AUGMENTING THE DRIVER'S VIEW WITH REALTIME SAFETY-RELATED INFORMATION

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ABSTRACT

In the last couple of years, in-vehicle information systems have advanced in terms of design and technical sophistication. This trend manifests itself in the current evolution of navigation devices towards advanced 3D visualizations as well as real-time telematics services. We present important constituents for the design space of realistic visualizations in the car and introduce realization potentials in advanced vehicle-to-infrastructure application scenarios. To evaluate this design space, we conducted a driving simulator study, in which the in-car HMI was systematically manipulated with regard to its representation of the outside world. The results show that in the context of safety-related applications, realistic views provide higher perceived safety than with traditional visualization styles, despite their higher visual complexity. We also found that the more complex the safety recommendation the HMI has to communicate, the more drivers perceive a realistic visualization as a valuable support. In a comparative inquiry after the experiment, we found that egocentric and bird's eye perspectives are preferred to top-down perspectives for safety-related in-car safety information systems.

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

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INTRODUCTION

In-vehicle information systems, such as personal navigation devices, built-in driver assistance units and Smartphones, have become standard equipment in today's cars - and their capabilities are quickly evolving. The most obvious advances are related to the visual presentation at the in-vehicle human-machine interface (HMI). On the consumer mass market, we see a clear trend towards increasingly realistic representations of the driver's outside world, including textured 3D renderings of highway junctions, road details, mountains, and buildings [14]. Arrows and icons are exactly overlaid over the virtual representation of the driver's field of view to aid in navigation tasks. This development towards realistic visualization is further strengthened by the advent of augmented reality navigation systems on market-available handheld devices (e.g. [12]).

Up to now, such realistic visualizations are mostly applied to navigation. However, with emerging co-operative vehicle-to-infrastructure or vehicle-to-vehicle communications technology [4,16,20,18], they will also become relevant for delivering more advanced safety-related services. For example, drivers could be notified about sudden incidents and provided with recommendations on how to react accordingly. In this context, the major challenge is the fact that the driver actions required can be fairly unusual and unexpected, and thus might not be adequately understood or implemented. For example, drivers may be asked to stop before a tunnel on the emergency lane due to an accident ahead.

In this application context, realistic visualization could represent both merit and demerit: information attached to a quasi-realistic mapping of the outside reality might be recognized more quickly than with today's schematic visualizations, but on the other hand the wealth of details might as well hamper the identification of task-relevant information. It should be clear that the effects of realistic visualizations on usability and user experience must be fully understood before recommending their use in millions of cars. In order to achieve this goal, systematic and reflective user-oriented research is needed.

In this paper, we present an experimental study to evaluate the influence of realistic visualizations on perceived driving safety and satisfaction. We were interested in finding out whether realistic visualizations provide an added value in terms of safety and user experience, or whether they are just "eye-candy" that could even endanger the driver and other traffic participants. We first specify the basic elements and characteristics of realistic visualizations. Departing from this, we formulate a set of research questions that are and describe the method of an experimental study to address them. We finally provide a detailed results description and provide suggestions for further research.

SPECIFYING REALISTIC VISUALIZATIONS

The extent of realism of an HMI's real-world representation can be described by a number of constituents (see Figure 1): map representation, viewing perspective, environmental objects, and augmentation. The possible properties of these constituents are now briefly described, and then prototypical combinations are presented.

Constituents of realistic visualizations

Map representation: Digital 2D maps have long been the standard way to present the outside world on the HMI. Meanwhile, however, the global availability of environmental models from map providers like Navteq Inc. has motivated the integration of 3D spatial representations also in portable navigation devices. Starting from basic 2.5D building representations and schematic landscape models, we witness a gradual increase in fidelity towards fully textured scenes with complete buildings.

Viewing perspective: Most HMIs provide dynamic map displays that automatically align themselves towards the driver's surroundings, based on orientation information derived by a compass or by the sequence of GPS coordinates. Another common feature is a "bird's eye" view on the road situation, with the camera being positioned slightly behind and above the virtual vehicle. When 3D maps with detailed objects are displayed, often also a fully egocentric view is provided, which matches the driver's field-of-view. This view then can be of use for the display of complex junctions, for example.

Environmental objects: Due to current developments towards realistic visualizations, an increasing amount of environmental objects becomes displayed to the user. This includes navigation-related objects, such as turn indications on the road and direction signs. High fidelity representations of surrounding objects are also used to provide location-based search and purchase, such as when a user is looking for the next gas station or shopping mall. Furthermore, significant architectural landmarks are shown in more detail.

Augmented information: To provide the actual recommendations on the HMI, the above-described scene representations are overlaid with virtual objects and elements that indirectly refer or point to aspects of the environment. In current systems, such additional virtual information typically relates to route indications, congestion information, as well as information on points-of-interest. Typical means of augmentation are color coded lines or arrows, icons, text and numbers. Visualization approaches reach from colored overlays over the road to virtual "follow-me cars" implicitly indicating the speed and direction (compare [13,8]).

Constituents	**Characteristics**		
Map representation	Schematic 2D	Untextured 3D	Textured 3D
Viewing perspective	Top-Down	Bird's Eye	Egocentric
Envir. objects	None	Selected	All
Augmentation	Text	Icons	Arrows and lines
	Match with real view of outside world →		

Figure 1: Constituents of Realistic Visualizations

Prototypical visualization styles

Each one of the aforementioned constituents is necessary to describe the extent of realism of an outside world representation on the HMI. However, the constituents also must be seen in combination, as their properties exert mutual influence on each other. The following combinations can be regarded as prototypical variants within the design space of realistic visualizations:

Conventional view: In most of the navigation systems currently available, a schematic 2D map of the outside world is presented from a bird's eye perspective, with occasional display of a few important points of interest in the environment. The recommended route is visualized by a schematic overlay over the map, and for recommendations and warnings icons are georeferenced on the map.

Realistic view: An idealized "reality view" of an in-car HMI would be a quasi-realistic 3D map representation, dynamically presented from the driver's own viewing perspective, including all environmental objects. This visualization would be augmented by accurately spatially-referenced overlay lines and arrows, as well as by 3D-spatially referenced icons. Realistic views may also be realized by augmented reality, provided that accuracy problems with aligning the virtual guidance information with the real scene are solved.

Conventional and realistic interleaved: most contemporary navigation systems also feature dynamic switching between different visualization modes, depending on current context. For example, in non-critical situations, a conventional bird's eye view is presented as default (with varying accuracy of environmental objects). However, when approaching critical points (such as highway junctions), the device might switch to a realistic view, in order to avoid ambiguous situations and reduce the potential for misinterpretation and navigation errors by the driver.

RESEARCH ISSUES

The key purpose of realistic visualizations is to reduce the amount of abstract symbolization. This way, map use is reduced to "looking rather than reading" [15]. In the car, realistic views could potentially make visual processing easier and enable better concentration on the driving task. Inferring from earlier results in cognitive psychology [5], one might argue that the more realistic a virtual representation (of the road situation) is presented, the easier a mapping to the real situation based on perceptual features is possible. Especially in complex driving situations, this could result in increased driving safety. Furthermore, a higher realism of visualizations may promise higher usage satisfaction and appeal to customers than standard visualizations.

On the other hand, also problematic aspects of realistic visualizations in cars need to be taken into account. First, it may take more time to identify task-relevant information in realistic displays, which would limit a faster mapping between virtual and real environment. This may lead to serious restrictions and poor compliance with international car safety standards, such as the 'European Statement of Principles' [6]. Furthermore, it is not clear which features of realistic views really help the user to match with the real road situation. They could as well just be "eye candy": nice to look at, but without any major safety benefit.

The general challenge in this regard is therefore to identify the safety impact of an increased realism of visualizations in selected realtime safety-related traffic telematics scenarios. When designing the HMI for in-vehicle safey information systems, 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.

Recommendations provided in these scenarios vary in their level of urgency. When driving along a prescribed route without any incidences, the information by the HMI must be monitored from time to time, but also in this case urgent reactions are not necessary. However, when the system calculates a detour (e.g., due to a congestion), the driver needs to be notified and given detailed instructions on how to change the directions. Recommendations get more urgent when a user is asked to use a certain lane on the road, due to temporary roadwork.

Unfortunately, existing research studies on the effect of visual presentations in the car may not fully apply, as these are about textual, iconic and simple spatial representations. Realistic representations have not yet been subject to rigorous examination in the open research community. While there are some approaches on the use of augmented head-up displays, especially the use of reality views on head-down displays are only beginning to be researched (compare [11]).

A generic approach to evaluate the added value of realistic visualizations is to compare the prototypical extreme variants of visualizing the real-world (as described in the previous section) with regard to their support for the driver. Based on these considerations, the following research questions have been formulated:

1. To what extent does any visualization of the real-world support drivers while following safety-related HMI recommendations, as compared to no real-world visualization?
2. To what extent does a realistic visualization support drivers while following safety-related HMI recommendations, as compared to a conventional visualization?
3. To what extent does an interleaved presentation of a conventional visualization (in non-critical situations) and a realistic visualization (in critical situations) support drivers while following safety-related HMI recommendations, as compared to the continuous display of a realistic visualization?
4. When considered in isolation, how are the constituents of realistic visualizations (map representation and perspective) likely to support the driver?
5. Does the urgency of the safety scenario influence the extent to which a realistic visualization can support a driver in following an HMI recommendation?

METHOD

We conducted a driving simulator study with potential future users of advanced traffic telematics systems.

Participants

28 participants, 16 male and 12 female, took part in the study. Their mean age was 32.7, ranging from 18 to 59 years. 70% were frequent drivers. 60 % of the users owned a navigation device. As remuneration, each subject received a voucher for a consumer electronics store.

Simulation environment

A simulation instead of a field environment has been chosen, because the investigated scenarios would be harmful for the involved drivers and impracticable with the currently installed telematics infrastructure. A number of simulation environments for driving have been developed, many of them dedicated for the purpose of in-car HMI evaluation. The fidelity of these simulators varies strongly, ranging from highly advanced moving-base simulators involving physical motion to single computer screens with game controller settings [3,19]. However, to the best of our knowledge, not even the most advanced prototypes provide dedicated simulation features with regard to realistic HMI visualizations.

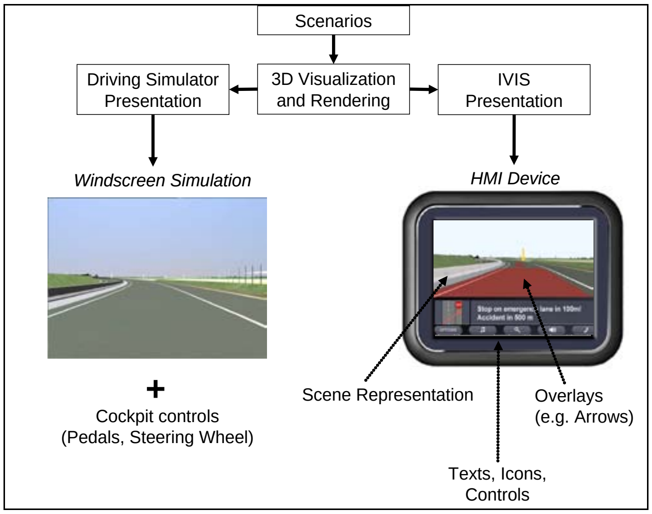


Figure 2: Realistic visualization rendering environment

To overcome this shortcoming, we have developed a versatile simulation environment that employs highly detailed geospatial models of current existing and future highways (see Figure 2). These models were originally created for construction planning and for the visualization of construction alternatives to facilitate public discussion.

As such, the models may guarantee a higher validity than in usual tests with abstracted highway simulations, due to a higher degree of user familiarity with the “look-and-feel” of a country’s (here: Austria) road infrastructure.

Both the “outside reality” (windscreen simulation) and the HMI display are rendered with the same rendering engine and based on the same spatial model. This architecture enables systematic and fine-grained variations of scene representations on the HMI display. Both the windscreen and the HMI simulations were rendered in realtime at 25 fps.

Our laboratory simulator was running on a Windows PC with a powerful graphics adaptor. Users were sitting on a driving seat and in front of a dashboard, both taken from a real car. They were operating a steering wheel, gas and break pedals (the clutch was not used; automatic transmission was assumed). The windshield view was displayed by a large 42” TFT screen, covering about 75 degrees of participants’ field of view. Our setup also follows the guidelines for the placement of personal navigation devices [7]: the in-car information system was modeled by a second 8” TFT screen (landscape format) mounted to the lower left side of the windscreen, next to the simulation car’s left A-pillar.

The screen layout of the HMI was designed to be consistent with contemporary in-car navigation systems (compare), involving a large ‘map area’ to represent the outside world, with an information area below that displays textual and iconic recommendations, as well as the current speed. At the very bottom, navigation elements were displayed, which were not active, as their functionality was not needed for the experiment.

Application scenario	Urgency	Possibilities for realistic visualization
Navigation: Driving on the highway and following the instructions of the navigation system. Not far from a highway exit, a new route is recommended, requiring the driver to react and leave the highway.	Low	Realistic representations of complex junctions, highlighting of dynamic route changes, e.g. integrated into today’s navigation HMI styles
Lane utilization: Driving on the highway and following the instructions of the HMI. Suddenly, the system warns the driver of an accident ahead and instructs the driver to use the right (or left) lane.	Medium	Mark lane utilization information directly on the scene representation, with an overlayed route projection
Urgent incident: Driving on the highway and following the instructions of the navigation system. Suddenly, the system warns the driver of an accident behind the curve and instructs the driver to stop on the emergency lane at a certain position.	High	Highlight where to drive or stop in urgent cases, with a an overlaid route projection and an arrow indicating the destination.

Table 1: Typical application scenarios for safety-related traffic telematics services, their urgency and related opportunities for realistic visualization.

Experimental application scenarios

The test users were exposed to three safety-related application scenarios, as specified in Table 1: navigation with unexpected route change, lane utilization, and urgent incident warning. The dramaturgical design of these scenarios followed a three-phase structure: the initial phase, the critical moment, and the final phase.

In the *initial phase*, users were driving for about 1 km along the highway, following the routing instructions of their in-car information system. Then, when entering a predefined zone, a warning was presented to the user, consisting of a short audio signal, a text message and an icon (see Figure 2). The first line of the text message recommends an action to the driver, together with an indication of distance. The second line provides information on the cause for the given recommendation.

The *critical phase* was between the point of the warning reception and the point at which the action requested in the respective scenario (the respective turn, lane selection, or emergency stop) should have been performed at the latest.

The *final phase* mostly served as a way to let users naturally finish their driving task. For example, in the lane change scenarios, the driver passed the partly blocked road section and was then told about the scenario end.

Experimental visualization styles

Four visualization variants were specified: 'none' (as a control condition), 'conventional', 'realistic', and 'interleaved'. Each visualization style was then realized for the three application scenarios, resulting in 12 different combinations. Figure 3 illustrates the realization of the conventional and the realistic view for navigation, lane change, and urgent incident. In the 'none' variant, the map area was filled with grey color. In the interleaved variant, the conventional view was in the initial and the final phase, and the realistic view in the critical phase.

Procedure and measures

The overall duration of test (from the participant's entering and leaving the test room) was approximately two hours. A test assistant was present to conduct the interview, to provide task instructions, and to note specific observations made during the experiment. Each individual test consisted of an introduction phase, in which the test persons were briefed about the goals and procedure of the test, and data on demographics and previous experiences was gathered. Then, the participants were enabled to familiarize themselves with the driving simulator and with the HMI. To minimize a potential habituation effect, it was assured that the users were informed about and had actively used each visualization and each application scenario. The subsequent phases of the study will now be described in detail.

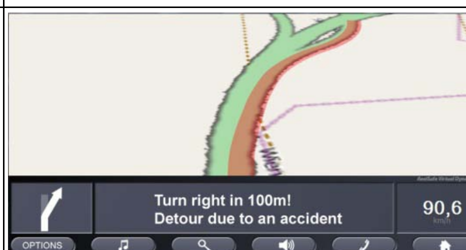
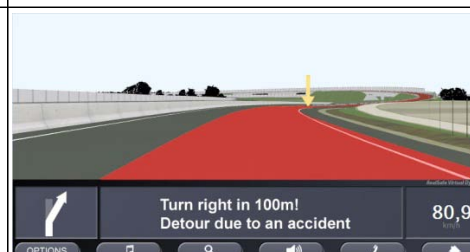
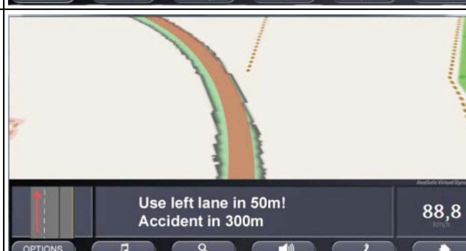
Safety Scenario	Conventional HMI View	Realistic HMI View
Navigation: route following with unexpected route change.		
Lange utilization: use a certain lane because of an accident ahead.		
Urgent incident: stop at a certain lane at a certain position.		

Figure 3: HMI Screenshots from the IVIS simulation for different application scenarios

Experimental part

The two independent factors of the experimental part were visualization and safety scenario. Each participant was driving 12 conditions, the product of 4 of scenario types and 3 of visualization variants. (This way, participants encountered every possible combination of visualization and scenario types). In order to avoid order effects, the sequence of conditions was varied systematically. At the start of each condition, the car was "parked" at the emergency lane of a highway. The participant was instructed to drive along the highway and to follow the instructions on the HMI as accurately as possible.

In the critical phase of each driving condition, the experimenter assessed *task completion*. Task completion was given if the subjects generally followed the system instructions (taking the right exit, selecting the right lane, and emerging stop on the right lane). Furthermore, the test facilitator noted incidents that occurred during the driving situation.

To capture the immediate driving- and HMI-related impressions, the participants filled out a questionnaire after each of the 12 conditions. The first question aimed at understanding the *general support* perceived in the driving situation. The two subsequent questions were designed to understand the visualization's support for *identifying the driving-task relevant information* (a potential problem area of detailed realistic visualizations) and its support for *finding matches between the road situation and the HMI display* (a potential advantage of realistic visualizations).

Final interview

The final interview aimed at gathering the participants' overall reflections of the driving situations experienced in the different conditions. The first two questions directly addressed the potential strengths by asking: "Did realistic visualizations support you in *finding accordances between the road situation and the HMI display*?", and the weaknesses "Did realistic visualizations deter you from *identifying the task-relevant details* in the necessary time span?"

Due to the realistic nature of the test, the 12 visualization variants tested represent specific prototypical *combinations* of constituents. In order to also obtain a rough understanding of the impact of the constituents of realistic visualizations in *isolation*, a systematic comparison was performed, based on an illustrated questionnaire. Due to their importance, 'map representation' and 'viewing perspective' were selected as the constituents of interest in the interview. Regarding the 'viewing perspective', the users were shown three clusters of screenshots of 2D and 3D views in navigation, lane change and urgent incident warning scenarios, one cluster only including top-down, the other only bird's eye, and the third only egocentric perspective. The participants were then asked to provide a ranking on the three different perspectives, with regard to their assumed support in the driving situations. The same principle was applied for 'map representation'.

RESULTS

In this section, the results from the experimental part, the post-experimental inquiry, and the comparative inquiry are described. The statistical analysis was based on the data-from 28 participants. Mean differences were calculated with non-parametrical techniques for dependent samples (Friedman and Wilcoxon tests). In all figures, the error bars represent 95% confidence intervals. Throughout the measures used in the study we did not find age- or gender-specific differences.

Experimental part

Task completion

Our results are characterized by a very high task completion ratio across all test conditions: 99.4% of the navigation, lane utilization and urgent stop recommendations were generally followed. We found no significant differences between the different visualization styles

Post-condition Questionnaire

Figure 4 presents an overview of participants' mean ratings of the four different visualization styles on three scales: perceived *general support* in the respective driving situation, support for *identifying the relevant details* and *matching with the outside real world*. On all three scales, participants rated those visualizations without a real-world representation worse than all others. Participants consistently judged the realistic view as more supportive than the conventional view (all differences significant, $p < .05$). On none of the three scales, any difference could be found between the realistic and the interleaved visualizations.

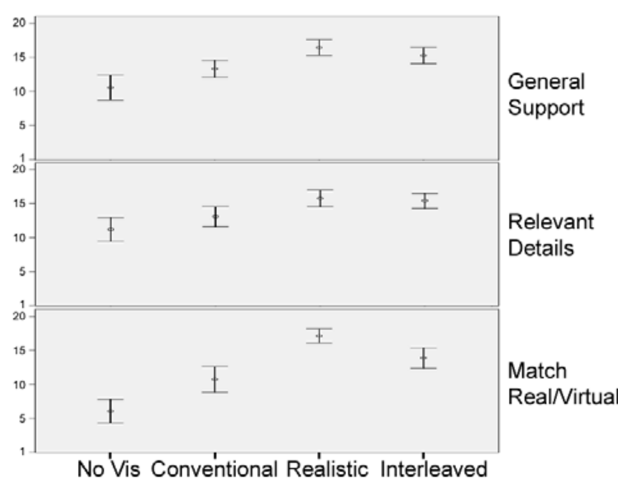


Figure 4: Mean post-condition ratings on the visualization styles, with regard to perceived general support in the driving situation, the support for identifying relevant details and for matching the virtual representation with the real-world

Figure 5 again shows the perceived overview support in the driving situation, but here separated by the *three safety scenarios*. The ratings are mostly consistent throughout all safety scenarios. A notable exception was observed when looking at the difference between the conventional and the realistic view: this was perceived as significantly lower rated in the urgent incident and lane utilization scenarios, but not in the navigation scenario ($p<.001$, $p<.004$, $p=082$). When directly comparing the rating values for the conventional visualizations between the different scenarios, the conventional visualization was rated better in the navigation than in the urgent incident scenario ($p<.01$). The mean ratings in the lane utilization scenario also tended to be lower, but the difference did not reach significance ($p = .065$).

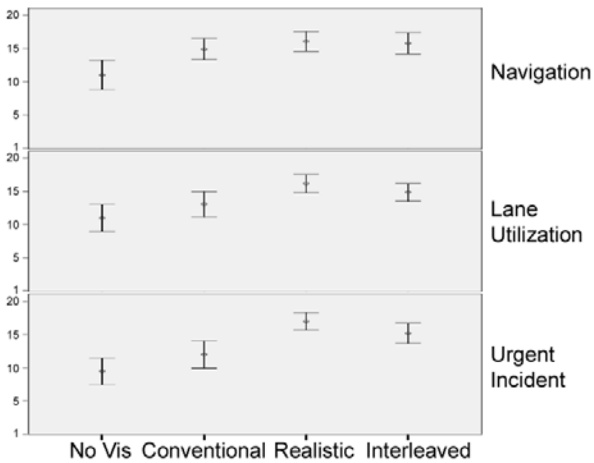


Figure 5: Mean post-condition ratings on the visualization styles, with regard to perceived general support in the driving situation, separated by the three safety scenarios.

Observations

The main observations of incidents that had been noted during the test conditions were as follows:

No visualization: When being confronted with on-screen navigation instructions, drivers did not encounter notable problems. In the two other scenarios, subjects often appeared to be confused about how they should behave correctly. They were unsure about where exactly to change lanes or where to stop (but as indicated above, the vast majority stopped at the right lane). Several users also got noticeably excited after receiving a warning and very attentively looked onto the road situation, to look for the announced incident.

Conventional: During navigation, no notable problems were observed. However, in the other two scenarios many users were unsure about where to stop or which lane to take. This was obviously due to the rather schematic visualization on the 2D map.

Realistic: In the realistic view conditions, we noticed hat users tried to follow the indicated arrow as closely as possible. In the urgent incident scenario, this attitude sometimes resulted in driving significantly slower to exactly stop at the indicated location. However, this behavior was mostly observed the first and second time a realistic view was used.

Interleaved: The switch from conventional view to the realistic view was noticed well by the drivers. In general, the observations made in the critical moment were similar to the ones made for the realistic visualization.

Participant impressions

The participants‘ comments provided after using the visualizations were as follows:

No visualization: The vast majority of users stated that without a real-word visualization it was difficult to follow the lane utilization and urgent incident recommendations on the HMI. They were basically regarded as a standard feature for every form of navigation devices.

A few participants stated that in principle it could suffice to provide safety warnings without a real-word representation, but that in this case a combination with audio output would be necessary. Furthermore, they wished the icon placed at a more prominent place on the screen (interestingly, many participants only took notice of the icon in the no-visualization condition).

Conventional: The majority of participants complained about the experienced difficulties in interpreting the overlayed lines and icons over the schematic 2D map, when following utilization and emergency stop recommendations. Furthermore, users of latest navigation systems criticized the relatively low number of displayed details on the map and the lack of a car position item. What was often positively valued was the good foresight provided by the bird’s eye perspective.

Realistic: Many participants stated that they felt safe when using the realistic visualization. A very often mentioned reason was that the “1:1” match with the outside world improved orientation. They would have liked to see even more spatially-referenced annotations, such a blocking icon directly placed on the respective lane. The display of many details was not seen as distractive from the relevant information. The few critical remarks were related to less foresight, as compared to the conventional view.

Interleaved: Participants provided similar comments with regard to the interleaved as to the realistic view. The switch was not seen as an added value by the participants. Many stated that they would have preferred a continuously displayed realistic view.

Final Interview

The participants widely stated that realistic visualizations had enabled them to find a match between the HMI and the real road situation (mean rating of 16.11 on a 20 point scale, SD = 3.8). Similarly, many participants stated that realistic visualizations had *not* hindered them in finding the relevant details on the screen display (mean rating of 5.5 on a 20 point rating scale, SD = 4.4).

Comparative inquiry

Figure 6 shows the ranking results from the comparative inquiry on the *perspectives* top-down, bird's eye, and egocentric, with regard to their assumed support in the driving situations. Overall, the top-down perspective was rated significantly lower than the other perspectives (for both $p<.001$). However, the ratings for bird's eye and egocentric perspective did not differ significantly from each other, the navigation scenario again differed from the other two scenarios: here the bird's eye view was preferred to the egocentric perspective ($Z=-2.05$, $p<.05$).

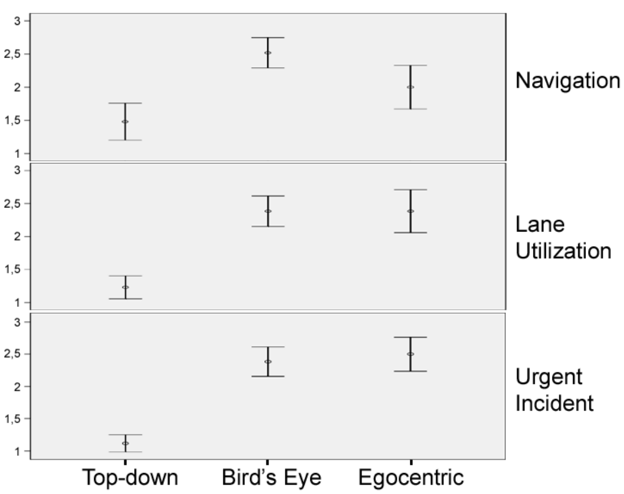


Figure 6: Mean interview rankings on perspectives, with regard to perceived general support in the driving situation, separated by the three scenarios.

The comparative inquiry on the map representation revealed a strong preference of 3D over 2D (77.4% vs. 22.6%; $Z=-3.49$, $p<.001$). Again, the navigation differed from lane utilization and urgent incident: here a difference between 3D and 2D could not be found.

CONCLUSIONS

In the following, the results are summarized with regard to the research questions:

Q1: Real-world visualization in general (baseline)

The results suggest that an HMI is perceived to support a driver better in following safety-related recommendations if it displays a real-world visualization, as compared to a pure textual and iconic message. A map appears to be regarded as a standard HMI feature, and it helps to better orientate oneself. The added value of such a real-world representation is consistently supported by user ratings and comments. On other hand, our task completion results show that the pure display of text and an icon obviously suffices to correctly follow a recommendation, at least in low-complexity driving situations.

Q2: Realistic vs. conventional visualization

We found that realistic visualizations is perceived as an added value when presenting safety-related recommendations on the HMI, as compared to conventional visualizations. This is a result that was not easily predictable: in principle, the many 'irrelevant' details shown in realistic visualizations could as well have been assumed to be disturbing. Also we found that realistic views do not decrease task completion, at least in simple scenarios.

Q3: Interleaving conventional and realistic visualization

Switching between a conventional visualization (shown in non-critical situations) and a realistic visualization (shown in critical situations) does not provide an added benefit, as compared to the continuous display of a realistic visualization.

Q4: Constituents of realistic visualization

Regarding the main constituents of realistic visualizations, we found that, when considered in isolation, 3D representtations are preferred to schematic 2D representations on the HMI. Regarding the viewing perspective, the top-down alternative appears to be not well suited for in-vehicle safety information systems. This is not only based on the results comparative inquiry results, but also by frequent comments throughout the test conditions.

Q5: Influence of safety scenarios

Throughout the study, we found that drivers felt even more supported by realistic visualizations when they had to follow urgent and non-standard instructions in the urgent incident and lane utilization scenarios. While drivers in principle followed the general instructions correctly, they often felt insecure when choosing the right lane or place to stop.

DISCUSSION

The experiment presented in this paper is the first comprehensive evaluation of the suitability of different visualization styles and their constituents for safety-related in-car information applications. The goal was to overcome the current scarcity of prescriptive knowledge on this important and safety-relevant topic.

Our simulator study results show that realistic HMI visualization styles have a significant positive impact on the user experience. In comparison to other visualization styles, realistic views provided added value in terms of driver support and perceived safety, beyond a purely aesthetic function as visual enhancement or "eye candy". These utilitarian benefits materialized particularly in more acute safety-critical scenarios which required effective and timely action by the driver. Furthermore, we did not find any evidence for negative impact of realistic views on participants, e.g. in terms of diminished task-performance, distractions by visual clutter or reduced safety. Our findings may thus challenge conventional recommendations which postulate the simplification and reduction of visual HMIs designs [6]. In the light of our results, the application of realistic views in safety contexts should be considered again on a broader level. We therefore suggest further systematic research on the merits and demerits of realistic visualizations for in-vehicle navigation and safety applications.

Our results also show that compared to traditional navigation, safety scenarios have different properties, and consequently different visualization requirements: in the navigation scenario, users saw no additional benefit of realistic views over conventional, schematic ones. However, with rising urgency of the scenarios, participants found realistic views to be significantly more useful. This shows not only that reality views provide tangible benefits for the driver, but also that safety-related HMI represents an application class distinct from pure navigation, requiring dedicated user experience research.

Our study participants were only exposed to relatively simple environments (highway) and tasks (such as stopping at the emergency lane). This may explain the observed insensitivity of users' (near to perfect) task completion rate to visualization style. Thus, our results should not be generalized towards more challenging high complexity scenarios. Under high strain and cognitive load, users might change preferences and perform better with other or even without HMI visualizations. Future studies should extend and validate the design space towards such higher complexity demands.

In this study, we were deliberately interested in understanding the effects of certain prototypical extreme variants (no visualization, conventional, realistic and interleaved views). Obviously, further visualization variants are possible in this context. Most importantly, we want to stress the fact that these three styles represent idealized variants highly suitable for experimental testing, but which in practice are rather encountered as downgraded or simplified implementations. For example, visualizations currently marketed as "reality views" actually still have many aspects of schematic representations: in many cases they do not display the current situation, but only display 3D templates or 2D images of prototypical junctions. To advance towards safe and satisfactory realistic visualizations in the car, the results clearly encourage the scientific advancement and understanding of the design space for realistic visualizations.

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