. the accuracy of following the HMI recommendations, were also very high for all three presentation styles Audio (M=6.46, SD=1.01), Map (M=6.22, SD=1.49) and AR (M=6.35, SD=1.12). Again, we did not find a significant mean effect for the presentation style, $F (2, 28)=2.817$, $p>0.05$, that is no difference between audio-only and the two audiovisual representations was detected.

Eye glances: Not surprisingly, drivers almost never looked on the screen when an auditory presentation was offered (Figure 3). The reason for the mean numbers being above zero was that the notification sound came from the direction of the HMI screen and thus in some situations people pre-attentively glanced at the empty screen. The overall difference in mean number of glances was significant, $F (2,28)=21,702, p<0,05$), as were the pairwise differences between audio and the two visual conditions Map and AR ($p<0.0167$).
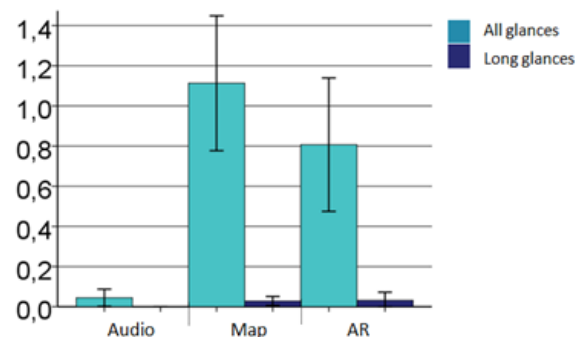

Figure 3: Number of all vs number of long glances per 10 seconds for the three investigated presentation styles

Subjective preference: The overall perceived support by the three different presentation styles is presented in Figure 4. While there is a strong difference between AR and Map (explained below), there was no significant difference between these visual presentations (computed together) and the audio presentation, Z<-2.188, p>0.0167; Z<0.00, p>0.0167 (p-levels Bonferroni-corrected, as noted above). During and after driving, Audio got exclusively positive remarks, and it was obviously seen as the most valuable channel for providing safety information. However, it also became clear that persistent visual information is also desired, especially for cross-verifying the safety information a few seconds after audio presentation.
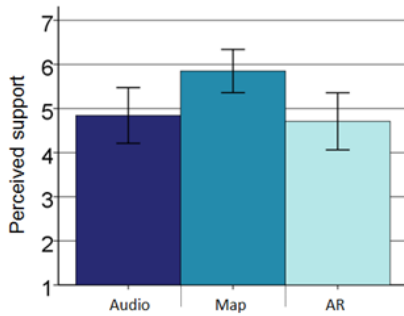

Figure 4: Mean perceived support by the HMI presentation style

4.3 AR vs. Map

Primary driving performance: No significant difference in primary driving performance was found between AR and Map (variance analysis, F(2, 27)=0.562, p>0.05).

Secondary driving performance: Again, a variance analysis did not result in a significant difference between the conventional map and the AR presentation styles, F(2, 28)=2.484, P>0.05.

Eye glances: Figure 3 shows a slight trend towards more glances onto the HMI in the Map than in the AR conditions. This difference was not significant when based on averaged values per test user (31 cases), but it was significant when treating each of the 358 analyzed test situations as cases (358 cases, U=5801.5, p<0.0167).

Subjective preference: As can be seen in Figure 4, there is a strong preference of Map over AR. This effect is significant, Z=-2.94, p<0.0167. Subjective statements during and after the drive suggest that the main advantage of the map view was probably the better overview to parts of the road beyond the current field of view. A problem with the AR setup was visibility: a pure camera image of the road is simply very dark, especially in case of cloudy weather, and therefore it may hinder efficient recognition of the traffic situation. On the positive side, AR was often mentioned to provide exact guidance with regard to the lane to be utilized.

4.4 Safety scenarios

Primary driving performance: Figure 5 shows that people drove very safely in most critical situations, namely the speed limitation, lane utilization and route change scenarios. Primary performance was a little lower in the emergency scenario than in the other scenarios, T=65.5, p<0.05. A two-factorial ANOVA revealed a significant interaction effect of presentation style and safety scenario with regard to primary driving performance, F (852,65,502)=2.939, p<0.05.

The contrasts show that in lane utilization and route change scenarios experimenter ratings of AR were comparably higher than in the other scenarios. This effect can be explained by the more detailed lane-related information provided by the AR presentation style.
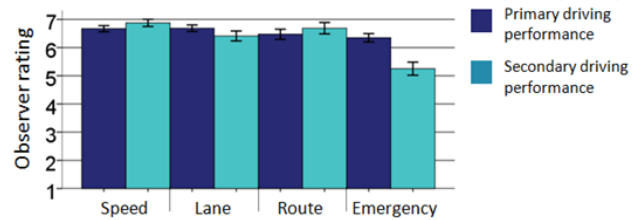

Figure 5: Experimenter ratings for primary and secondary drivingperformance for the four safety scenarios

Secondary driving performance: As can be seen in Figure 5, accuracy in following the speed limitation, lane utilization and route change recommendations was very high. The only strong outlier was the emergency scenario, where a significant difference to the route was detected, T=78.5, p<0.05 (no other pairwise significance tests were calculated to avoid overtesting biases). This is because drivers did not always stop at the exact specified position in the highway's emergency lane. We did not find any significant interaction effects of presentation style and safety scenario.

Eye glances: For the different safety scenarios, significantly different mean glance durations have been found, F(2, 937, 82.23)=10.584, p<0.05. Participants looked significantly less frequently on the screen in normal route following situations than in all other safety situations, and most in emergency stop situations. We also found a significant interaction effect of safety scenario and presentation style, F (5,874,82.23)=2.479, p<0.05. Figure 6 shows that while in the Audio conditions no strong difference in glances between the scenarios was observed, the distance between the values of AR and Map vary between the scenarios.
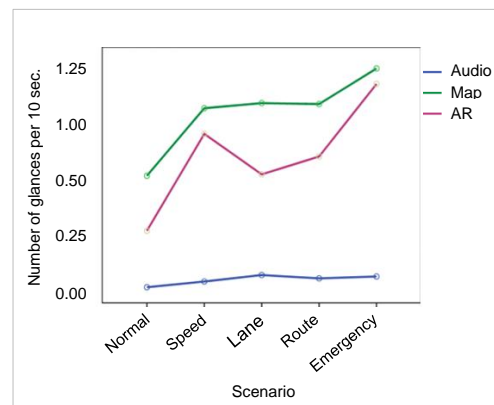

Figure 6: Interaction effects between the safety scenario and the presentation style, with regard to the mean number of glances per 10 seconds

In the case of speed limitation and emergency stop, the values are much closer to each other than in the lane utilization and route change scenarios. This is confirmed by the analysis of the ANOVA results, where the contrast comparing the three presentation styles between Normal and Speed is significant, F (2, 28)=3.74, p<0.05. The same applies for the contrast between route change and emergency stop, F(2,28)=3.779, p<0.05.

Subjective preference: Figure 7 shows the rating results for the perceived support by three kinds of HMI elements: the outside world representation, which is displayed on the left half of the HMI screen ('pic'), the text (and icon) message boxes on the right ('text'), and the audio messages ('aud'). The results in Figure 7 are presented separately for the Map and the AR screens (left vs. right), as well as for the normal and safety scenarios (top vs. bottom).
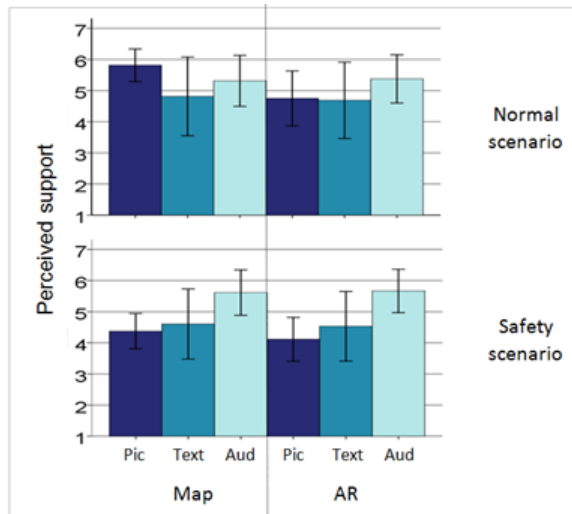

Figure 7: Perceived support of the real-world representation (left screen side in Fig. 1), the message boxes (right screen side) and the audio messages

Interestingly, the text and iconic information on the HMI ('text') was regarded as similarly important as the audio information. Note also that the outside world representation ('pic') was only regarded important for the Map alternative during normal route following scenarios. In the safety scenarios, audio was preferred to visual representations of the outside world.

5. CONCLUSIONS

We conducted an experimental road study to understand to which extent visual information on the HMI is needed to communicate realtime safety services to the driver, taking audio-only as a baseline.

Ad RQ1: Should real-time safety recommendations only be presented auditorily, or also visually?

Our answer to this question is that designers should very seriously consider presenting driving recommendations in an audio-visual form.

On the one hand, we found that audio-only presentations of safety recommendations are correctly understood and efficiently processed by the drivers. In our scenarios, adding visual information did not appear to improve comprehensibility of the safety messages and compliance with the given recommendations.

On the other hand, while our subjective rating results strongly suggest audio as an efficient channel for providing safety instructions, they additionally point to the desire by participants to receive the safety messages visually in iconic and textual form. Furthermore our data indicates that a map is clearly desired by drivers. Note that in our scenarios we have not found negative effects of visual presentations: glances appear to be usually short and infrequent, and driving performance does not degrade significantly.

Ad RQ2: When safety recommendations are presented visually, should the outside world be represented by a conventional map or by augmented reality?

We suggest that, at the current state of knowledge and development, conventional maps should be given priority to HDD augmented reality visualizations when it comes to presenting standard route guidance and most safety information on the highway. We obtained the possibly surprising finding that augmented reality presentations do not distract drivers (in terms of glances) and do not affect driving safety in the investigated highway usage situations.

In principle, this result could indicate a generally better support by realistic presentations for cognitive processing of driving recommendations, as compared to schematic maps. However, when also taking into account the comparatively low subjective ratings, we rather assume that subjects tended not to rely as much on AR presentations and for this reason also paid less attention to them. This interpretation would be in line with the SEEV (salience-effort-expectancy-value) model by Wickens et al. [21], which also assumes more glances to areas that are of special value and interest.

Behavioral observations and subjective comments point to two necessary improvement areas of current HDD AR solutions. First, an overview beyond the driver's field of view is needed, especially in the high-speed motorway context. In this regard, future studies should experiment with different combinations of exo- and egocentric perspectives (compare for example [12] for design inspirations). Second, visual computing approaches (such as selective increases of luminance and contrast of the scene video) may be needed to improve pre-attentive perception of the road situation.

Ad R3: Should different presentation styles be chosen for different driving scenarios?

Our data confirms that the HMI requirements for safety recommendations are differing from standard route following on the motorway. First, the higher number of glances indicates a higher demand on the driver in safety situations. Second, a visual outside world representation is seen as less supportive in case of a safety scenario than in a normal route following scenario.

While auditory driving recommendations are generally recommendable, this is even more the case for safety situations than for normal route following. As drivers often keep the audio function disabled in typical route following situations, this modality may even need to be enforced to ensure the suitable presentation of safety-relevant messages, most importantly in the case of an urgent incident notification or even an emergency stop. Apart from that, it appears evident from our data that for normal route following situations drivers regard a map view as an absolutely necessary feature.

Adding more visual detail and match with the outside world by introducing augmented reality appears to support safe driving in situations where exact location information is needed, such as in the tested lane utilization and route change scenarios. Here, primary driving performance was slightly higher and necessary glances to the screen were fewer than with the other presentation styles. Replication studies are encouraged to further investigate this possibly relevant interaction effect.

Road experiments inherently offer high naturalism and thus are needed as a sort of 'ground truth' for the interpretation of related simulator studies. However, one should always be aware of the limitations implied by road experiments. First, due to the

significant management and conduction effort, a limited number of participants can usually be involved. Second, driving conditions, such as the traffic density, cannot be controlled as in a simulator and therefore cannot be disregarded as experimental factors on their own. Third, due to safety concerns, some constraints had to be imposed on participants' age and driving experience, as well as on the included driving conditions (test drives were only made at daytime and in case of unproblematic weather conditions).

Our study was focused on motorway safety scenarios, as this represents the most relevant near-future application scenario related to vehicle-to-infrastructure systems in Austria. This of course implies that our findings cannot simply be transferred to other environments and task types, such as city navigation. It is possible that augmented reality may unfold more potential for the more complex decision situations usually involved in such a context. As our focus was on guidelines for near-future safety information systems, we only included HDD conditions in our study. Road-based studies with advanced prototypes of HUD AR solutions are highly recommended for future research.

6. ACKNOWLEDGMENTS

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