# Presenting Information on the Driver's Demand on a Head-Up Display

Renate Haeuslschmid(✉), Christopher Klaus, and Andreas Butz

LMU Munich, Munich, Germany
renate.haeuslschmid@ifi.lmu.de

**Abstract.** Head-up displays present driving-related information close to the road scene. The content is readily accessible, but potentially clutters the driver's view and occludes important parts. This can lead to distraction and negatively influence driving performance. Superimposing display content only on demand – triggered by the driver whenever needed – might provide a good tradeoff between the accessibility of relevant information and the distraction caused by its display. In this paper we present a driving simulator study that investigated the influence of the self-triggered superimposition on workload, distraction and performance. In particular, we compared a gaze-based and a manually triggered superimposition with the permanent display of information and a baseline (speedometer only). We presented four pieces of information with different relevance and update frequency to the driver. We found an increased workload and distraction for the gaze- and manually triggered HUDs as well as an impact on user experience. Participants preferred to have the HUD displayed permanently and with only little content.

**Keywords:** Head-up display · Information on demand · Gaze interaction

## 1 Introduction

Head-up displays (HUDs) present driving-related information within the windshield area at an increased distance of approximately 2 m from the driver. This lets the driver read the HUD content faster because she can switch faster back and forth between the road scene and the display. In addition, it allows the driver to perceive the road scene ahead with peripheral vision when reading the HUD and thereby maintain a better lane position [7,11]. Compared to head-down displays (HDDs), drivers spend less time looking at the HUD than at HDDs [1,8,19] but still show faster reaction times [6,23]. To exploit those benefits it seems like an obvious choice to transfer more information onto the head-up display – especially information that is accessed frequently.

However, the HUD's location also increases the risk of distraction. Drivers cannot process the HUD content and the road scene simultaneously and hence show higher reaction times to road events when reading the HUD [12]. The HUD can capture the drivers' cognitive and visual attention ('cognitive capture'


R. Bernhaupt et al. (Eds.): INTERACT 2017, Part II, LNCS 10514, pp. 245–262, 2017.
DOI: 10.1007/978-3-319-67684-5_15


**Fig. 1.** A participant on the baseline track with a permanently displayed speedometer.

and 'tunnel vision') and leave too little resources for the driving task without the driver being aware of it [21,22]. This is related to change and inattentional blindness where the driver misses appearing or changing objects despite looking in their direction [24], e.g., driving directly into congested traffic without noticing [2].

The information usually presented on a HUD is relevant for driving and meant to increase safety by informing the driver, e.g., warning of hazards. But this additional information also increases the driver's load – potentially in a situation that is already highly demanding. The driver may actually react with an immediate glance away from the road simply when the content is updated [17]. Salient information or objects can capture the driver's attention, independently of their current urgency or relevance [15,18,20]. In addition, the HUD content can clutter the driver's view and occlude important parts of the driving scene, in turn causing distraction or an impeded perception of the surroundings.

To make use of the benefits of the well-accessible display location and at the same time decrease the risk of distraction of the continuously visible information, we propose to display the HUD content only on demand when the driver explicitly triggers it. We propose two methods to trigger the superimposition of the head-up display content: triggered by a glance into the HUD area and triggered by a shift paddle on the steering wheel. We compare these two methods with a permanent display and a baseline and measure the driving performance, user experience and the driver's workload and preferences.

## 2 Interaction Techniques in the Car

Contemporary cars provide a variety of input techniques. Each technique has characteristic advantages and disadvantages and hence a specific area of use. Kern et al. [10] analyzed modern cars (in 2007) regarding the integrated input modalities and developed a design space based on their findings. Haeuslschmid et al. [3] updated this design space (in 2016) specifically for head-up displays and proposed the following categories: touch & controls, gestures, speech, and gaze.

The group of *touch & controls* comprises haptic and hand-controlled input devices such as buttons, switches, multi-functional controllers, and touch screens. When placed on the steering wheel, the driver can leave both hands on the wheel while interacting with the car – which is considered safer than driving with one hand only. While drivers have learned to handle standard controllers blindly, touch interaction requires the driver to look at the display. Touch screens are still very limited in giving haptic feedback to the user and the corresponding interface and controller layout makes blind use almost impossible. As argued by Haeuslschmid et al. [3], touch interaction can only be applied to head-up displays in combination with an additional touch surface that controls the HUD remotely; touch is not applicable to the HUD itself.

The first cars with *gesture interaction* are currently entering the market; e.g. BMW series 7[1]. The midair gestures force the driver to remove one hand from the steering wheel but can be performed blindly without searching for a controller. This input technique is still developing and it remains unclear whether it is really practicable for in-car use. The gesture set is limited as the driver has to learn it by heart and seems to be applicable to only a small set of functions.

Similarly to gestures, *speech interaction* also shows potential for improvement. Speech interaction allows the driver to keep both hands and eyes focused on the driving task and is very suitable for text input but rather hard to use for object selection and manipulation [3] – the interaction procedure may become very long and cumbersome. Natural language understanding is a challenging task, especially in a noisy environment such as the car.

To our knowledge, there is no car on the market using *gaze interaction* as an explicit input method: The driver's gaze is monitored, e.g., for drowsiness warnings [25,26], but the driver can not actively select or manipulate in-car interfaces. Pomarjanschi et al. [18] showed that an assistance system that guides the drivers' gaze towards hazards leads to shorter reaction times to the event and a reduced gaze variation afterwards. The authors argue that gaze guidance can enhance driving behavior and increase safety. Haeuslschmid et al. [4] compared screen-fixed hazard warnings on a typical HUD to world-fixed – presumably gaze-guiding – ones and reported that the world-fixed warnings let the driver spend more time monitoring the driving scene, which suggests increased safety. Kern et al. [9] and Poitschke et al. [16] investigated gaze interaction as an active

[1] http://www.bmwblog.com/2016/01/05/new-control-concepts-from-bmw-showcased-in-new-7-series/; Accessed 30 Jan 2017.

interaction method for cars. Kern et al. [9] investigated an input technique that combines gaze- and button-interaction and compared it with speech interaction and conventional touch interaction. The driver's gaze point is used to preselect objects on a screen. By pressing a button on the steering wheel the driver can then confirm this selection. They found that the combined variant is slightly slower than the touch screen but significantly faster than speech interaction. It was further found to be more distracting than touch interaction. Poitschke et al. [16] compared gaze-based interaction with conventional touch interaction regarding task completion time, distraction and cognitive load. The authors found lower task completion times for gaze interaction, especially in situations with low demand. They also reported higher reaction times for gaze interaction than for the touch variant, However, the opposite was found for gaze experts. They argued that untrained users tended to stare at the objects and devoted their entire attention to it while trained users did not think about the process and acted fast. The participants rated gaze interaction more desirable and less demanding. We decided to test gaze interaction and shift paddle interaction in our study since both do not require the driver to remove a hand from the steering wheel. Gaze interaction seems to be a promising new interaction technique and is obvious since the driver needs to look at the display anyway in order to read it. Controller-based interaction is well-established and easy to use. Both, gaze and shift paddle, can be matched to the two status of HUD hidden/displayed easily and naturally. Speech interaction would require two commands and does not suggest a natural way of switching between the two states.

## 3 User Study

### 3.1 Pilot Study

We performed a pilot study in order to optimize the HUD application and implementation. We recruited six volunteers explicitly for the pilot study. The experienced a familiarization drive, driving with speedometer only, the permanent display as well as three information on demand concepts: shift paddle-triggered and two variants of gaze-triggered displays: A glance into the HUD area superimposes (1) the entire content (one large gaze-sensitive area) and (2) only the piece of information placed close to the gaze-point (four separate gaze-sensitive areas). While the first approach is comparable to the other display conditions regarding amount of and search for information (and the related distraction), the latter presents less information but rather requires knowledge about the location of the information and hence might lead to different search behavior.

By running this pilot study, we also evaluated the overall study design, the test setup and the reliability of the eye tracker. However, the major aim of the pilot study was to select one gaze interaction approach. The questionnaires as well as the individual feedback showed that there is a clear tendency towards the gaze interaction variant which controls the entire HUD content. Consequently, we decided to test this variant in the subsequent user study. Based on the results of the pilot study we also increased the distance between the gaze-sensitive area and the driving task by shifting it further to the lower edge of the display.

### 3.2 Participants

We recruited 20 participants by means of social networks. Our participants were on average 24 years old (SD = 2.4) and 18 of them owned a valid drivers license. Five participants had previously used a head-up display.

### 3.3 Study Design

We designed a within-subjects driving simulator study with four conditions: baseline (speedometer only), permanent display, gaze-triggered display, and shift paddle-triggered display of the HUD content. This corresponds to four driving tracks and one additional introductory familiarization drive. Therefore, we developed five different driving tracks. Each of them consisted of one individual driving video and a computer-generated ConTRe task (motion of arrow and brake light timing). The driving tracks were assigned in a counter-balanced way (Latin Square) to the display conditions. The order of the test tracks was also counter-balanced and participants were assigned randomly to one group. Each test track lasted 3 min; leading to an overall study duration of 60 min.

The aim of this study was to explore the user experience of information displayed on demand – triggered by gaze and a shift paddle. Therefore, we had to ensure that participants use the HUD and read the content frequently: We asked them to report changes in the HUD content verbally by naming the type of information that changed (except for the speedometer) and required driving at a constant speed (for which they had to use the speedometer). As for the secondary HUD monitoring task, we only measured the detected changes as the success rate. Since we did not aim to evaluate the information design or its memorability and since the comparability (of complexity and hence workload/distraction) of three content sets could not be ensured, we decided to use the same information set in all three HUD conditions. To avoid predictability, we altered the update timing of each piece of information for each driving track. To evaluate the driver's workload and user experience, we chose the NASA TLX[2] and UEQ[3] questionnaires. Furthermore, we designed an individual questionnaire that collects data about the driver's preferences and compares the four conditions directly.

*Driving Task.* We based our driving task on the continuous tracking and reaction task (ConTRe task) developed by Mahr et al. [13]. Instead of maneuvering a simulated car within the lane boundaries, the driver steers a cylinder ('self') to overlay another autonomously moving cylinder ('reference'). A red and a green light, similar to a traffic light, are placed above the autonomous cylinder and require an immediate braking or acceleration reaction of the driver when

[2] https://humansystems.arc.nasa.gov/groups/tlx/.
[3] http://www.ueq-online.org/.

switched on. We designed the task to be moderately hard according to the definitions of Mahr et al. [13]. The autonomous bar moves to 9 random positions within the lane boundaries per minute and remains at one position for 0 to 3 s. We adapted the standard task to our user study in order to reach a more realistic feeling of driving and a better interplay with the HUD information. Instead of an automated driving at a certain speed, we required a continuous control of the gas pedal for speed control and requested the participants to drive at a constant speed (120 km/h). Since additionally reacting to both green and red lights (according to the suggested timing) would be overwhelming and the mixed use of the gas pedal for speed control and traffic light response would be confusing, we decided to only collect the driver's response performance by the red light and limit the gas pedal to the speed control. The red light is turned on four times per minute: When the light switches on, the driver has to brake immediately; when it switches off (after 1 s), the driver has to accelerate to 120 km/h again. This allowed for the use of a speedometer – an information that changes continuously and has to be accessed frequently in order to reach a high driving performance – as head-up display content. We further used two arrows pointing at each other instead of two cylinders since we assume that this could lead to more precise steering.

The standard ConTRe task disconnects the steering behavior and the car's motion in the simulated world. This allows the use of footage of real driving instead of a simulated world. We recorded footage (30 fps, 1280 × 720 resolution) of driving on a straight highway with a speed of approximately 100 km/h. These videos were used in our driving simulator as a background scene; with an adjusted frame rate these videos were appropriate to simulate driving at a speed of 120 km/h. The participants received feedback about the current speed through the playback of the video; when they lowered the speed, the videos were played back slower. The speed decreased naturally by 1 km/h per second.

*Head-Up Display Content.* We selected four pieces of information with varying relevance for the driving task as well as varying update frequencies from 10 to 30 s, as depicted in Fig. 2. We selected information with low to high relevance for the driving task or the driver as a person based on the categorization for information according to its contexts [5]. Further, we chose continuous to singular updating, as we expect that the different display conditions might be suitable for different types of information.

1. **Speed:** The speedometer adjusts continuously to the gas pedal pressure and has to be monitored consistently. This information is available in all four conditions since it is of high relevance for the driving task, as in real driving.
2. **Personal message:** The personal message is of low relevance for driving but might be of high relevance for the driver. Its content is adjusted twice during each driving track.
3. **Gas:** The filling of the gas tank is of medium relevance for the driving task. Its value is designed to decrease naturally and changes 4 times during each driving track.

4. **Weather:** The weather information is of low relevance (as long as there is no risk of icy roads) and by nature very constant throughout the study duration. Consequently, this information was not updated.

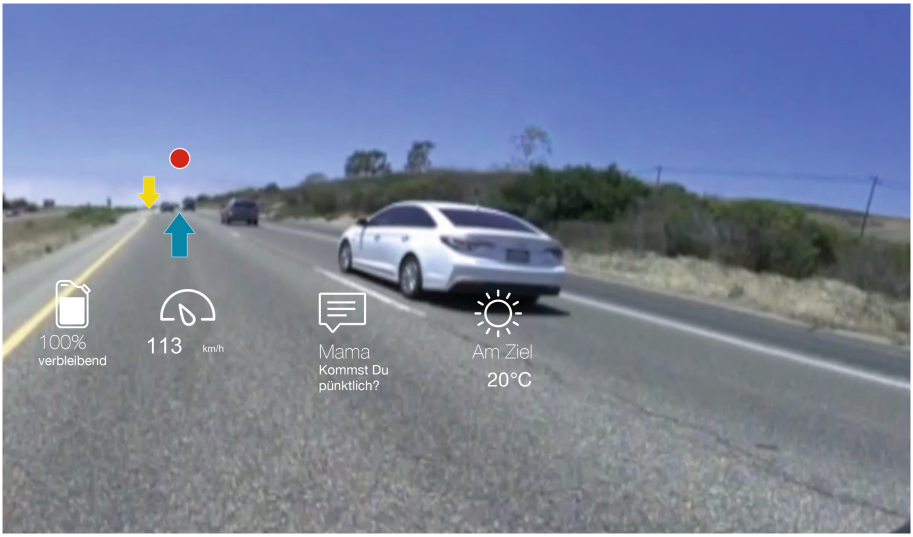


**Fig. 2.** An example view of the driver. The driving simulator software runs an adjusted version of the ConTRe task and footage of real driving with superimposed HUD content.

The HUD information was placed in an area of −6° to 13° horizontally and −3° to 6° vertically. The vanishing point of the street constitutes 0°. These values also defined the gaze-sensitive area; a glance into this area superimposed the HUD content. In both information on demand conditions, the content was superimposed with a defined delay of 300 ms in order to avoid unintended display due to uncontrolled glance behavior. When the driver's gaze left the sensitive area or the shift paddle was released, the content remained visible for an additional 500 ms before it blanked out. The position of each piece of information is the same in each condition in order to avoid confusion or an implicit evaluation of the information placement: gas at −4°, speedometer at 0°, message at 6°, weather at 12° horizontally (corresponding to the center of the item).

### 3.4 Procedure

In a first step, participants had to complete a demographic questionnaire. Then, the experimenter introduced them to head-up displays in general and to the study goals and procedure. The experimenter asked the participants to take a seat in the setup and calibrated the eye tracker. The study started with a test drive during which participants familiarized themselves with the driving task and the setup. In the process, the experimenter explained the driving task in detail and instructed the participants to only use the right foot to control the pedals, as in a real automatic car. Then participants were introduced to the HUD information and asked to report content changes verbally. The participants then performed the four test tracks and filled in the UEQ and the NASA TLX questionnaires after each of them. After the study, they were asked to fill a final questionnaire.

### 3.5 Apparatus

Our test setup (see Fig. 1) used a 42″ display (1920 × 1080 px resolution) for the presentation of the driving simulator and a gaming steering wheel with pedals (Speedlink Drift O.Z.) for its control. The head-up display content was presented on the display and controllable through shift paddles and gaze. Two shift paddles were attached to the back side of the steering wheel, enabling interaction with both hands. The gaze interaction was realized by means of a Tobii REX eye tracker which was placed behind the steering wheel. The display was positioned at a distance of 1.65 m to the driver and shifted to the right (as was the windshield). The vanishing point of the road was set to be straight in front of the driver. Our driving simulator was based on footage of driving on a straight highway and the continuous tracking and reaction task (ConTRe task). We implemented the driving simulator, the head-up display and the interaction techniques in a single monolithic Java application.

## 4 Results

### 4.1 Driving Performance

To evaluate the driving performance, we measured the participants' accuracy in steering as well as the brake light reaction time and success rate. The mean values and standard deviations are depicted in Table 1. We analyzed each metric by means of repeated measures ANOVAs with Bonferroni-adjusted $\alpha$-level.

**Table 1.** We measured the driving performance as steering accuracy and reaction time and success rate for the response to brake lights.

| Display condition | Steering | Reaction time (ms) | Success rate |
|---|---|---|---|
| Speedometer | M = 9.4, SD = 4.8 | M = 618, SD = 189 | M = 0.4, SD = 0.5 |
| Gaze-triggered | M = 15.3, SD = 11.1 | M = 792, SD = 252 | M = 2.0, SD = 2.2 |
| Shift paddle-triggered | M = 11.4, SD = 4.9 | M = 704, SD = 188 | M = 1.1, SD = 1.5 |
| Permanent display | M = 12.2, SD = 5.0 | M = 715, SD = 204 | M = 2.2, SD = 2.7 |

*Steering.* We measured the steering performance as the mean deviation between the reference arrow and the arrow representing the self. The ANOVA test showed a non-significant main effect ($F(1.6, 26.4) = 3.9$, $p = .042$). Post-hoc tests showed that driving with the speedometer only led to a significantly better steering performance compared to the permanent ($p = .009$), the gaze-triggered ($p = .014$), and the shift paddle-triggered HUD ($p = .05$). We did not find a difference between the two triggered HUDs. Neither we found a significant difference between the triggered HUD variants and the permanent HUD.

*Brake Light Reaction.* We measured the participants' reaction time to appearing brake lights as well as the missed brake lights. The ANOVA tests showed that the brake light reaction time ($F(3.0, 51.0) = 4.2$, $p = .009$) varied significantly. Post-hoc tests showed that the speedometer only variant leaded to significantly faster reaction times compared to the permanent HUD ($p = .033$), the shift paddle-triggered HUD ($p = .39$), and the gaze-triggered HUD ($p = .007$).

To analyze the missed brake lights, we performed a Friedman test with Wilcoxon post-hoc tests and found a significantly different success rate ($\chi^2(3) = 11.2$, $p = .011$). When driving with the speedometer only, the participants missed significantly fewer lights compared to the permanently displayed HUD ($Z = -2.6$, $p = 0.1$) and the gaze-triggered HUD ($Z = -2.8$, $p = .004$). Surprisingly, participants missed significantly fewer lights when driving with the shift paddle-triggered compared to the gaze-triggered HUD ($Z = 2.0$, $p = .048$).

### 4.2 HUD Monitoring Performance

We asked our participants to report updates of the HUD content verbally by naming the updated piece of information (e.g., 'message'). Overall, six updates occurred. A Friedman test with Bonferroni correction and Wilcoxon post-hoc tests showed a significant difference in update performance ($\chi^2(3) = 14.2$, $p = .001$). As expected, participants missed significantly more changes when information was displayed only on demand (gaze: $M = 1.2$, $SD = 1.2$, $p = .003$; shift paddle: $M = 1.4$, $SD = 1.4$, $p = .002$) compared to the permanent display ($M = 0.2$, $SD = 0.4$). There was no significant difference between the two self-triggered HUDs.

### 4.3 Workload

We measured the participants' workload by means of the standardized NASA-TLX questionnaire on a scale from 0 to 100; with 100 representing high workload. A repeated measures ANOVA showed that the workload depends on the display variants ($F(2.3, 39.7) = 5.9$, $p = .004$). We then analyzed this result by means of pairwise comparisons and found that the overall workload when using the gaze-triggered HUD ($p = .008$) and the shift paddle-triggered HUD ($p = .007$) is significantly higher compared to driving with the speedometer only. Although we did not find a statistically relevant result for the permanent display, the mean values indicates that it induces a workload level between the information-on-demand concepts and the baseline in our sample. Also, we did not find a statistically significant difference between the two self-triggered HUDs. The NASA-TLX is subdivided into the subscales mental demand, physical demand, temporal demand, overall performance, frustration level, and effort. We performed a repeated measures ANOVA with Bonferroni-adjusted $\alpha$-level for each of the subscales and depicted the mean values and standard deviations in Fig. 3.

*Mental Demand.* The ANOVA test showed a significant difference in mental demand ($F(2.7, 45.7) = 6.3$, $p = .002$): The gaze-triggered ($p = .002$) and the shift paddle-triggered HUD ($p = .001$) as well as the permanently displayed HUD ($p = .01$) led to a significantly higher mental demand compared to the baseline.

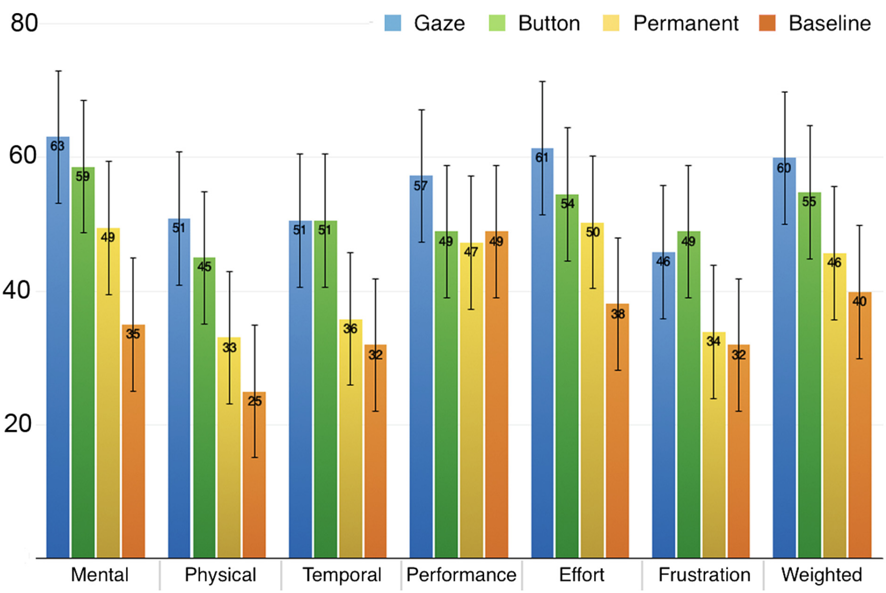


**Fig. 3.** The permanent HUDs induce the lowest workload; the more information is displayed the higher is the caused workload. The control of the HUD further increases the workload; the gaze-triggered HUD variant more than the shift paddle-triggered one.

*Physical Demand.* We found a significant influence of the display variant on the physical demand ($F(2.8, 47.6) = 7.7$, $p < .001$): The gaze-triggered ($p = .001$) and the shift paddle-triggered ($p = .003$) display as well as the permanently displayed HUD ($p = .04$) induced significantly higher physical demand compared to the baseline. Furthermore, the gaze-triggered information led to a higher physical workload than its permanent display ($p = .007$).

*Temporal Demand.* Also, the temporal demand depends on the display variant ($F(2.7, 46) = 4.4$, $p = .01$): The gaze-triggered ($p = .027$) and the shift paddle-triggered HUD ($p = .02$) led to a significantly higher temporal demand than driving with the speedometer only.

*Overall Performance.* The ANOVA test did not identify any statistically significant differences in the overall performance when using the HUD variants.

*Frustration Level.* We did not find a significant influence of the display variant on the frustration level. However, post-hoc tests showed that the shift paddle-triggered HUD leads to a higher frustration than the permanent HUD ($p = .02$) as well as the baseline ($p = .025$). We did not find a significantly higher frustration for the gaze-triggered HUD.

*Effort.* We found a significant effect of the display variants on the required effort ($F(3.0, 51.0) = 4.8$, $p = .005$): The participants had to invest significantly more effort when controlling the HUD with gaze ($p = .004$) and with shift paddle ($p = .014$) compared to the baseline. Also, the permanent display required more effort compared to the baseline ($p = .05$) by the participants. We rarely found statistically relevant results for the permanent display compared to the driver-triggered HUDs but the values indicate that the induced workload is between those and the speedometer only HUD in our sample.

### 4.4 User Experience

We applied the standardized UEQ questionnaire to measure the participants' experience when using the different display variants. The UEQ is subdivided into the aspects novelty, stimulation, dependability, efficiency, perspicuity, and attractiveness. The results for the single aspects are depicted in Fig. 4. We analyzed our data by means of Friedman and Wilcoxon tests and report the statistics below.

*Novelty.* We measured a significant difference for novelty of the four HUD variants ($\chi^2(3) = 17.9$, $p < .001$): The gaze interaction was rated the newest variant and received significantly higher values than the speedometer only HUD ($Z = -3.4$, $p = .001$) and also than the shift paddle-triggered variant ($Z = -2.0$, $p = .044$). Furthermore, we found a significant higher value for the shift paddle-triggered HUD compared to the baseline. ($Z = -2.3$, $p = .023$) The permanent variant with the full HUD content was also rated more innovative than the speedometer-only variant ($Z = -3.5$, $p < .001$).

*Stimulation.* We did not find any dependencies between the stimulation level and the display variants.

*Dependability.* We measured a significant difference in dependability ($\chi^2(3)$= 18.5, p< .001): We found a significantly lower dependability rating for the gaze-triggered HUD compared to the permanently displayed HUD (Z = −2.3, p = .024). Furthermore, the speedometer only HUD received significantly higher values than the shift paddle-triggered HUD (Z = −2.7, p = .007), the gaze-triggered HUD (Z = −3.5, p< .001), and also than the permanent HUD (Z = −2.6, p = .01).

*Efficiency.* The perceived efficiency varies nearly significantly when using the different HUD variants ($\chi^2(3)$ = 9.8, p = .021): The efficiency is rated lower for the gaze-triggered HUD (Z = −2.4, p = .017) and the shift paddle-triggered HUD (Z = −2.6, p = .009) compared to to the speedometer-only version. Surprisingly, the speedometer only HUD is perceived more efficient than the permanent HUD (Z = −2.5, p = .013).

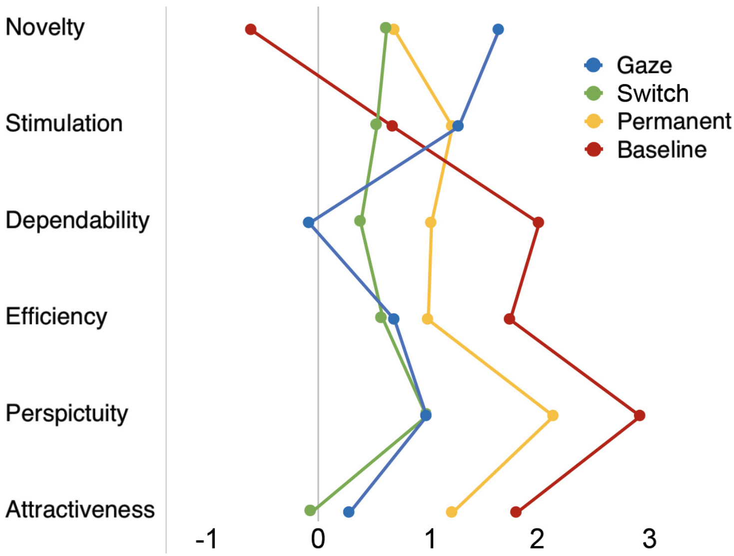


**Fig. 4.** The permanently displayed HUDs, and especially the variant with the speedometer only, provide a better user experience than the driver-triggered HUDs (UEQ results on a scale from −3 to 3).

*Perspicuity.* The perceived perspicuity varies significantly ($\chi^2(3)$ = 26.4, p< .000): The permanently displayed HUD received significantly higher values than the gaze-interaction (Z = −2.1, p = .034) and the shift paddle interaction (Z = −2.5, p = .013) conditions. Also, the speedometer only HUD received significantly higher values than the gaze-interaction (Z = −3.6, p< .001) and the shift paddle interaction (Z = −3.1, p = .002) as well as the permanent HUD (Z = −2.7, p = .006).

*Attractiveness.* The HUD variants differ significantly in attractiveness ($\chi^2(3) = 25.24$, $p < .001$): Participants found the two self-triggered HUDs less attractive than the speedometer only HUD (gaze: Z = −3.0, p = .003; switch: Z = −3.5, p < .001) as well as the permanent HUD (gaze: Z = −2.0, p = .047; switch: Z = −2.6, p < .008).

*Summary.* To sum this up, apart from *novelty* and *stimulation*, the minimal display of the speedometer led to the best user experience; followed by the permanent display of HUD. While gaze interaction was rated high for novelty and stimulation, it received comparably low values for the remaining aspects. The shift paddle-triggered variant received overall very neutral ratings.

## 4.5 Final Comparison and Qualitative Feedback

We used self-designed questionnaires with a 5-point Likert-scale (1–5) to gather insights into the participants' preferences and to collect qualitative feedback. Participants rated the driving task as medium realistic and demanding. The position of the HUD content felt intuitive and was easy to remember which suggests that there was no disadvantage in finding the information when it was presented only on demand.

The superimposition of information was more irritating for the participants when it was gaze-triggered (median = 4) and shift paddle-triggered (median = 3.5) compared to the permanent display (median = 2). The permanently displayed HUD was rated more distracting than the baseline (median = 1) but less distracting (median = 2) than the driver-triggered HUDs (median = 4).

Our participants felt less safe driving with the gaze-triggered HUD (median = 3) compared to all other conditions (median = 4). However, participants also stated that they played around more with the gaze interaction which suggests that the distraction and the perceived risk might be lower when participants are used to this interaction technique. The participants felt most in control of the HUD content when using the shift paddle-triggered variant (median = 5), closely followed by the permanent and the speedometer display (median = 4.5); our participants rated the feeling of control neutral when using the gaze-interaction (median = 3). The participants who stated that the gaze-triggered HUD was frequently displayed without their intend rated the gaze-triggered HUD lower in user experience and overall preferred the other HUD variants. A Spearman correlation showed that the likability of the gaze-triggered HUD correlates with the control over the display ($r_s = -0.579$, p = 0.012). The HUD information was displayed fast in all self-triggered HUD conditions (median = 5) but its access was faster in the permanent display (permanent:median = 5; gaze: median = 2.5; shift paddle: median = 4). Our participants mentioned that the gaze-controlled HUD superimposed information without their intent; showing need for improvement for our implementation but also potential for this interaction method in general. Further, they said that an acoustic feedback to content updates would be very helpful (permanent:median = 4; gaze: median = 4.5; shift paddle: median = 5).

Participants wanted to have the speedometer displayed on the HUD but are not as interested in other, non-driving related information and an explicitly triggered display. We expected that a combined version, e.g., a permanent speedometer which can be augmented with further information using gaze or a shift paddle, might be of interest to the participants but our results fail to support this thesis.

## 5 Summary and Interpretation of the Results

We conducted a driving simulator study on the potential of displaying an in-car head-up display only when explicitly triggered by the driver. We used the ConTRe task along with driving videos and adjusted it in order to reach a good compromise between study control and realism. As for the superimposition of the HUD we proposed two techniques: gaze- and shift paddle-based interaction.

This paper presents a first exploration of those two variants in a lab scenario but follow-up research should aim for a real world study. Below, we discuss our results as well as the limitations of the study design and setup and how we expect our results to hold in a real world scenario.

### 5.1 Discussion and General Limitations

The fact that participants reported most of the HUD content updates shows that they accessed the HUD and used the interaction methods. Hence, they are qualified to evaluate the tested HUD concepts. We found that driving performance was impeded by the head-up display and particularly by the gaze-triggered variant. This is not surprising since driving is a primarily visual task and hence driving and the HUD control competed for the visual attention. Participants stated that the information was superimposed fast when using the gaze interaction but also that it was displayed unintentionally, potentially leading to unwanted glances at the HUD. We expect that a more sophisticated eye tracking implementation may lead to better results, However, there will always be a delay between gaze shift and superimposition, which inevitably causes higher glance times.

Both the gaze- and the shift paddle-based interaction caused an increased workload. Although the difference to the permanent HUD display was not significant, values indicate consistently that a permanent display of the same amount of information requires less resources. Further, participants mentioned that they were able to concentrate most on driving when they were not in control of the HUD. We expected that the display of information only on demand could decrease the driver's workload but our results do not confirm this thesis. However, we think that the task of reporting the content updates forced the participants to access the information more often than they would do in real life. Also, a mixed approach – the permanent display of the speedometer and the superimposition of additional information – might further increase the demand.

The permanently displayed HUDs received higher user experience ratings than the information-on-demand concepts. For the gaze-triggered HUD we argue that a more reliable setup could improve the user experience. The implementation of the shift paddle-triggered HUD worked well and seven of our participants kept it triggered for longer than 20 s – utilizing it as a permanent display. In our opinion, it is questionable if a well-implemented information-on-demand approach can ever reach the user experience and workload level of a permanent display. We think that a long-term study is needed in order to find out whether and how the user behavior might change. Further, complementing the driver-triggered HUD with audio feedback might improve user experience and lower the workload.

### 5.2 Limitations of the Study Design and Setup

We performed a pilot study in order to validate our study design and setup and particularly to decide how to design the gaze-based interaction. Based on its results, we refined our study design and decided for a gaze interaction that controlled the entire HUD instead of single pieces of information. However, it seems that the eye-tracker had problems to track the eye gaze of some participants. Our results and the individual feedback from the participants indicated that it worked well for most of them but that the HUD content was occasionally displayed unintentionally for others. As we found that the likability of the gaze-triggered HUD depended on the control over the display, we think that a more sophisticated eye-tracker may lead to a higher rating in user experience.

Our study setup comprised one display for the driving simulator as well as the HUD content. The lack of distance between the road scene and the HUD content also disabled the foreground-background segregation which invites drivers to focus on the HUD [14]. Furthermore, it enabled the participants to switch faster between HUD and world and also to read the displayed information while visually focusing on the driving task (as mentioned by the participants). Also, our tasks forced participants to access the displayed information frequently – potentially more often than they would access it in real life. In a real car, participants might favor an explicitly triggered head-up display since the benefit of the simultaneous reading is lowered and the permanent display might be more distracting.

The switching times in a real car towards a real HUD will be higher than in our study. We assume they will be further increased for the gaze-triggered HUD compared to the shift paddle-triggered variant since the driver has to glance into the sensitive area but can only focus on the HUD once it is displayed. Presumably, the re-focusing in depth is separated from the glance into the HUD area – and potentially increases the switching time. This is not the case for the shift paddle-triggered HUD. Considering this and the better driving performance, we think that the shift paddle-triggered HUD is the safer alternative of the two.

The videos presented a real driving scene while driving simulators only present virtual and often unrealistic environments, e.g., without any other road users. The steering wheel did not affect the car's position in the world and gave feedback about the steering performance by adjusting the position of an arrow instead. Regarding the speed, the participants received feedback through the speed of the video playback. Our driving task differs from real driving – as every driving simulator does – however, our participants rated it as medium realistic.

## 6 Conclusions

The study presented in this paper explored the display of the HUD information only on demand – triggered by gaze or a shift paddle – and compared it to its permanent display. Our results show that the overall workload increased, although the information was displayed for a shorter time. Further, the user experience of the two information-on-demand variants was generally rated lower which might be caused by the eye-tracker. Participants rated the gaze- and shift paddle-triggered HUD as more distracting from the primary task. The fact that participants liked the speedometer-only HUD more than the full HUD content shows that they are generally not as interested in having driving-irrelevant information cluttering their view on the road. However, their statements indicate that a display on demand showing driving-related but not permanently needed information complemented with audio notifications might be more desirable. As follow-up research, we propose a real world study that utilizes a gaze- or shift paddle-triggered HUD. We further think, that a long-term study would be very interesting since prior research showed that gaze interaction becomes less demanding [12,16] and user behavior may change over time.

## References

1. Briziarelli, G., Allan, R.W.: The effect of a head-up speedometer on speeding behaviour. Percept. Mot. Skills (1989)
2. Dellis, E.: Automotive head-up displays: just around the corner. Automot. Eng. **96**(2) (1988)
3. Haeuslschmid, R., Pfleging, B., Alt, F.: A design space to support the development of windshield applications for the car. In: Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems, CHI 2016, pp. 5076–5091. ACM, New York (2016). http://doi.acm.org/10.1145/2858036.2858336
4. Haeuslschmid, R., Schnurr, L., Wagner, J., Butz, A.: Contact-analog warnings on windshield displays promote monitoring the road scene. In: Proceedings of the 7th International Conference on Automotive User Interfaces and Interactive Vehicular Applications, AutomotiveUI 2015, pp. 64–71. ACM, New York (2015). http://doi.acm.org/10.1145/2799250.2799274
5. Haeuslschmid, R., Shou, Y., O'Donovan, J., Burnett, G., Butz, A.: First steps towards a view management concept for large-sized head-up displays with continuous depth. In: Proceedings of the 8th International Conference on Automotive User Interfaces and Interactive Vehicular Applications, Automotive'UI 2016, pp. 1–8. ACM, New York (2016). http://doi.acm.org/10.1145/3003715.3005418
6. Iarish, I., Wickens, C.D.: Attention and huds: flying in the dark? In: Society for Information Display International Symposium Digest of Technical Papers, XXII, pp. 461–464 (1991)

7. Kaptein, N.A.: Benefits of in-car head-up displays, TNO report no.: TNO-TM 1994 B-20. Technical report, TNO Human Factors Research Institute (1994)
8. Kato, H., Ito, H., Shima, J., Imaizumi, M., Shibata, H.: Development of hologram head-up display. Technical report, SAE Technical Report Paper No. 92060 (1192)
9. Kern, D., Mahr, A., Castronovo, S., Schmidt, A., Müller, C.: Making use of drivers' glances onto the screen for explicit gaze-based interaction. In: Proceedings of the 2nd International Conference on Automotive User Interfaces and Interactive Vehicular Applications, AutomotiveUI 2010, pp. 110–116. ACM, New York (2010). http://doi.acm.org/10.1145/1969773.1969792
10. Kern, D., Schmidt, A.: Design space for driver-based automotive user interfaces. In: Proceedings of the 1st International Conference on Automotive User Interfaces and Interactive Vehicular Applications, AutomotiveUI 2009, pp. 3–10. ACM, New York (2009). http://doi.acm.org/10.1145/1620509.1620511
11. Kiefer, R.J.: Effect of a head-up versus head-down digital speedometer on visual sampling behaviour and speed control performance during daytime automobile driving. SAE technical report paper no. 910111. Technical report, SAE (1991)
12. Liu, Y.C.: Effects of using head-up display in automobile context on attention demand and driving performance. Displays **24**(4–5), 157–165 (2003). www.sciencedirect.com/science/article/pii/S0141938204000022
13. Mahr, A., Feld, M., Moniri, M.M., Math, R.: The ConTRe (continuous tracking and reaction) task: a flexible approach for assessing driver cognitive workload with high sensitivity. In: Adjunct Proceedings of the 4th International Conference on Automotive User Interfaces and Interactive Vehicular Applications (AutomotiveUI 2012), Portsmouth, NH, USA, pp. 88–91 (2012)
14. Mazza, V., Turatto, M., Umiltà, C.: Foreground-background segmentation and attention: a change blindness study. Psychol. Res. **69**(3), 201–210 (2005). http://dx.doi.org/10.1007/s00426-004-0174-9
15. Mulckhuyse, M., van Zoest, W., Theeuwes, J.: Capture of the eyes by relevant and irrelevant onsets. Exp. Brain Res. **186**, 225–235 (2008). Experimentelle Hirnforschung Experimentation Cerebrale
16. Poitschke, T., Laquai, F., Stamboliev, S., Rigoll, G.: Gaze-based interaction on multiple displays in an automotive environment. In: 2011 IEEE International Conference on Systems, Man, and Cybernetics, pp. 543–548, October 2011
17. Poitschke, T.M.: Blickbasierte Mensch-Maschine Interaktion im Automobil. Ph.D. thesis, Universität München (2011)
18. Pomarjanschi, L., Dorr, M., Barth, E.: Gaze guidance reduces the number of collisions with pedestrians in a driving simulator. ACM Trans. Interact. Intell. Syst. **1**(2), 8:1–8:14 (2012). http://doi.acm.org/10.1145/2070719.2070721
19. Sojourner, R., Antin, J.F.: The effects of a simulated head-up display speedometer on perceptual task performance. Hum. Factors **32**(3), 329–339 (1990)
20. Theeuwes, J., Kramer, A.F., Hahn, S., Irwin, D.E.: Our eyes do not always go where we want them to go: capture of the eyes by new objects. Psychol. Sci. **9**, 379–385 (1998)
21. Trent, V.: Keeping eye and mind on the road. Ph.D. thesis, Uppsala University (2005)
22. Weintraub, D.J.: HUDs, HMDs and common sense: polishing virtual images. Hum. Factors Soc. Bull. **30**, 1–3 (1987)
23. Wickens, C.D., Long, J.: Conformal symbology, attention shifts and the head-up display. In: Proceedings of the 38th Human Factor and Ergonomics Society Annual Meeting, pp. 6–10. Human Factors Society (1994)

24. Wickens, C.D., Horrey, W.: Models of attention, distraction, and highway hazard avoidance. In: Regan, M.A., Lee, J.D., Young, K.L. (eds.) Driver Distraction Theory, Effects, and Mitigation, pp. 57–69. CRC Press, Boca Raton (2008)
25. Yeo, J.H.: Driver's eye detection method of drowsy driving warning system. US Patent 6,130,617, October 2000. http://www.google.com/patents/US6130617. Accessed 9 June 1999
26. Yeo, J.H.: Driver's drowsiness detection method of drowsy driving warning system. US Patent 6,243,015, June 2001. http://www.google.com/patents/US6243015. Accessed 17 June 1999