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## A comparison of display concepts for a navigation system in an automotive contact analog head-up display

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### Abstract

Contact analog head-up displays (cHUDs) enable the presentation of augmented reality (AR) information in the driver's primary field of view and are a promising display innovation in light of the increasing degree of assistance and automation in modern cars. As cHUD technology still faces several limitations, robust and error-tolerant display concepts are required. Four design variations (*cut-off*, *no cut-off*, *tilt*, *2D*) of two display concepts (*boomerang*, *arrow*) for contact analog navigation were realized in a mock-up setting in which the virtual cHUD image was overlaid on a video recording of a real driving scene. Thirty participants (within-subjects design) rated attractiveness, positional accuracy, functionality, clearness/unambiguousness, distraction, quality of 3D representation, interpretability, and intuitiveness. The results suggest that the variation *tilt* cannot be recommended for application in an automotive cHUD. The boomerang concept was preferred over the arrow concept. The results have important implications for the design of contact analog information in an automotive cHUD.

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## 1. Introduction

The nature of the driving task has been changed by the increase of assistance and information systems in the vehicle that are supposed to enhance safety and comfort while driving [1]. Although these systems aim at disburdening the driver, he is still in charge of supervising these systems, their operations and correct functioning. Innovative display technologies play an important role in the ergonomic implementation of the interaction between driver and vehicle in the context of increasing degrees of assistance and automation in modern and future automobiles. Conventional head-up display (HUD) technology is already implemented in many series vehicles of different manufacturers. Via a virtual image appearing in front of the car, HUDs enable the presentation of information in the driver's primary field of view. This helps the driver monitor driving-related information, such as the speedometer or Advanced Driver Assistance Systems (ADAS) with minimum focal accommodation and eye movement effort, i.e., while keeping his eyes on the road, resulting in safety benefits such as reduced eyes-off-the-road times and faster reaction times to unexpected traffic events [2–5].

A further stage of conventional HUD technology is the realization of augmented reality (AR) in the HUD, i.e., the combination of real and virtual information via the projection onto a transparent plane [6]. In a so-called contact analog head-up display (cHUD), information is still presented in the driver's primary field of vision, but now directly superimposed onto the real driving environment outside the car. By providing this immediate spatial context information, contact analogy in an automotive HUD is supposed to reduce the driver's cognitive effort required to interpret the information displayed and correctly transfer it to the traffic environment. AR cues have already been shown to be efficient in directing the driver's attention to and improving his detection of critical traffic events or objects [7–10]. Due to its intuitiveness and the spatial information provided, AR information in an automotive cHUD may help to increase situation and system awareness, and may improve the understanding of ADAS such as ACC.

Although cHUD technology seems to imply numerous advantages over other information presentation approaches, there are several challenges to the successful implementation of an automotive cHUD. Deviations of the virtual information from the ideal location in the outside environment, due to imprecise sensor (e.g. GPS) or road map data, bear the risk of driver distraction and annoyance. Depending on the characteristics of the optical system, the driver's sitting position, head posture, and movements, as well as pitch and yaw movements of the vehicle [11] may lead to displacements of the virtual image in relation to the driving environment. Package limitations constitute another challenge, as they determine the maximum display range of the virtual image. The resulting limitations, especially in the horizontal plane, prevent information in the cHUD from being displayed in contact analog manner across the whole windshield. Instead, the virtual information will either be cut off or has to renounce contact analogy at some point. Furthermore, adding virtual information to the real world within the driver's primary field of vision may interfere with his perception of the traffic scene, reducing accuracy and increasing reaction times for the detection of critical objects or events [12] due to masking, clutter, interposition, or divided attention. These limitations have to be considered when developing concepts for presenting information in an automotive cHUD.

Whereas the general optical quality of current cHUD systems has been subject to ongoing improvements, some of the technological limitations mentioned above will most likely not be eliminated in the foreseeable future. In light of these limitations, an optimized ergonomic concept for presenting information in the cHUD, with respect to or within the technological boundaries, becomes even more important. Potential display concepts should support the augmentation, aim at maximizing functionality, and intuitiveness while minimizing distraction or masking of (critical) real life objects. Although there are guidelines for the presentation of visual information in the vehicle [13,14], focused research on the design of display concepts for a cHUD has been scarce and, if at all, has mainly been realized in driving simulators with the virtual image of the cHUD directly integrated into the simulated driving environment, which does not precisely constitute an augmented reality but a virtual reality setting.

In the current study, four design variations of two display concepts were each realized in an innovative mock-up setup in which the virtual cHUD image was accurately overlaid over a video recording of a real driving scene. The detailed description and illustration of the setup is given in the following.

## 2. Method

### 2.1. Participants

Thirty participants (seven women, 23 men,  $M_{age} = 32.9$ ,  $SD_{age} = 6.4$ , range = 22-52 years) took part in the study. All participants were employees of AUDI AG, recruited via an e-mail distribution list, with an average of 26,383 km driven per year. Fifty-seven percent of the participants were users of a conventional head-up display. All participants gave written, informed consent and did not receive any monetary compensation for their participation in the study. All participants reported having normal or corrected-to-normal vision.

### 2.2. Experimental setup, display concepts and design variations

The experimental setup (see Fig. 1) consisted of a cHUD mock-up and a projection screen 10m in front of the mock-up. Video recordings of a real driving scene (driver's perspective) were projected onto the screen (resolution 1280 x 960 pixel). The virtual image of the cHUD (physical resolution: 858 x 600 pixel), starting at 12m in front of the mock-up, was superimposed on top of the driving scene. The setup resembled a driving simulator, but differed in that participants in the current study were not able to actively intervene in the driving process and the driving scene was not a simulation, but a video recording of a real drive.

In the current study, two display concepts (*boomerang* vs. *arrow*) for a navigation system in a cHUD and four variations of each concept were implemented (see Fig. 2 and 3). In the four design variations, the navigation symbol (display concept: boomerang or arrow) was either (a) cut off by the limited display range when turning onto a street (*cut-off*), (b) not cut off (*no cut-off*), (c) tilted along its longitudinal axis when approaching the maneuver point (*tilt*), or (d) supplemented by a 2D (not contact analog) arrow when approaching the maneuver point (*2D*).

### 2.3. Procedure

All participants were presented with all four variations of the two display concepts. The order of the display concepts was randomized, but within each concept the variations were presented in a fixed order (a-d; see previous section) due to technical limitations. The recorded route on which the cHUD image was superimposed was the same for both display concepts, with an approximate length of 600 m passing through a residential area with little traffic. After having seen each variation of a concept, participants filled out a questionnaire, i.e., eight times in total.

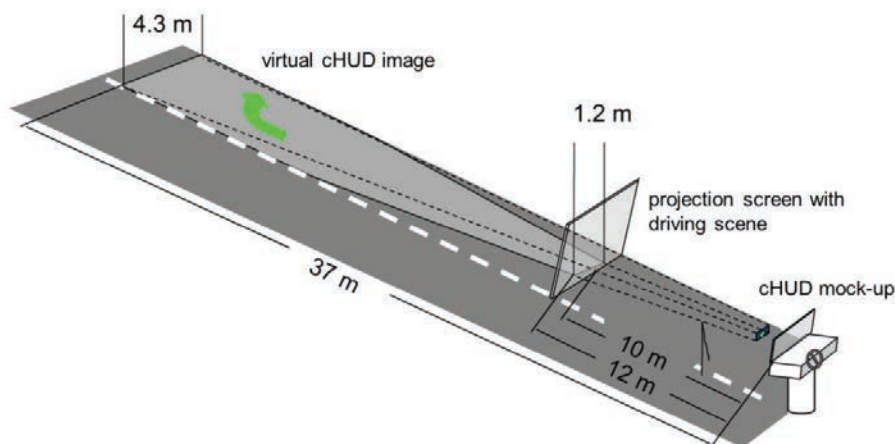


Fig.1. Experimental setup with cHUD mock-up and projection screen.

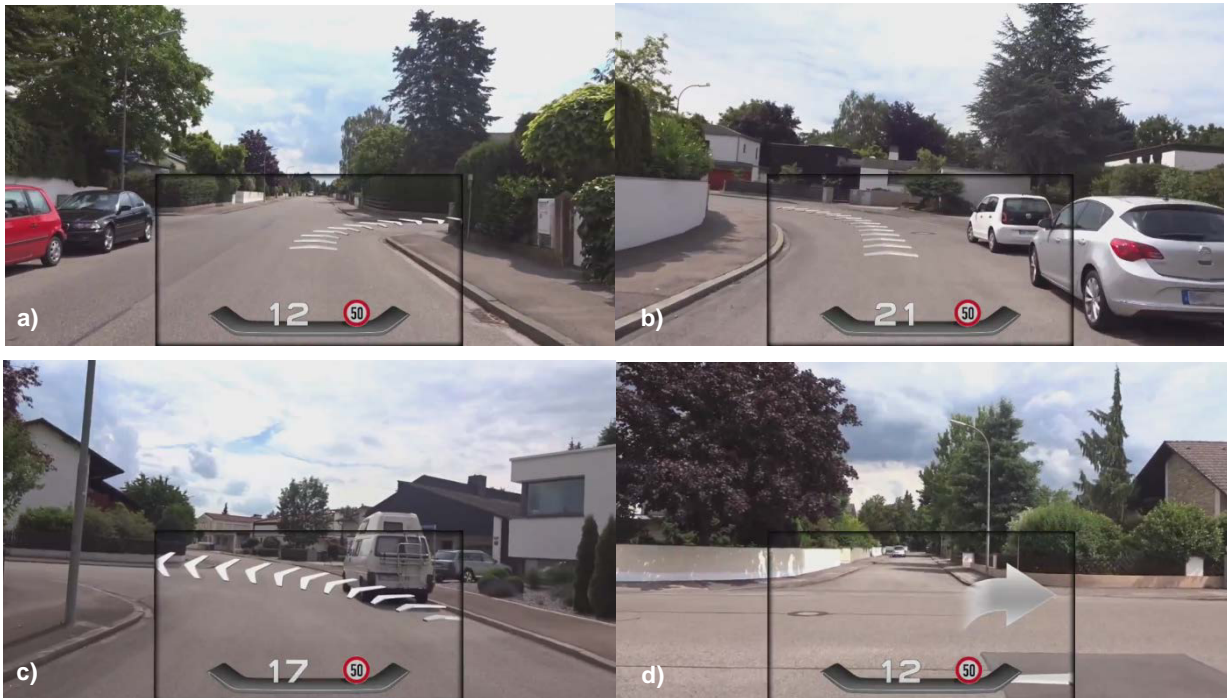


Fig. 2.Boomerang concept with the four different design variations: (a) cut-off, (b) no cut-off, (c)tilt, (d) 2D.



Fig. 3.Arrow concept with the four different design variations: (a) cut-off, (b) no cut-off, (c)tilt, (d) 2D.

In the questionnaire, participants rated attractiveness (“The design of the navigation symbol was attractive.”), positional accuracy (“The navigation symbols were displayed at the correct location in the environment.”), functionality (“The design of the symbols was functional.”), clearness/unambiguousness (“The navigation instructions provided by the symbols were clear, i.e., unambiguously comprehensible.”), annoyance (“The design of the symbols was annoying.”), distraction (“The design distracted me from the traffic.”), quality of 3D representation (“The 3D representation of the navigation symbols was well recognizable.”), interpretability (“The design of the symbols required a high degree of concentration in order to interpret them.”), and intuitiveness (“The design of the symbols was intuitive.”) on a 5-point Likert scale with the endpoints *fully disagree* and *fully agree*.

### 3. Results

Two-way (Concept [boomerang, arrow] x Variation [cut-off, no cut-off, tilt, 2D]) repeated measures ANOVAs were calculated to analyze all items separately. Greenhouse-Geisser corrections were applied in case of violations of sphericity. Post-hoc *t*-tests with Bonferroni-correction were calculated for all significant main effects of the factor variation.

The arrow concept was rated significantly more ambiguous than the boomerang concept,  $F(1,28)=4.84$ ,  $p<.001$ , as well as more difficult/effortful to interpret,  $F(1,28)=4.42$ ,  $p=.003$ , and less intuitive,  $F(1,28)=4.32$ ,  $p=.003$  (see Fig. 4). For all other items, no significant main effect of the concept was revealed.

The ANOVAs revealed a significant main effect of the design variation for the items attractiveness,  $F(3, 26) = 25.09$ ,  $p<.001$ , accuracy,  $F(3, 26) = 16.16$ ,  $p<.001$ , functionality,  $F(3, 26) = 14.09$ ,  $p<.001$ , clearness/unambiguousness,  $F(3, 26) = 8.64$ ,  $p<.001$ , annoyance,  $F(3, 26) = 27.66$ ,  $p<.001$ , distraction,  $F(3, 26) = 18.71$ ,  $p<.001$ , interpretability,  $F(3, 26) = 4.81$ ,  $p=.002$ , and intuitiveness,  $F(3, 26) = 8.77$ ,  $p<.001$ . The variations did not differ significantly from each other with respect to the quality of 3D representation.

As can be seen in Fig.5-7 and the indicated results from the Bonferroni-corrected post-hoc *t*-tests, the variation tilt was rated the least attractive, least accurate, least functional, most ambiguous, most difficult to interpret, and least intuitive compared to all other variations. The variations tilt and 2D were perceived as significantly more annoying and distracting than cut-off and no cut-off, as can be seen in Fig. 6 (b and c).

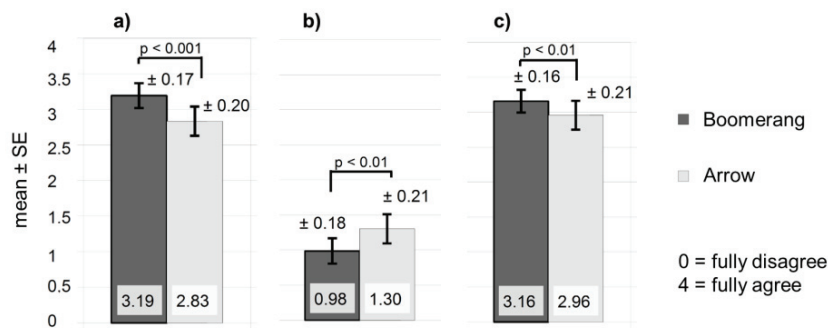


Fig. 4.(a) Clearness/Unambiguousness: “The navigation instructions provided by the symbols were clear, i.e., unambiguously comprehensible.”;(b) Interpretability: “The design of the symbols required a high degree of concentration in order to interpret them.”; (c) Intuitiveness: “The design of the symbols was intuitive.”

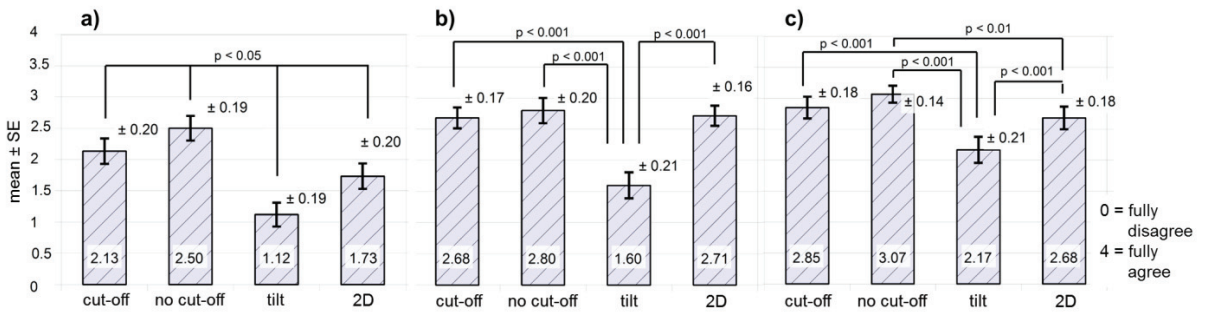


Fig. 5. (a) Attractiveness: “The design of the navigation symbol was attractive.”; (b) Positional Accuracy: “The navigation symbols were displayed at the correct location in the environment.”; (c) Functionality: “The design of the symbols was functional.”

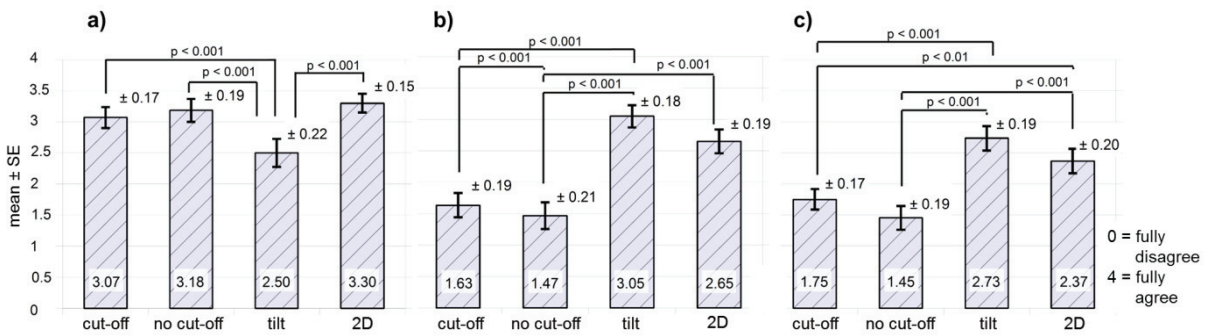


Fig. 6. (a) Clarity/Unambiguity: “The navigation instructions provided by the symbols were clearly/ unambiguously comprehensible.”; (b) Annoyance: “The design of the symbols was annoying.”; (c) Distraction: “The design distracted me from the traffic.”

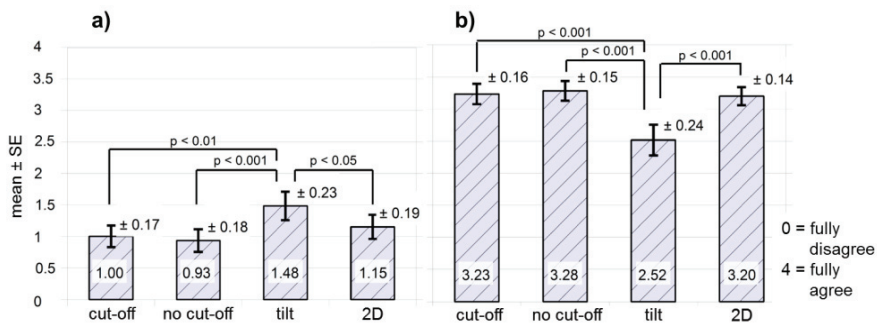


Fig. 7. (a) Interpretability: “The design of the symbols required a high degree of concentration in order to interpret them.”; (b) Intuitiveness: “The design of the symbols was intuitive.”

#### 4. Discussion

In the current study, different display concepts and design variations for contact analog navigation in a HUD were compared in light of current technological limitations of automotive cHUD systems. Although participants were not actively driving, the advantage of the experimental setup over a driving simulator was the realization of an augmented reality scenario with the virtual image of the cHUD overlaid on the video recording of a driving scene. In most driving simulator studies, cHUDs are also only simulated by integrating the symbols directly into the simulation environment.

Significant differences between the two navigation display concepts were only revealed for clearness/unambiguousness, interpretability, and intuitiveness. For each of the three items, the boomerang concept was preferred over the arrow concept. One possible reason is that the continuous, extensive, and rather salient arrow bears a greater risk of interfering with the driver's perception of the traffic scene than the string of boomerangs due to masking or attentional and cognitive capture [12,15]. This should be verified in a future study, which also takes into account objective measures of driving performance and attention.

For eight of the nine items, significant differences between the design variations were revealed. All in all, the variation tilt received significantly worse ratings than all other variations. Only for distraction and annoyance, tilt and 2D were both rated significantly worse than the other two variations. Based on the current results, the variation tilt can, therefore, not be recommended for the application in an automotive cHUD. With respect to a 2D symbol in addition to the contact analog symbol, it is possible that this combination might have caused disadvantageous display clutter [5,15]. Whether it is sensible to temporarily replace the contact analog navigation symbol by a static 2D representation in certain situations or to smoothly transform the 3D into a 2D representation is subject to further investigations. Interestingly, having the navigation symbol cut off by the horizontal borders of the virtual image did not have a negative impact on the ratings as might have been expected. It is possible that an additional animation/movement of the virtual symbol such as the tilt may have attracted the driver's attention more strongly than the cut due to the saliency of the movement [16]. Although animation can be purposefully used to direct attention e.g. to hazards, the animation in the context of navigation may have rather been perceived as distracting or annoying and may not have been intuitively understandable. This issue needs to be addressed in future investigations.

In general, as in a conventional HUD, display clutter and highly salient, obtrusive design of the AR information should also be avoided in a cHUD. Although a comparison of different cHUD display concepts for ACC has revealed surprisingly little differences between a minimalistic and a very salient, stimulating display concept concerning workload and standard deviation of the steering wheel [17], as virtual elements in the cHUD are presented in the driver's safety-critical primary field of vision, it is advised to only display information situationally and if desired by the driver.

#### 5. Conclusion

All in all, future research should aim at developing and evaluating guidelines for the safe and ergonomic design of display concepts for automotive cHUDs against the background of the characteristics of the information to be displayed, as well as the technological and environmental limitations. As the current study only included subjective ratings as dependent measures and was conducted in a laboratory setting, the results need to be validated in a naturalistic driving study using also metrics for driving and navigation performance. Future investigations should focus on the optimal design of different cHUD display concepts with respect to the driver's attention, workload, and driving performance, as well as usability and customer acceptance. While the current study focused on navigation only, the integration and prioritization of information from different ADAS needs to be addressed in future studies.

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