When does the driver benefit from AR-information in a navigation task compared to a Head-Up Display? Results of a driving simulator study

Kassandra Bauerfeind\textsuperscript{1}, Julia Drüke\textsuperscript{1}, Lennart Bendewald\textsuperscript{1}, & Martin Baumann\textsuperscript{2}  
\textsuperscript{1}Volkswagen Aktiengesellschaft - Group Research, \textsuperscript{2}Ulm University, Germany

Abstract

With Augmented Reality (AR), additional information can be presented to the driver, which is directly related to the environment. Thus, the driver can perceive and understand the information more easily. Especially when driving with a navigation system, this visual support can lead to an improved understanding of the route in ambiguous situations. The aim of the driving simulator study was to examine the effectiveness and acceptance of AR-information in a navigation task compared to a Head-up Display (HUD). While driving in an urban area, the driving task was to identify the correct destination street by means of navigation information presented either in the AR display or the HUD. The decision-point for the right destination street, navigation errors and subjective data were recorded (N = 59; 37.1 years, SD = 11.1 years). Results showed that while driving with the AR display, participants found the correct destination street significantly earlier compared to the HUD. Furthermore, the AR display led to reduced navigation errors compared to the HUD. The AR display was evaluated as “more useful” and as “a greater reduction” regarding mental load than the HUD. Recommendations for an adequate use of AR-information for navigation can be derived from this study.

Introduction

In the late 1950s, the first Head-Up Displays (HUD) were in development by the military to present flight relevant information in the pilot’s field-of-view (Newman, 1995; Prinzel & Risser, 2004). Because of this head-up transparent screen, a concurrent scanning of the provided information and the environment is possible. In 1988, this technology found its way into the automotive field (Weihrauch, Meloeny & Goesch, 1989). The projection of light into the windshield or on a specific combiner screen enables the presentation of information into the driver’s field-of-view. Instead of looking down to gather relevant information in the instrument cluster, like speed and navigation information, the driver is able to keep his “head up” and receive all the necessary information on the bottom of his visual field. Since there is no need of looking down, driver glances away from the road can be reduced. Kim et al. (2013) indicated that glances away from the road can lead to divided attention, which can distract from the driving task and may therefore increase the risk of accidents. However, the presented information in a HUD are not directly
related to the environment. The driver has to map the information, hovering above the bonnet, to the real traffic situation. For the mapping a focal re-accommodation is necessary. Through the new technology of Augmented Reality displays (AR display) this mapping is highly facilitated. Augmented Reality enables to enrich the environment with virtual information, which is perspective correctly superimposed with the relevant objects in the environment. The user gets the impression that specific objects can be marked in the environment. Because of spatial closeness of real and virtual objects, a fast and easy comprehensibility of information is possible. Furthermore, eyes can dispense with a focal accommodation beyond the distance of 10 meters (Cutting & Vishton, 1995). This is why an accommodation is not necessary in the interaction with AR-information.

Kim et al. (2013) and Tönnis (2008) determined that AR displays are suitable for warning systems since reaction times can be decreased. Rusch et al. (2013) found out that AR displays are efficient in leading drivers’ attention to critical traffic events and objects as well as supporting them in detecting them. Because of the superimposition, the mapping of the presented information to the real traffic situation is facilitated. According to Bengler et al. (2015) and Pfannmüller et al. (2015) AR displays are supposed to require less mental effort regarding understanding and interpreting information in comparison to HUDs or map material (Kim & Dey, 2009), since the virtual information is already placed into the environment. As AR enables the driver to dispense with switching between the relevant information and the real traffic situation, this technology is also suitable for presenting navigation information to the driver. Because of the appearance of spatial proximity of the presented navigation information and the real street, the driver should benefit especially in a navigation task from the visual assistance through AR. According to Kim and Dey (2009) AR displays can help to reduce navigation errors and divided attention. It is expected that AR displays are particularly beneficial in ambiguous situations, for instance complex intersections or turning scenarios with many possible turns, which are very close to each other.

It is to be investigated to which extent the visual support of AR can lead to an improved understanding of the route especially in ambiguous situations. Thus, if finding the right destination is simplified with an AR display comparing to a HUD. Furthermore, it has to be determined whether navigation errors can be reduced with an AR display. It is assumed that drivers are able to decide earlier for the destination street in a navigation task than when driving with a HUD. Drivers are assumed to make less navigation errors (deciding for the wrong destination) with an AR display, than when driving with a HUD. The experiment was designed to examine the effectiveness and acceptance of an AR display compared to a HUD in an ambiguous navigation scenario. While driving in an urban area, the driving task was to identify the correct destination street by means of navigation information presented in the AR display or in the HUD.
Method

Navigation displays: HUD and AR display

In this study the two display types HUD vs. AR display were compared (see Fig. 1). The HUD is the current model version from AUDI with a perceived projection distance of about 1-2 meters, hovering above the bonnet. The projected picture in the HUD appears in 2D. In the study 300 m before the destination street the HUD presented navigation information in terms of a straight blue arrow to the driver (see Fig. 1, left). The turning direction (right or left) was presented to the driver once 80 m before the destination street is passed (see Fig. 1, left (2) & (3)). In contrast, with the AR display the driver experienced the augmented picture to be superimposed in his driving environment (see Fig. 1, right). The picture seems to be placed into the specific area in the surroundings, giving the impression to be a turquoise 3D arrow. This arrow was visible 300 m before the destination street and did not change when approaching the destination.

Driving scenario and driving task

In the study an urban driving scenario was used. Participants started by entering an urban area with many intersections on a straight road without any traffic lights. The intersections were 40 m apart. There were no other road users on the streets. Participants were asked to respect the road traffic regulations (50 km/h in cities). Each drive took about 1 min and 30 sec. The task was to identify the correct destination street by means of navigation information presented in the display (HUD or AR display). Because of the minor distance between the intersections the navigation task was ambiguous. The participants were asked to find the correct destination street. To detect this moment of identification, they had to switch off the display by pressing a specific button on the steering wheel (see Fig. 2). The experimenter emphasized to be able to ensure hitting the right destination street,
when switching off the display. Furthermore, the participants had to navigate to the destination. They received feedback concerning the correctness of their choice (right or wrong) by the experimenter. In case of a navigation error, they were not told which street was the correct one and had to repeat the scenario.

**Additional task**

In addition to the navigation task, the participants had to perform an auditory cognitive, spatial non-driving-related task. This was done to raise the drivers’ mental load, as the driving scenario was very easy when driving on a straight main road without other traffic. In the non-driving-related task the participants heard positive numbers from one to nine out of two speakers, one in front and one behind the mock-up. The task was to rate every number by answering “right” when hearing even numbers from the front speaker as well as odd numbers from the back speaker. Participants had to say “wrong” when hearing odd numbers from the front speaker as well as even numbers from the back speaker. The interval of the numbers was two seconds. The correctness of this task was recorded. The results of the non-driving-related task is not focused in this paper.

![Figure 2](image)

*Figure 2. The red circle marks the button on the steering wheel, which the participants needed to press to switch off the display when deciding for the correct destination street.*

**Static driving simulator**

The study was conducted in a static driving simulator with a mock-up from the Group Research of Volkswagen Aktiengesellschaft, equipped with an automatic gear and one projection screen 3.8 m in front of the mock-up. The projection screen’s width was 3.8 m and the resolution of the projector was 1920 x 1200 pixels. A 56° field of view was covered. The simulation was implemented with the software Virtual Test Drive (VIRES Simulationstechnologie GmbH, 2014). The two display types (HUD and AR display) were realised with the software Unity and were projected by a separate projector. The participants were able to experience the simulated world as well as the navigation information in the display in 3D due to a stereo simulation and shutter glasses.
Participants

The sample included 61 drivers. Because of simulator sickness and the lack of 3D-vision, data of 59 participants were analysed (18 female). The participants were on average 37.1 years old (SD = 11.1 years) and drove 18274.7 km per year (SD = 11368.9 km). 44% of the participants had gained experience with a HUD, whereas the majority indicated to rarely use it. The participants were recruited from the test driver pool of Volkswagen Group Research.

Experimental design

In the study a within-subjects design was used (see Fig. 3). Half of the participants started with the HUD in seven drives, followed by seven drives with the AR display. The other half of the group drove the two display types the other way around. Each drive lasted about 1 minute and 30 seconds.

Figure 3. Experimental setup of the driving simulator study.

In the study (1) the decision-point of the correct destination street, (2) navigation errors and (3) subjective data about the evaluation of the display types were recorded (see Fig. 3). The decision-point defines the distance to the destination street, by switching off the display. For the analysis, the last three drives out of seven drives per participant were considered. This was done to ensure that the participants were familiar with the task of switching off the display as soon as they identified the correct destination street. For analysing this data, a t-test for dependent samples was used. Furthermore, the navigation errors were determined. Deciding for the wrong destination street was counted as a navigation error and the participant had to repeat this drive at the end of the correspondent display type session. For the analysis, a Wilcoxon-signed-rank test was used. After the seven drives per display type, participants got an evaluation questionnaire, consisting of closed and open questions. The closed questions were answered with a 15-Point rating scale (Heller, 1982) (see Table 1 and Fig. 4). In addition to the evaluation questions, participants also rated the non-driving-related task as well as the driving situation after each drive. In the beginning of the study, they stated socio-demographic information,
such as age, gender, use of visual aids and right- or left-handed and gave information about their condition. Data were analysed using repeated measures Analysis of Variance (rmANOVA) to examine the effects of display type (HUD vs. AR display) and the order of test condition (starting with HUD vs. starting with AR display) as between subject factor.

Table 1. Examples of items from the evaluation questionnaire regarding the display types.

<table>
<thead>
<tr>
<th>Category</th>
<th>Item</th>
</tr>
</thead>
<tbody>
<tr>
<td>appropriateness</td>
<td>“How appropriate was the display for the navigation task?”</td>
</tr>
<tr>
<td>reduction of mental load</td>
<td>“How strong did the display reduce your mental load?”</td>
</tr>
<tr>
<td>usefulness</td>
<td>“How useful was the display for the navigation task?”</td>
</tr>
<tr>
<td>like/dislike</td>
<td>“How much do you like the display for the navigation task?”</td>
</tr>
<tr>
<td>comprehensibility</td>
<td>“How comprehensible was the display for the navigation task?”</td>
</tr>
<tr>
<td>comfort</td>
<td>“How pleasant was it with the display in the navigation task?”</td>
</tr>
</tbody>
</table>

![Figure 4](image)

Figure 4. 15-point rating scale according to Heller (1982) with regard to the question: How useful was the display for the navigation task?

Procedure

In the beginning of the experiment, the participants stated the socio-demographic questions. They were also tested on stereo vision with the Butterfly Stereo Acuity Test (VAC Vision Assessment Corporation, 2007) and on colour vision. The participants were allowed to wear their own glasses underneath the shutter glasses, which enabled them to see the simulation in 3D.

The navigation task and the non-driving-related task were explained to the participants. Furthermore, they were instructed concerning the button at the steering wheel to switch off the display when they were sure they found the right destination street. After training the navigation task, they practiced the non-driving-related task without driving. Finally, they practiced both tasks simultaneously. The participants fulfilled the training till they were sure to manage the navigation task with each display type. After the training the experiment began. Half of the participants started with the HUD, followed by the AR display and the other half started with the AR display. They completed the two sessions, each with seven drives. In case of a navigation error (identifying the wrong destination street), they had to repeat the drive at the end of the respective display session. After each drive, participants also rated the non-driving-related task as well as the driving situation. Furthermore, they evaluated the two display types by the questionnaire after each display session. The participants received a present for their participation.
Results

Decision-point for finding the right destination street

The t-test for dependent samples showed that on average participants with the AR display switched off the display 69.5 m (SE = 2.8 m) before the destination street compared to 39.9 m when driving with the HUD (SE = 1.8 m), $t(56) = -13.71, p < .001, r = .88$ (see Fig. 5).

![Figure 5. Boxplots of the decision-point for finding the right destination street of all participants for the last three drives per display type (N = 59).](image)

Navigation errors

Navigation errors were not normally distributed, as assessed by the Shapiro-Wilk-Test, $p < .001$. Results of a Wilcoxon signed-rank test showed that driving with an AR display ($Mdn = 0.10$) lead to significant less navigation errors in comparison to driving with the HUD ($Mdn = 1.03$), $z = -4.24, p < .001, r = -.39$ (see Fig. 6). With an AR display 53 participants made no navigation error, whereas with a HUD 31 participants were error-free. Furthermore, participants never made more than one navigation error when driving with an AR display.

Subjective evaluation

The participants rated the AR display significantly better than the HUD (see Fig. 7a-f). There was a significant main effect concerning appropriateness ($F(1, 57) = 138.90, p < .001, \eta^2_p = .71$). Thus, participants evaluated the AR display as more appropriate for the navigation task than the HUD (AR display: $M = 12.7, SD = 1.6$; HUD: $M = 8.0, SD = 2.7$) (see Fig. 7a). The interaction between display type x order of test condition was not significant ($F(1, 57) = 0.90, p > .10, \eta^2_p = .02$). Furthermore, there was a significant main effect concerning the reduction of mental load ($F(1, 57) = 130.39, p < .001, \eta^2_p = .70$; interaction display type x order of test condition, $F(1, 57) = 1.33, p > .10, \eta^2_p = .02$). Participants rated the AR display as a
greater reduction of mental load for the navigation task than the HUD (AR display: $M = 11.2, SD = 2.2$; HUD: $M = 7.3, SD = 2.4$) (see Fig. 7b). There was also a significant main effect concerning usefulness ($F(1, 57) = 74.37, p < .001, \eta_p^2 = .57$; interaction display type x order of test condition, $F(1, 57) = 0.08, p > .10, \eta_p^2 = .00$).

**Figure 6. Numbers of navigation errors (wrong destination street identified) of all participants ($N = 59$), 839 drives in total. AR display: $N = 53$ participants without navigation error, HUD: $N = 31$ participants without navigation error.**

Participants evaluated the AR display as more useful for the navigation task than the HUD (AR display: $M = 12.5, SD = 2.0$; HUD: $M = 8.6, SD = 2.9$) (see Fig. 7c). In addition, there was a significant main effect concerning like/dislike ($F(1, 57) = 214.74, p < .001, \eta_p^2 = .79$; interaction display type x order of test condition, $F(1, 57) = 2.36, p > .10, \eta_p^2 = .04$). Participants liked the AR display more for the navigation task than the HUD (AR display: $M = 11.9, SD = 2.3$; HUD: $M = 6.2 SD = 2.5$) (see Fig. 7d). Concerning comprehensibility there was also a significant main effect between the display types ($F(1, 57) = 67.33, p < .001, \eta_p^2 = .54$; interaction display type x order of test condition, $F(1, 57) = 0.13, p > .10, \eta_p^2 = .00$). Participants rated the AR display as more comprehensible for the navigation task than the HUD (AR display: $M = 12.9, SD = 1.8$; HUD: $M = 9.8, SD = 2.7$) (see Fig. 7e). Furthermore, there was a significant main effect concerning comfort ($F(1, 57) = 106.73, p < .001, \eta_p^2 = .65$; interaction display type x order of test condition, $F(1, 57) = 0.00, p > .10, \eta_p^2 = .00$). Participants evaluated the AR display as more pleasant for the navigation task than the HUD (AR display: $M = 12.4, SD = 1.8$; HUD: $M = 8.3, SD = 2.7$) (see Fig. 7f).

**Discussion**

The aim of this driving simulator study was to examine the effectiveness and acceptance of AR-information in a navigation task compared to a HUD. Since it is possible to present additional information to the driver, which are directly related to the environment, this technology could support the driver in particular in ambiguous situations, like complex intersections or close turning opportunities. Thus, the drivers should be able to find the correct destination street much earlier than when
benefitting from AR-information in a navigation task

driving with a HUD. As the marking of specific objects in the environment seems to be possible, this visual assistance provides an intuitive way of presenting and understanding the information. In the study it was also assumed that with an AR display less navigation errors will occur compared to the HUD.

Results of the study presented here confirmed that with the AR display the participants found the correct destination street much earlier compared to the HUD. According to the decision-point the participants found the correct street approximately 70 m before the intersection, in contrast to the HUD (40 m before the intersection). Because of the appearance of spatial proximity of the presented navigation information and the real street, the mapping is facilitated with AR. Participants seem to have an improved orientation in the traffic situation with the AR display than driving with the HUD. This can be confirmed regarding the

Figure 7. Boxplots of subjective evaluation regarding appropriateness, reduction of mental load, usefulness, like/dislike, comprehensibility, and comfort (N = 59), (1: low consent, 15: high consent on the specific item).
navigation errors: Participants showed less navigation errors when driving with the AR display. In the study of Kim and Dey (2009) the focus was on elderly drivers benefitting from AR-information regarding way finding. They made significantly less navigation errors with AR compared to map material in the centre console. It is also to note, that in the study presented here participants did not do more than one navigation error with the AR display. The AR display proved to present the information in an intuitive way, which implies this fast and easy comprehensibility of augmented information. Furthermore, in the study presented here participants preferred the AR display and rated this display type as more appropriate for the navigation task. This could be due to the fact, that they also evaluated the AR display as more comprehensible. As a result, they rated the AR display as more useful and as more pleasant than the HUD. The participants stated that driving with the AR display was a greater reduction of mental load. This is assumed by Bengler et al. (2015), Kim and Dey (2009) and Pfannmüller et al. (2015).

In regard to the limitations of this study, it has to be mentioned that in the driving scenario there was no other traffic on the street. The participants could decide for the right destination street without paying attention to other vehicles or pedestrians. This also implies that there was no masking of the destination street due to parked cars or heavy vehicles such as trucks. It would be interesting to investigate, whether drivers still benefit from AR-information, which are interfering with other road users. It has to be examined, whether the overlay of AR-information onto other road users still serve as a visual aid in navigation or might rather produce an information overload. Thus, the interaction with AR-information in a more realistic navigation scenario has to be examined. Object of a future study will be the investigation of the effectiveness and the acceptance of AR-information in a navigation task with different traffic density conditions. Results should also be validated in an on-road driving study.

According to further limitations of the study, the timing of presenting turning information in the two display types has to be considered. The HUD was based on a current version, which implied the time of presenting turning information to the driver (turning right or left). In the study, this information was presented once 80 m before the destination street was passed. In contrast, an AR display presented information concerning the turning direction from the very first moment the display turns visible (300 m before the destination street). Presenting relevant information directly at the place of the event, thus as early as possible, is a benefit of Augmented Reality, which makes the comparison with a HUD difficult. However, despite this early moment of presenting turning information in the AR display, the participants had to approach the ambiguous situation to perceive the exact localization of the AR-arrow. Future studies should concentrate on the time-wise comparability of presenting relevant information in these two display types.

Conclusion

In conclusion, this study contributes to a better understanding of drivers’ interaction with AR-information in a navigation task in comparison to a HUD. Results have confirmed that drivers can benefit from AR-information as this visual assistance provides an intuitive way of presenting information and thus a fast and easy
benefitting from AR-information in a navigation task

understanding for the driver. Especially in ambiguous situations, this technology supports the driver by a better orientation in the navigation task. The results have shown that the drivers recognized the right path much earlier and they made less navigation errors than with a HUD. Overall, this study supports the acceptance and effectiveness of an AR display in an ambiguous navigation task. Recommendations concerning the time-wise presentation of AR-information for an adequate use in navigation can be derived from this study. However, further research is needed to investigate other aspects of environmental factors on drivers’ interaction with AR-information. For instance, the effect of traffic density on the effectiveness of AR-information is necessary to examine. Furthermore, other information types such as warnings or system intervention (e.g. from advanced driver assistance systems) need to be investigated in future studies, as this study focused on navigation. Only with an overall understanding of the role of AR during driving, recommendations for an adequate use to support the driver will be possible.

References


