Personalizing Content Presentation on Large 3D Head-Up Displays

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Abstract

Drivers' urge to access content on smartphones while driving causes a high number of fatal accidents every year. We explore 3D full-windshield size head-up displays as an opportunity to present such content in a safer manner. In particular, we look into how drivers would personalize such displays and whether it can be considered safe. Firstly, by means of an online survey we identify types of content users access on their smartphones while driving and whether users are interested in the same content on a head-up display. Secondly, we let drivers design personalized 3D layouts and assess how personalization impacts on driving safety. Thirdly, we compare personalized layouts to a one-fits-all layout concept in a 3D driving simulator study regarding safety. We found that drivers' content preferences diverge largely and that most of the personalized layouts do not respect safety sufficiently. The one-fits-all layout led to a better response performance but needs to be modified to consider the drivers' preferences. We discuss the implications of the presented research on road safety and future 3D information placement on head-up displays.

Keywords: head-up display, windshield display, personalization, preferences, layout, content, 3D, augmented reality

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Introduction

Driving a car is a safety-critical task. Being distracted from this primary task can lead to fatal accidents. Despite knowing better, many drivers distract themselves by interacting with their phones: Drivers spend 5 times as much time looking away from the road when interacting with a smartphone. Reading text on the phone increases the crash or near-crash risk by a factor of 23 (Virginia Tech Transportation Institute, 2009). In particular, young people feel a strong desire or pressure to be constantly on the phone, also while driving (V. K. Lee, Champagne, & Francescutti, 2013). It is not surprising that phones are a prevalent factor of distraction and cause about 80% of all accidents (Hosking, Young, & Regan, 2009; Virginia Tech Transportation Institute, 2005). One major challenge is that smartphones are designed to be operated under full attention. This is rarely the case while driving a car. Rather, drivers need to constantly shift their attention between the road and the smartphone. As a result, interaction with the smartphone is usually cumbersome and strongly distracts the driver.

In-car displays provide an opportunity to address this by moving the content closer to the driver's primary visual focus. In fact, drivers even expect mobile applications to become accessible and personalizable on in-car displays (e.g. Buckl et al., 2012; Heikkinen et al., 2013; Tractinsky, Abdu, Forlizzi, and Seder, 2011). We think that among the different displays available in cars, head-up displays (HUDs) are particularly promising to increase safety and improve user experience (Kaptein, 1994; Tretten, Normark, & Gärling, 2009). A head-up display appears like a transparent display floating above the car's hood. The image is placed around the vanishing point of the road, which is closer to the driver's area of visual focus than any other in-car display. This lets the driver perceive information faster and better monitor the situation on the road ahead (Kaptein, 1994; Kiefer, 1991; Liu & Wen, 2004; Christopher D. Wickens & J. Long, 1994). This benefit has been recognized both by car manufacturers and researchers and fostered the development of a large, 3D version of the HUD, the so-called *windshield display*. This display creates new opportunities regarding the design and placement of content.

At the same time, the car industry faces an increasing trend towards adaptive and personalized interfaces and devices (Meixner et al., 2017). In particular, personalization on smartphones receives considerable attention. Users can, for example, personalize the content as well as the layout, i.e., which content is presented where and when. Users deviate from one-fits-all approaches and demand personalization also in the car (Fishwick, 2006; Tractinsky et al., 2011). This suggests, that designers of HUD interfaces need to respond to this trend by allowing users to also personalize the presentation of content on the windshield display. This, however, creates another challenge: Users may position content such that it takes away more attention than other layouts, hence, negatively influencing their driving performance. We, therefore, wanted to understand the apparent trade-off between layouts which minimize drivers' distraction and fully personalized layouts.

We started from the general question which content, driving-related or not, drivers want to see on their personal HUD. In an online survey, we asked drivers about the content they access on their personal phones, as well as which information they want to access on their head-up display. Next, we approached the question, *where* on the HUD drivers would place such content. To do so, we let drivers create their personal HUD layouts in a 3D virtual reality room and subsequently assessed the safety of these layouts. Lastly, we compared the personalized layouts against a layout optimized for attention (called *one-fits-all layout* below) in a driving simulator study. Based on the analysis of task performances and user preferences we discuss the potential implications of the personalized head-up displays. We found that drivers have diverging content and layout preferences and that they want personalization but also that their personalized layouts led to slower response times, which in turn means sacrificing safety.

Research Approach

When moving content initially designed for a smartphone to a windshield display, different aspects need to be considered, because we shift from a primary to a secondary user interface. Most importantly, this concerns the *layout*, on which we will focus here. Further aspects include the design of the content itself (text vs. image vs. video, complexity, etc.) and how drivers interact with it.

With regard to the layout, one approach is to employ a layout optimized for attention, which assigns content to 3D information spaces. Such an approach was presented in related work (Häuslschmid, Shou, O'Donovan, Burnett, & Butz, 2016). However, it prevents any form of personalization by the driver. In particular for mobile devices but also in the car it is unclear whether people would actually accept such a fixed layout (Fishwick, 2006; Meixner et al., 2017). We believe the user interface to take a major role in drivers' purchase decision in the future. It will, therefore, be quite important to understand whether or not or to which degree it should be possible to personalize the UI layout.

At first sight, one might think that a personalized information layout might not only be preferred but also present a safer alternative since drivers would find items at the presumably intuitive location at which they placed them. But drivers might not be aware of the potential hazards of the display itself as well as their own layout. For instance, centrally placed information can occlude road hazards and lead to hampered or delayed detection.

As a result, we investigate personalization on large 3D head-up displays in three steps. We put forward the following research questions to understand (1) the drivers' content preferences, (2) the drivers' personalized layouts and (3) to evaluate their safety (see figure 1).

Background: Vision & Perception

Depending on the driving situation, up to 90% of the visual attention is allocated to the driving task (Cohen & Hirsig, 1990). The perception of additional information on the HUD competes for the same resources. The driver's perceptual abilities are not a constant resource and depend, for example, on task demand and location as well as the current state and constitution of the driver (e.g., fatigue, mental load, age) (Crundall, Underwood, & Chapman, 1999; Houtmans & Sanders, 1984; Summala, Nieminen, & Punto, 1996).

The useful field of view (FoV) is where information can be perceived without head or eye movements. Its size depends, for example, on the workload. In general, visual perception deteriorates towards higher eccentricities (Ecker, 2013; Gish & Staplin, 1995; Häuslschmid, Forster, Vierheilig, & Butz, 2017; Poitschke, 2011; Trent, 2005):

In the central FoV (2° around the focus point) and the foveal FoV (between 2° and 10°), humans perceive contrast, contours and colors well. When driving, central vision is required, for example, to find and identify objects and hazards as well as to estimate distance (William J Horrey, Wickens, & Consalus, 2006). Peripheral perception (starts at 10° and covers the remaining visual field) is limited to motion, light alteration and orientation of objects, has a lower resolution and reduced mental processing capacities, which leads to higher reaction times. While driving, peripheral vision is used to monitor, for example, the lane markings and position, other cars and road signs (Mourant & Rockwell, 1970; Owsley & McGwin, 2010). Peripheral vision can divert the driver's foveal vision to objects that seem to need closer examination (Mourant & Rockwell, 1970). For the windshield display, this means that content needs to be placed according to the properties of those visual fields (Häuslschmid, Osterwald, Lang, & Butz, 2015; Häuslschmid, Schnurr, Wagner, & Butz, 2015), for example, important information should be located rather close to the center.

Tasks which require foveal vision are influenced by visual scanning, that is the driver's eye fixations (William J Horrey et al., 2006). The performance of tasks that depend less on foveal vision are less influenced by visual scanning, which suggests they can be performed with peripheral vision. Chapman and Underwood (1998) assume that experienced drivers can predict the locations of potential dangers and adapt their visual search accordingly. Drivers look where relevant information is expected (Senders, 1964). The driver's eye movements and visual scanning patterns depend on further aspects, such as road familiarity (Mourant & Rockwell, 1970), road curvature (William J. Horrey & Wickens, 2004), driving experience (Konstantopoulos, Chapman, & Crundall, 2010), expectancy (William J Horrey et al., 2006), visibility and weather conditions (Konstantopoulos et al., 2010) and the complexity of the situation (information bandwidth) (Senders, 1964). Consequently, visual scanning is complex and variable, yet, research shows consistent patterns and even learns to predict the driver's gaze patterns (Fridman et al., 2017). Drivers tend to focus far down the road and fixations gather primarily around the right road edge, slightly higher than the horizon (when driving on the right side) (Mourant & Rockwell, 1970).

We reviewed several studies (e.g., Chapman and Underwood, 1998; Fridman et al., 2017; Konstantopoulos et al., 2010; Mourant and Rockwell, 1970; Serafin, 1994) on the drivers' eye movements and visual scanning regarding the locations which drivers fixate when driving (within the road scene). We regard these locations as generally relevant for safe driving. We argue that HUD content should not (permanently) be placed within these areas due to potential visibility and safety issues. Based on these studies, more general HUD placement research and our experience and knowledge about driving and driving scenes, we identified two areas of interest (AOIs) within the driver's FoV that are later used for the safety assessment of the personalized layouts (see figure 2): One area is critical for safe driving at all times and accessed continuously when driving. The second area is important in often occurring situations such as multi-lane driving or intersections. Drivers frequently fixate this area and additionally monitor it with peripheral vision. Depending on the driving situation, also other parts of the FoV can be crucial for driving. Generally, the top and bottom edge of the windshield seem to be the areas least used for driving. Also from an occlusion perspective these areas are the safest for content display. However, perception and response performance are poor within these areas. This again shows the need to consider both, the drivers vision and preferences, for the definition of a view management concept for windshield displays.

Related Work

Phone Use While Driving

Smartphones have become so important for their owners that they often rely or even depend on them (Anderson, 2015). Consequently, phone use does not stop in the car. Heikkinen et al. (2013) observed eight drivers during their usual travels and documented their interactions with brought-in devices such as the smartphone. They found that the tasks drivers perform while driving are very similar to the ones performed in other contexts. Drivers reported or were observed to use navigation and map-based services, communication and social media services, music and video playback. They make phone calls, read and write messages, prepare and manage work tasks and browse the web, emails and their calendar. The drivers were, to some extent, aware of the safety risks involved but argued that their cars did not support these tasks. They further pointed at interaction problems caused by the size of the smartphone touch screen and the design of the interface. Interruptions of the interaction process, e.g., due to driving maneuvers, can force the driver to unlock the phone or even authenticate repeatedly. Interacting with the phone while driving can be tedious and cumbersome and lead to visual, manual and cognitive distraction (Caird, Johnston, Willness, Asbridge, & Steel, 2014). Furthermore, it may cause drivers to change their use behavior and act against better knowledge (goal activation model (Fox & Hoffman, 2002)). These problems again emphasize the need for an alternative display such as the HUD.

Heikkinen et al. 2013 ask for enjoyable and safe solutions to the identified interaction problems. Apparently, drivers actually expect mobile applications to become accessible via in-car displays (e.g., Bratzel, 2011; Buckl et al., 2012; Heikkinen et al., 2013; Tractinsky et al., 2011). Car manufacturers respond to this in different ways (Meixner et al., 2017): Some integrate the required functions into in-car systems. Others provide an interface to connect the smartphone via Android Auto or Apple CarPlay and let the driver access the phone with the car's built-in controls and displays. However, research and development still focus on head-down displays such as the central information display and do not consider the HUD for such content.

Risks & Benefits of HUDs

Driving a car requires continuous, but not full attention and drivers can divide their attentional resources to several tasks. However, this often impacts driving performance (J. D. Lee, 2004). Problematically, drivers are not always aware of this tradeoff. They may feel aware of the situation as they are looking in the direction of the road scene. However, research shows that the mental resources (and the visual attention) devoted to the road scene are reduced and potentially too low for safe driving when using the HUD (e.g., impaired detection of hazards) (Trent, 2005). Even though the display and the road scene are spatially close to each other, drivers can hardly process both simultaneously. However, their feeling of being able to do so may encourage them to engage in even more non-driving-related tasks. The display may capture the driver's attention and cause a diminished perception of the surroundings (cognitive capture and attentional tunneling) or let the driver miss important events (change and inattentional blindness (Christopher D. Wickens & Horrey, 2008)). This underlines the need for well-perceptible interfaces and *natural* interaction techniques. When designed appropriately, the HUD can be safer than other in-car displays. Its prominent position reduces the effort and time needed to switch between the road scene and the display. It also promotes fast reaction times to road events and a better steering performance when reading it (Kaptein, 1994; Kiefer, 1991; Larish & Wickens, 1991; Christopher D. Wickens & J. Long, 1994).

Information Placement & 3D Layouts

Tretten et al. (Tretten et al., 2009) let drivers assign a variety of content to the different in-car displays. Warnings, safety-critical and vehicle information and primary driver content was preferably presented on the HUD. Service information was assigned to the HUD when the driving task was little demanding. The HUD was the overall preferred display location by drivers experiencing simple tasks. When the tasks were more complex or cognitively demanding, drivers preferred the head-down displays. The authors suggested to separate content based on the induced cognitive load and its safety-criticality. Further, they suggested that only content that can be visually scanned quickly and easily should be placed on the HUD. Yet, it was not investigated how and where within the HUD content should be presented.

Windshield displays (WSDs) can overlay and potentially register the content to the road scene – which further reduces accommodation effort and focus switches between display and world (Plavšic, Duschl, Tönnis, Bubb, & Klinker, 2009; Sato, Kitahara, Kameda, & Ohta, 2006). The WSD, hence, constitutes a special type of augmented reality (AR) display. AR is assumed to enhance safety by providing a natural and understandable interface (Gabbard, Fitch, & Kim, 2014; Lauber & Butz, 2013). It is assumed to be processed faster and increase safety, since a spatial transformation between the display and the world is not necessary (Plavšic et al., 2009). However, not all information is related to the outside world. The world-registered information would need to be combined with traditional screen-fixed information. For most of this information, e.g., text messages, there is no established or obvious display position.

A first one-fits-all layout concept for windshield displays approaches this problem and proposes information spaces for 2D- and 3D-registered as well as screen-fixed content placement (Häuslschmid, Shou, et al., 2016). It proposes different zones (distances), which are deduced from Hall's theory of proxemics (Hall, 1966) and areas (facing the driver), which are tied to the context and type of the content. Together, zones and areas span five 3D spaces for the specific types and contexts of information (see figure 3): (1) urgent warnings for, e.g., an emergency break of the lead car, (2) textual content (alternatively in area 5) such as messages or news, (3) personal and entertainment content such as music control or incoming call, (4) ambient information, e.g., time and date, (5) vehicular information such as current speed or low gas warnings. The authors built their concept mainly on literature about location-dependent response performances to select areas which promote high performance. They gathered first insights into where drivers would place abstract content by means of paper-based questionnaires and a static VR driving scene. The authors reviewed their one-fits-all concept based on these findings but consider personalization as future work and only for the content but not for its placement. This concept was used as a baseline for the quantitative evaluation of the personalized layouts presented in our studies.

Personalization

Personalization on personal devices such as the smartphone leads to a better user experience (e.g., Wang, Tan, and Clemmensen, 2016). Personalization now also is a growing topic in the automotive domain (Meixner et al., 2017), but still limited to head-down displays. Users personalize their devices such as the smartphone to such an extent that they are regarded as the *extended self* (Shklovski, Mainwaring, Skúladóttir, & Borgthorsson, 2014). Most people customize the application layouts on their smartphones and revise these layouts when they change an application. They apply layout criteria such as frequency of use, importance, relevance and context (Böhmer & Krüger, 2013).

Drivers bring these devices into the car and expect that the smartphone content becomes accessible on in-car displays (Buckl et al., 2012; Heikkinen et al., 2013). In addition, they expect in-car interfaces to become personalizable (Tractinsky et al., 2011) and they actively deviate from the one-fits-all interfaces (Fishwick, 2006). Personalized interfaces have the potential to increase safety, as drivers may discard unwanted information that would cause discomfort from the display (van Velsen, Huijs, & van der Geest, 2008). Drivers accept personalization and feel a higher emotional and personal connection to the system (Normark & Mankila, 2013). In addition, the alignment to their own mental model can improve user experience (Piccinini, Simões, & Rodrigues, 2012).

Normark identified user needs and iteratively developed and tested personalizable interface prototypes for the car's dashboard (Normark, 2014, 2015). The final prototype appears like a large smartphone integrated into the center stack: The driver can download apps, move it to another display position and adjust its appearance and functions. The participants seemed to adapt the interface easily and quickly and assumed that the personalized content and layout may make driving better and safer.

Yet, the benefits of personalization can only be exploited when users know what is best for them and personalize the device accordingly (Normark, 2015). For others, personalization needs to be kept within safe limits. Generally, a default option, such as the one-fits-all layout, is recommended as a starting point (Normark, 2014). Drivers can than decide by themselves whether they want to personalize it or not.

Survey About Content Preferences

We conducted an online survey to learn which content drivers access on their phones and which content they would like to see on their personal HUD.

Method

The survey was presented as a single page website in English and German language. We provided two videos explaining the concept of HUDs and AR. Participants were asked about any prior experience with HUDs. In the main part, we first asked participants about apps and information they access on their smartphone while commuting or traveling as a driver or co-driver. Next, we presented 16 exemplary items based on smartphone and HUD applications identified in prior research (Häuslschmid, Pfleging, & Alt, 2016; Heikkinen et al., 2013); namely vehicle status, fuel & battery, navigation, car-following, traffic & street signs, points of interest, public transport, commercials, economical driving monitoring, work & tasks, driver-to-driver communication, music playback control, music selection, garage opener, phone calls and messages. Those examples were meant to inspire and encourage participants to think about the content they would like to access on a HUD. Participants were then asked to select the items they would like to see on their HUD. In addition, participants had the opportunity to add their own items. In the end, we asked participants to report their age, whether they owned a driver's license, what their driving experience was and asked for further comments.

We ran a pilot study at an university event where 32 visitors filled in the survey. From these participants we obtained valuable feedback that helped us to improve the survey. In particular, we reduced the length, improved the clarity of the questions and descriptions and extended the pre-defined list of items.

Participants

The survey was distributed via mail and social media. We received 66 replies to our questionnaire from which we excluded four incomplete surveys. The remaining 62 drivers had a mean age of 26.1 years (SD=5.2) and all held a driver's license. Two participants owned a car with a HUD and 16 occasionally used one; 44 participants had no HUD experience. After watching the explanatory videos all participants understood the concept of head-up displays.

Results & Discussion

Fifty-nine participants used smartphone applications in the car, three participants reported to never use a phone while driving. Participants selected on average 6.6 items, representing content or applications, that they would be interested in using on their personal HUD (SD=3.2). This includes both the 16 items we initially presented as well as items that participants added themselves. They created 41 meaningful items, 35 of which are related to driving. All items are listed in table 1.

Limitations

We are aware of several limitations of the survey. First, the choice and suggestions of participants are hypothetical and future work needs to verify which applications and content will really be transferred by drivers onto a HUD. Second, participants focused on driving-related applications and it remains an open question whether, when being provided the opportunity, drivers would want to access more non-driving related content and apps as this becomes possible on HUDs. Since currently 3D HUDs are not widely available and hence not well-known, we believe our survey to provide some useful early insights into drivers' future preferences.

Summary & Interpretation

Our findings regarding the preferred applications and information people access while driving confirm results from prior research (Heikkinen et al., 2013). Looking at items that participants want to have available on the HUD, both the overall number as well as the number of suggested items is an indicator that personalization may be an important feature in future (3D) HUDs. This is also backed by the observation that in the survey some participants did not select any non-driving related content and explicitly stated that they do not want to be exposed to social media and messages while driving. At the same time, others wanted all notifications to also be shown on the HUD, which underlines the need for the personalization of the content. Regarding the desired content, participants focused on driving-related items, such as navigation. Given that many vehicles do not come with an integrated navigation system (and drivers often use their own smartphones), participants saw an opportunity here to better integrate this feature with the car. In addition, they thought of further features that are often only available in premium cars, such as current speed limits next to the current speed as well as traffic warnings. Further findings also suggest the need for shifting non-driving related smartphone content to the HUD. This is particularly apparent for phone calls. While only one out of five drivers stated to initiate calls while driving, almost half of the participants would like to be informed about incoming calls on the HUD. Since calls need to be answered in a timely manner, they are easily missed in the car, as reaching for the phone is sometimes not possible. This can be addressed by shifting this feature to the HUD. Responding to text messages is usually not time-critical, but visually more demanding than an incoming call symbol. In addition, messages could raise privacy concerns in case co-drivers are present. There is also an opportunity for personalization here, i.e., drivers may want to place such information outside of the field of view of the co-driver. Finally, we found that despite most cars allowing music to be played, many participants use their phone instead (e.g., Spotify). In our survey, participants wanted to transfer music apps to the HUD as well.

Collection of Personalized Layouts

The prior online survey provided insights into the drivers' content preferences for their personal HUD. In the following study we let drivers choose *intuitive* locations for some of this content. We gathered personalized layouts and assessed whether participants respect the priority of driving and safety.

Method

The study was designed as 2 × 2 within-subject study with the independent, counterbalanced variables *driving scene* (city, freeway) and *default depth* (5 m, 15 m). We conducted a pilot study with four participants, which showed little depth adjustments. As a consequence, we introduced the second depth level (15 m) to find out whether participants found 5 m appropriate or simply did not know which depth to choose. We requested the participants to define their layout in three steps: (1) *single:* each item is displayed and adjusted separately, (2) *preliminary:* all items are displayed and an overall layout is defined and (3) *final:* the layout is optimized by adjusting it to a new driving scene. Participants were given a tablet with a touch interface containing a list of 10 exemplary WSD items (extracted from the online survey) and with controls for defining the location, depth and size of these items (see figure 4). Their task was to find locations which feel *natural* and to define their personal layouts, similar to setting up their WSD for the first time. Participants controlled the icon's settings by means of the iPad interface but needed to look at the scene to relate their changes to the driving scene.

We chose still images as they allowed a thorough consideration of the personalized layout and particularly AR placements, without time pressure. We presented 180-degree stereoscopic images of exemplary driving scenes and let participants define and adjust their layout according to the scene. To decrease the influence of the scenes and to receive a well-thought layout, we presented two different scenes: one showing a crowded intersection and one showing a freeway with other road users.

As for the icons, we selected ten pieces of information based on the findings of our online survey. We chose content with varying contexts (driver & co-driver, vehicle, environment, time) and task levels (primary, secondary and tertiary task). We further ensured that the selected information is well applicable to the one-fits-all concept; meaning that each piece of information is clearly related to one of the suggested information spaces and that each space contains one to two pieces of information. In particular, we selected navigation information, speedometer, traffic and low gas warning, points of interest, music control, incoming call, personal message, weather and time & date (task relation and context are explained in table 2). Next, we designed a homogeneous set of icons that follows common design rules (see figure 4). When first displayed, each item appears directly in the driver's straight line of sight (0°, 0°) and with an angular size of 11 x 11°. To reduce the influence of the pre-set depth on the participants' depth adjustments we decided to display all items at either 5 m or 15 m. Independently of the position, icons always faced the participant to ensure legibility.

Participants

We recruited 23 participants (9 female) by means of leaflets and an online recruiting system. Our participants were aged between 18 and 58 years (mean=24.3, SD=8.6). All of them had normal or corrected-to-normal vision. All of our participants held a driver's license and had a driving experience of 6.9 years on average (SD=8.2). The participation was voluntary at all times and compensated with vouchers for an online store.

Materials

Since HUDs with continuous depth coverage are not yet commercially available, we had to simulate both the display and the environment. For the perception of depth, a stereoscopic display was required – suggesting a head-mounted display or a VR situation room. A VR situation room seemed to be the better alternative as it provided a higher image quality and participants were not cut off from the outside world. As the real HUD is reflected into the windshield, the digital image can only add but not cut off light rays (additive blending). To create a VR scene similar to a real HUD, we displayed the icons with 70% opacity and used an additive blending mode. For our study, we used a near-to-spherical projection system with a diameter of approximately 10 m and a bridge to walk through its center. It provides a full-surround, stereoscopic view with a resolution of 24 megapixels. In combination with shutter glasses, it provides a high-quality 3D image enabling precise depth perception. The static driving scenes were taken with a 360° Nokia OZO camera with a resolution of 3840×2160 px. For the study, we reduced both pictures to a 180° forward view.

For the driving setup we installed the windshield of a Toyota Pickup with a retainer on a table. The driver's visual field comprises approximately 180° but is limited by the retainer, a gaming steering wheel and a rear view mirror to obtain a view as in a real car (see figure 5). Participants were seated on a chair similar to a car seat, the height of which was adjusted to calibrate the participants' eye level. The participants received an Apple iPad with a 12.9" screen and a customized web interface for the placement task (see figure 4). The experimenter controlled its interface and the study setup remotely by means of a web-based study controller.

Procedure

Participants were first asked to fill out a demographic questionnaire and then introduced to HUDs and AR. Then, the experimenter explained the study background and procedure and asked for their consent for participation. Participants were then equipped with shutter glasses and a tablet and seated in the driving setup. The experimenter requested them to imagine that they are really driving a car and guided each participant through the process in order to avoid mistakes. Participants first had to select one item from the list which superimposed it as overlay to the driving scene. Then, the participant could drag it to the preferred location and adjust its depth and size by two separate sliders. When the participant was satisfied with the settings, the icon could be hidden by deselecting it in the list. Participants proceeded with the next icon until all icons were placed (*single* layout). Next, all items were displayed simultaneously and the participant had to readjust the overall layout if necessary. Adjustments ranged from solving small overlap problems to entirely redefining position, depth and size value of an icon (*preliminary* layout). The experimenter then changed the driving scene and requested the participants to once again verify or, if needed, readjust the layout until satisfied (*final* layout). The study ended with a final questionnaire. The study took approximately 35–45 min per participant.

Results & Discussion

Layout Variants. We compared the three layout variant of the three test phases (*single*, *preliminary* and *final* layout) and the influence of the background scene by means of repeated measures ANOVAs with Bonferroni adjusted alpha level.

We found that the participants adjusted the layouts in each phase but they do not vary significantly. Yet, the first, presumably most intuitive, locations of the single items differ significantly from the final layout regarding the horizontal placement (p=.006) and size (p<.001) but not for the vertical position and depth. This means that in the end participants chose locations which are far away from the ones that were chosen in the beginning. Statistically significant differences (p<.04) have been found between the placement of the single and the preliminary layout of all items.

We did not find a significant effect of the driving scene on the layouts. Overall, the results suggest that the participants tried to interrelate the items (e.g., regarding context or relevance) and to find a layout that is meaningful for them. Surprisingly, we found the size of the items to be decreased significantly for each layout variant (p<.002 each). One reason for this might be that participants felt they were too prominent in relation to the driving scene when thinking more about good placements.

Locations & Layout Patterns. We more closely analyzed the final layouts of the participants. The mean horizontal and vertical location for each icon as angles are presented in table 2 and figure 8. We performed a Wilcoxon pairwise comparison between driving-related (primary and secondary task) and non-driving-related information. The test showed that driving-related information is placed significantly closer to the center than unrelated content (Z=-3.88, p<.0001). We did not find a significant difference between primary- and secondary-task related content.

In addition, we visually inspected each layout, searching for specific patterns as these evolved. We found that some participants only made minor changes to the layouts in the different phases. At the same time, others chose very similar locations for each single item first. The layouts of these participants then changed considerably until the final version. These participants enhanced the alignment of the single items to each other in each iteration. This hints at different strategies people used for the item placement. Four examples of final personalized layouts are shown in figure 7.

We found that many participants lined up content along the lower windshield edge (65.2%; at least four items in even distance). In addition, content was also placed along the left edge (17.4%; at least three items in even distance), above and on top of the central area (vanishing point of the street), or also above the center stack or centrally within the right half of the windshield. Generally, participants placed information rather below than above the horizon. This suggests that participants adopt concepts known from other UIs (such as the MacOS dock or the Windows task bar) where items are positioned such that participants can focus on their primary task while at the same time enabling quick perception and access to these items.

Participants placed content with the same context close to each other. Often, participants separated driving-related and unrelated content and assigned one to the left and the other to the right side of the center. Navigation information, speedometer and warnings were often lined up below the center. HUDs are regularly placed in the same area and also the one-fits-all concept suggests this location for driving-related content. The warning symbol was placed prominently above or on top of the center, sometimes occluding the lead car. Also the one-fits-all concept suggests placing urgent warnings above the center.

As for the ambient information, the items time & date and weather are almost always placed next to each other. Most drivers chose a location far away from the center, for example, within the right half of the windshield or within the sky. Accordingly, the items incoming call and message are bound to each other. Personal content is often placed along the left edge of the windshield; drivers seem to agree on the top left corner for the incoming call item. Drivers have different opinions about the affiliation of the music and point of interest items. They are sometimes placed close to each other but often also separated and affiliated to the personal content or the ambient information. Surprisingly, we found very few placements that could be interpreted as registered to the world (AR), although we made sure they are aware of the concept of AR. The navigation item was often placed on top or above of the road which suggests some kind of registration, but the point of interest item (restaurant) was nearly never placed in spatial relation to the road or a building. Overall, figure 8 nicely shows the locations often chosen by participants and visualizes some of the patterns. For most participants, we detected several of the above patterns. Two participants seemed to place content randomly. One participant developed a layout which is similar to the one-fits-all layout.

Size. The angular sizes are depicted in table 2. We performed a Friedman test on the size values of the final layouts. The test showed a significant size difference for the ten items ($\chi^2(9) = 41.07, p < .0001$).

We further analyzed the size values in regard of the items' relevance for driving. We performed a Wilcoxon pairwise comparison between driving-related and non-driving-related information. The test showed that driving-related information was given significantly more space (Z=-2.55, p=.011). We did not find a significant difference between primary- and secondary-task related content. Yet, the results suggest that our participants gave priority to safety-relevant information through assigning larger sizes to it.

Depth. Table 2 shows that participants hardly adjusted the depths of the icons, although, we used two considerably different depth levels. The mean depth value of the personal layouts is 6.03 m (SD=3.23) for a default distance of 5 m and 15.08 m (SD=3.75) for a default distance of 15 m. All participants placed most icons within a very narrow depth range of approximately 1–2 m and only 2–3 icons considerably closer or further away. However, these icons and locations do not seem to follow a specific pattern. This indicates that drivers want most content to be in a narrow depth range but do not have preferences where this range is. However, it generally indicates that participants had problems finding appropriate depths and that there is no such thing than an *intuitive* depth for WSD content.

We analyzed the depth values of the final layouts by means of a Friedman test. The test showed no significantly different depth placements for the ten items. We could neither find different depth assignments regarding the items' task-relevance.

Qualitative Feedback. The concept of HUDs and AR was clear to the participants. Almost all drivers want to have control over the information layout and either adjust it frequently depending on the need (n=19) or once in the beginning (n=3). The large number of people who want to be able and adjust the layout frequently is interesting, since it contradicts observations from other personalizable UIs. For example, users make, in general, rather few changes to the arrangement of icons in the dock, task bar or to their smartphone home screen. Future work should investigate this in more detail, in particular *when* users are interested in updates to the layout.

Generally, participants think that the danger of HUDs depends on the type and amount of information displayed on it. Also, participants stated that the amount of information displayed during the study (10 icons) is appropriate (n=7) or too much information (n=15). On average, drivers want six pieces of information on their HUD; which is in line with the finding of the online survey. They prioritized the presence of general types of information on the HUD (a high median indicates high priority): **(1)** information about the car (median=6), **(2)** warnings (median=5), **(3)** navigational information (median=4), **(4)** entertainment information (median=3), **(5)** social and personal information (median=2), and **(6)** public information (median=1).

This prioritization reflects well the assigned location on the windshield (see table 2): Important information was placed centrally and most participants (n=22) gave priority to driving-relevant content (as depicted in figure 6). Drivers wanted content related to safe travel and way finding. Many participants wanted personal, social and public information, e.g., incoming calls or appointments, to be displayed only on demand – about one third of our participants was completely against such information on a HUD.

Safety Assessment. Although our participants were advanced drivers, some of them did not hesitate to place items in areas which are critical for safe driving. They neglected potential visibility and safety risks – for themselves but also for other road users and pedestrians.

We reviewed the 23 personalized layouts with the safety-critical and safety-relevant areas of the driver's field of view at hand (see figure 2). We found that 11 of the 23 drivers placed items within the safety-critical (and -relevant) area (red). This area is highly important for safe driving, for example, to monitor the distance to the lead car and especially permanent information display should be avoided here. Within this area, drivers placed primarily the navigation item but also urgent warnings, the speedometer and messages. Consequently, we argue that these layouts may not be safe for road use.

A total of 18 drivers placed content within the safety-relevant area (yellow). Other (crossing) cars, pedestrians, traffic signs, etc. appear within this area and need to be detectable and recognizable by the driver. Placements within this area can lead to visibility and in turn to safety issues, depending on the content presentation. Appropriate information design would need to ensure that the real world objects are fully visible. We do not recommend to use these layouts on real roads. Only five drivers did not place any content within the safety-critical or -relevant areas. Obviously, these layouts arrange items along the bottom and some also along the top edge of the windshield. These layouts seem to be safe and applicable to the real world.

These findings hint at some interesting directions for future research. As cameras become capable of analyzing the driving scene, windshield displays can be built that allow taking into account users' preferences with regard to content placement while at the same time ensuring safe driving. For example, as pedestrians are approaching, items placed in this area could be temporally hidden.

Limitations

This study was subject to several limitations. Firstly, the task closely resembled an initial setup (e.g., as persons buy a new car). Hence, we cannot draw any conclusion regarding whether or not people would change the layout later on. Since our participants stated to be interested in doing so, this is an interesting direction for future research. Secondly, we only used a static scene. The lack of movement may have made people less careful in placing items as opposed to a situation in which they were driving. At the same time, conducting the study while driving would have been difficult. Drivers will be in a similar situation as personalizable HUDs become available. Hence future work needs to more closely investigate the process. Due to driving being safety critical, a meaningful approach would be to apply certain restriction to the layout, as suggested in our work.

Summary

In this study, we gathered insights into personalized HUD layouts. Almost all participants acknowledged driving-related information as being most important and were willing to limit the HUD to it. Yet, drivers did not hesitate to place information within driving-relevant areas, for example, overlaying other cars or pedestrians. Although our participants are all experienced drivers, they seem to not be aware of which areas are relevant for safe driving. For safe driving, they have to visually scan these areas (William J Horrey et al., 2006) but this process seems to be outside the humans' consciousness. This lack of awareness points at a safety risk of personalized layouts.

However, drivers want to personalize their layouts and adjust it frequently according to their current needs. This prevents training and, consequently, enhanced performance. A well-designed one-fits-all layout might be safer and due to its consistency (as opposed to a layout that might be frequently changed by the driver) be easier to learn so that the users' searching and reading performance will improve over time. Users will learn which type of information is displayed where and know whether a stimulus occurring at one location is urgent or not only by its location.

We conclude that if personalized layouts need to be allowed in the car it should be limited to safe areas. The display of personalized content according to defined layout patterns should be considered in future work.

Personalized vs. One-fits-all Layout

The prior study collected driver preferences for WSD locations for different information types. In addition, we observed various personalized layout approaches. In the second study, we focus on performance and safety. In particular, this study investigates whether the personalized layouts or an one-fits-all layout leads to safer driving and better response performance to incoming information. Furthermore, this study investigates whether the locations for the different types of information are appropriate considering their relevance and importance for the driving task in order to ensure that important and driving-relevant information is processed fastest by the driver.

Method

We used a 2×2 within-subjects study design with a continuous tracking and reaction task (ConTRe task) (Mahr, Feld, & Moniri, 2012) as the (primary) driving task and a detection response task (DRT) (Ranney, Baldwin, Smith, Mazzae, & Pierce, 2014) as the secondary task. The study contains two test segments; one for the personalized and one for the one-fits-all layout. Each segment is subdivided into baseline (60 s), intervention (180 s) and another baseline (30 s); with smooth transitions. During a baseline, the participants have to perform the driving task only; in the intervention part, they also have to perform the DRT.

For each test segment, we defined a driving track consisting of driving footage and a driving task. We used stereoscopic videos of driving on a freeway instead of a standard simulator to reach a highly realistic scene and depth perception. The driving tracks are presented in a fixed order to the participants. The test order and assignment of the layouts to the driving tracks are counterbalanced.

Driving Task. The ConTRe task was proposed by Mahr et al. (Mahr et al., 2012) as a tool for a highly controlled evaluation of in-car information systems, especially in conjunction with detection tasks. The task has been successfully applied in other studies, specifically regarding speech interaction (Demberg, Sayeed, Mahr, & Müller, 2013; Häuslschmid, Klaus, & Butz, 2017). The ConTRe task requires the driver to steer, accelerate and brake as in real driving but it decouples its effects from the surrounding scene: The driver does not adjust the speed and orientation of the car in a virtual world. Instead, the driver controls a blue cylinder – representing the self – to meet the position of a yellow, autonomously moving cylinder – corresponding to a lead car. The lateral position of the self-cylinder is controlled by means of a steering wheel. The reference cylinder moves autonomously to the left and to the right according to predefined coordinates but remains within the lane boundaries: It varies its lateral position 20 times per minute around the center of the lane and can rest at one position for up to 2 s; this corresponds to a medium difficult task (Mahr et al., 2012). Both cylinders stay at a constant distance of 5 m to the driver so that they seem to move along the road; this distance corresponds to the distance between driver and the canvas of the VR Situation Room – meaning it is non-conflicting in vergence and accommodation – and consequently minimizes the eye effort for the driving task.

The reference-cylinder is equipped with a traffic light on its top which enables the measurement of the driver's response times on the primary task events: The top light shines red and instructs the driver to brake immediately. The green light is placed below and requires an immediate acceleration reaction. The pedals are only used to respond to those lights and do not control the speed of the cylinders or videos. Eight lights (4 green, 4 red) are randomly scheduled per minute; one light shines for 1 s and is always followed by a pause of 4 to 20 s.

Detection Response Task. As secondary task, we chose a detection-response task. DRTs are commonly applied for the investigation of location-dependent response performance (Tsimhoni, 2000; Tsimhoni, Green, & Watanabe, 2001). It requires the participants to detect and respond to stimuli occurring in their visual field, e.g., by a button press (Ranney et al., 2014). As stimuli we chose the simple shapes circle, triangle and square, filled with yellow color. To respond to circles, the drivers had to press the right button on the steering wheel, for triangles and squares it was the left button. This distinction ensured that participants actually processed the stimulus. Disappearing stimuli had to be ignored.

We decided against the use of meaningful icons (like in the preceding study) to avoid biases in the results: If we would have presented meaningful content, such as a warning and the daytime, we could not conclude if the driver reacted faster to the warning due to its location or design or because it is more important or urgent than the daytime. By using abstract shapes (as also suggested by Yoo, Tsimhoni, Watanabe, Green, and Shah, 1999) we obtained results which can be attributed exclusively to the location. We decided for the color yellow since it was well-distinguishable from the driving scene and different from the ConTRe task lights.

Overall, 45 stimuli were displayed during each test track. Stimuli appeared or changed every 3 to 5 s, as suggested for the DRT by NHTSA (Ranney et al., 2014). These events are randomly scheduled and distributed over 10 locations. A maximum of 10 stimuli was visible at a time. The locations correspond either to the ones of the participants' personal layout or of the view management concept. To define the precise positions for the one-fits-all layout, we applied the concept to the items and scenes of the first study. For the depths, we either chose the center of the zones or the depth of the augmented objects. The exact locations are depicted in the figures 9 and 10. All stimuli were displayed at the same size, independently of their location and the participants' size values.

Participants

We invited all participants who completed the first study. From the 14 volunteers, we recruited 2 participants for the pilot study and the remaining 12 participants (4 female) with a mean age of 23 years (SD=3.4) and a driving experience of 5.4 years (SD=3.3) for the main study. The participation was voluntary at all times and subjects were compensated with vouchers.

Materials

We used the same VR situation room and driving setup as in the first study. The steering wheel and the pedals were now used for the driving task and adjusted to feel natural to the experimenters. All data was logged in 100 ms intervals in JSON files. To record the driving videos we mounted the Nokia OZO camera on the hood of a Nissan Pathfinder. We recorded the stereoscopic surround footage on a freeway at a speed of approximately 60 mph. We rendered the videos with a resolution of 2000 × 2000 px at 20 fps. This reduced the perceived speed of the car to 40 mph but guaranteed a smooth play back of the video on the available hardware.

Procedure

The participants were welcomed and introduced to the study procedure. They were asked whether they agreed to the consent form and want to participate in the study. If so, participants were equipped with shutter glasses and seated in the driving setup. After an introduction to the driving task, participants performed an unrecorded test drive for up to 3 min familiarize themselves with task and setup.

Furthermore, the experimenter explained the DRT and emphasized the priority of the driving task. Then, the first test started: After driving the baseline part, stimuli appeared, changed and disappeared – requiring the driver to press a button or to ignore it. The test track ended with another short baseline drive. Participants had to complete a second driving track with the same procedure and to fill out a closing questionnaire. The study lasted approximately 20 min.

Results & Discussion

Driving Performance. We assessed the driving performance with the metrics lateral deviation, response time and missed ConTRe lights. All values and standard deviations are depicted in table 3.

The *lateral deviation* (in m) describes the horizontal distance between the reference- and the self-cylinder. We analyzed the lateral deviation by means of a repeated measures ANOVA. We found a statistically significant difference between baseline and intervention (F(1,11)=6.51, p=.027) but not between the two conditions.

The *response time* (in s) describes the time drivers needed to react to the ConTRe lights. We analyzed response times by means of a repeated measures ANOVA, which showed a non-significant difference between baseline and intervention as well as the two conditions.

The metric *missed ConTRe lights* represent the count of lights (simulating a traffic light) to which the drivers did not respond. A Wilcoxon test revealed a significant impact of the secondary task on the responded lights (Z=-2.82, p=.005). Furthermore, Wilcoxon tests showed a significant deterioration for both layout variants (individual: Z=-2.69, p=.007 and one-fits-all: Z=-2.26, p=.024). We did not find a statistically relevant difference between the two layout variants.

As expected, the secondary task lowered the driving performance. This is a normal effect in a divided attention task, especially when the secondary task is very challenging. In the final questionnaire, participants stated that the driving task felt realistic and that it was generally easy to perform. In addition, they found that the secondary task was hard and that it strongly impacted their driving performance.

Response Performance. The response performance is measured as response rate and response time. All values are depicted in table 3.

The *response rate* describes the ratio of the stimuli a participant responded to and the overall displayed ones (n=45). The participants responded to significantly more stimuli (Z=-2.31, p=.021) when placed according to the one-fits-all layout.

The *response time* describes the time the participants needed to respond to appearing or changing stimuli (max=3 s). Our statistical analysis did not reveal a significant difference.

We performed a Pearson product-moment correlation analysis on response rate and time. These metrics correlate significantly for the one-fits-all layout (r=.69, n=10, p=.029). This emphasizes the difference between locations with high and low response performance; meaning that locations with high response rate promote also a low response time. This is a desirable effect provided that content is assigned appropriately in regard of its importance. We did not find such correlation for the personalized layouts.

Information-Specific Response Performance. The appropriateness of the assignment of the content to a location or area is highly relevant for a layout concept: Generally, the response time should increase with the level of task-relation. Drivers should react faster and more reliably to content related to the primary task compared to the secondary or tertiary task. The response performance to critical information should be the highest. Also, information related to the car and driving in general should be easy and fast to access. Generally less important information like time & date is placed at potentially less distractive or interruptive locations (with low performance). Table 2 depicts the ten pieces of information from the first study, the task-relevance, the context and area, the eccentricity from the center and the response time and rate.

Our findings show that the response times for both layout variants generally increase with the task level (see table 4). Both concepts show high response rates for urgent and driving-relevant information and slightly higher values for the less urgent secondary and the less important tertiary task related information. This suggests, that participants considered the information relevance when they placed the items.

Diverging eccentricities of the two layout variants may explain the overall better results of the one-fits-all layout. We calculated the angular distance from the center (eccentricity) and performed a Wilcoxon signed-rank test: Items of personalized layouts are placed further away from the center than the items of the one-fits-all layout (see table 3). We did not find a statistical difference between the eccentricities of the two layout variants.

This suggests that not eccentricity but the location is the reason for the better results of the one-fits-all layout.

Vision research showed that response performance generally decreases with growing eccentricity (Gish & Staplin, 1995; Trent, 2005). We performed a Pearson product-moment correlation analysis on eccentricity and response time. We found a significant correlation for eccentricity and response time for the personal layouts (r=.75, n=10, p=.013) as well as for the one-fits-all layout (r=.74, n=10, p=.014). This correlation and the correlation between response rate and time is supported by prior vision research.

Limitations

Instead of a driving simulator, we decided for stereoscopic driving videos in conjunction with the ConTRe task. Like any simulated driving task, also the ConTRe task is artificial by nature in order to enable precise control and measurability. Yet, the ConTRe task enables the use of highly realistic driving videos which is important for a study on visual perception. The manual control of the steering wheel is disconnected from the motion and orientation of the car and used to match two cylinders instead. Since the reference-cylinder moved in moderate speed and within the lane boundaries, rather small steering angles were required in order to match the two cylinders. Those steering motions are designed to be comparable with standard steering of freeway driving.

We decided to use simple shapes instead of meaningful icons in order not to influence the processing time by the complexity of the icon or the subjective urgency or relevance of the icon. This reduces realism but increases the internal generalizability of and control over the experiment. Still, we can assess the response performances for the information types using the assigned positions in the personal layouts. The secondary task simulated a worst-case scenario and was designed to challenge and nearly overload the driver to show even small differences between the one-fits-all concept and the personalized layouts. A real HUD might and should display less and more constant information. Then, the difference between the two layout variants might be less prominent.

Summary

The one-fits-all layout promoted better response rates and slightly better response times which indicates that information was easier to detect and faster to access. The time needed to perceive and process a stimulus is equal for both layouts since we used the same stimuli. This indicates, that at equal response performance (as in a realistic, non-challenging scenario), participants would need fewer resources for the secondary task and, hence, could devote more resources to the driving task; which is associated with increased safety.

The eccentricity of the locations of the personalized layouts and the one-fits-all layout are overall similar. We found response time and eccentricity to correlate significantly for the personalized layouts as well as the one-fits-all layout. Furthermore, both layout variants respect the task-relevance of information, which also is reflected by the response performance. The response performance is high for critical information and decreases with the content's relevance for driving which is generally desirable.

Extensive prior research showed that response time increases and response rate decreases at larger eccentricities, however not manadatorily simultaneously (e.g., Gish and Staplin, 1995; Trent, 2005). Our findings are in line with prior research. We found lowered response rate to highly eccentric stimuli but as stimuli were still detected. We assume that due to the high workload the drivers' useful field of view shrinked but without influence on the visual cone. In reality, less content would change or appear than in our study, which will reduce the effects on the visual field. Yet, future research needs to verify this hypothesis and to investigate whether the detection of real peripheral stimuli (e.g., road hazards) is also affected, preferrably in a real world study.

Discussion & Implications

We learned from the online survey that drivers have different smartphone usage behaviors and demands regarding the HUD content. Generally, drivers seem to prioritize driving-related and particularly safety-critical information over entertainment functions and smartphone content. The first user study supports this finding but also showed the drivers' different perceptions regarding the layout of content. The results suggest that there is no generally intuitive position or depth for the different types of information. Drivers seem to be unaware of where they look for driving or underestimate the importance of their gaze direction. Most personalized layouts display information in areas that are required for driving. WSD content can occlude the driving scene and appearing hazards and hamper or delay reaction to a risk. Consequently, we do not consider these personalized layouts safe. However, the same risk also exists for some areas of the one-fits-all layout.

The second study showed that the one-fits-all layout promotes better response performance than the personalized layouts. This generally supports the design of the attention-optimized one-fits-all layout. However, the difference will probably be smaller in real driving settings due to the expected lower workload. Drivers want to personalize their layouts and research suggests that this can be beneficial for the overall user experience, usability and safety (Normark & Mankila, 2013; Piccinini et al., 2012; van Velsen et al., 2008). From the three studies we conclude that neither an one-fits-all layout nor completely personalized layouts are the optimal solution.

We suggest to use the one-fits-all layout as a default for those drivers who do not want to personalize it. Yet, as this layout also suggests locations within the areas critical for driving, we argue that it needs to be refined and propose the following modifications: Many participants lined up icons along the bottom edge of the windshield. This is similar to the vehicular and personal areas proposed in the concept. We suggest to adjust these areas to be of the same height and start at the same vertical position. This creates a more connected and larger display area that suits the most prominent layout pattern. Larger areas would allow for a larger presentation of the icons – which could promote faster reading of especially complex information, such as maps or text, but might also increase distraction. In addition, we recommend to abolish the reading area as it falls into the driving-critical field of view. Further research needs to identify a suitable location – we recommend to consider a time and space multiplexing with the vehicular area (below the driver's line of sight). Participants and the experimenters experienced a stimulus appearing in the area for urgent warnings as interrupting and acquiring immediate attention. This supports the idea to use this area exclusively for very urgent and safety-relevant warnings. As our drivers cared little about the depth of the content, we point at a need for further investigation and potentially an adaptation of the assigned depth ranges.

The HUD content needs to be personalizable. However, limitations, e.g., in terms of amount, complexity or information density could be applied. For instance, textual content and maps may be limited to low speeds or even waiting cars. Future research has to study how drivers would use the WSD when it provides driving-related as well as unrelated content from the personal smartphone. It needs to make sure that the permanent and (for the driver) presumably safe provision does not cause the driver to get overly engaged with the display – potentially even more than with the smartphone only.

Drivers should be allowed to adapt the default layout to define their personal layout. However, the degree of control needs to be limited. For instance, the usable areas exclude the ones that are critical or relevant for safe driving (see figure 2). Future research should investigate how drivers would then define their layouts – given the area restrictions and free choice of content – and how these layouts support information uptake and impact driving. In addition, layout algorithms may be applied to optimize the driver's layout, e.g., to well-align content to the bottom edge or to use consistent gaps or sizes.

Conclusions & Future Work

Cars have become a place where we communicate and consume information far beyond the actual driving task. Yet, road statistics show the danger of phone use while driving and point at the need for a new approach. One such approach is to move the content from the personalized phone to a personalized head-up display. A large and potentially 3D HUD can accommodate new content, however, its placement in a large 3D space has not been widely explored in a systematic way.

In an online survey we gathered insights into which content drivers access on the phone while driving and which information they would like to see on their personal HUDs. By means of consecutive studies we shed light on the question whether an one-fits-all or a personalized view management for in-car head-up displays is the safer solution. We obtained 23 personalized layouts and gathered insights into potential safety issues. Our results showed that even experienced drivers do not always respect the important areas of the driving scene and place information in potentially safety-critical locations. We think that a well-informed one-fits-all layout is the safer alternative. Yet, drivers want to define their own layouts. In case this is demanded, we recommend to restrict the areas for information placement to uncritical areas.

For the follow-up study, we recruited a subset of our participants and tested their personalized layouts against an one-fits-all layout. We found that using the one-fits-all layout, participants responded slightly faster and to significantly more stimuli. The one-fits-all layout is based on locations with high detection-response performance and our study showed that it actually promotes fast information uptake. Yet, we think that the one-fits-all concept could benefit from incorporating the drivers' preferences.

Future work on personalization of WSD layouts may exclude safety-relevant locations from the areas in which participants can place items, e.g., in favor of the top and bottom edge. Beyond this static concept, a study regarding visual search behavior could determine how easily information can be found. World-fixed information, while certainly harder to implement in HUDs, is an ongoing and future interest in our research efforts. Furthermore, a detailed qualitative study should investigate how substantially, how often and why drivers would adjust their personalized layouts. A follow-up study could then examine their task performance in the long term.

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Table 1

New Table: Content that people access while driving (left column) and that they would like to see on their personal windshield display (right column).

Smartphone Apps used while Driving	**Content desired on the WSD** ***Pre-Defined Items:***
navigation (62.1%)	navigation (80.6%)
messages (60.6%)	fuel & battery (67.7%)
music (40.9%)	head way (car-following) (51.6%)
phone calls (21.2%)	traffic & street signs (51.6%)
browser (16.7%)	music playback control (50.0%)
Facebook (16.7%)	phone calls (46.8%)
other social networks (15.2%)	vehicle status (40.3%)
news (15.2%)	music selection (41.8%)
games (13.6%)	messages (30.6%)
e-mail (15.2%)	economical driving (25.8%)
weather (9.1%)	points of interest (19.4%)
camera (9.1%)	garage opener (17.7%)
traffic & jams (4.5%)	public transport (11.3%)
calendar (4.5%)	driver 2 driver comm. (9.7%)
communication (3.0%)	work & tasks (8.0%)
finance (3.0%)	commercials (3.2%)
notes (3.0%)	***Self-Defined Items:***
other applications (10.5%)	speed and speed limits (25.8%)
	weather & temperature (9.7%)
	path finding (8.1%)
	traffic warnings & signs (6.5%)
	points of interest (6.4%)
	entertainment and infotainment (6.4%)

Table 2

The icons tested in the first study along with the task-relation, the mean horizontal (X) and vertical angle (Y) in ° and calculated eccentricity ($Ecc.{=}\sqrt{X^2 \ \times Y^2}$*), angular size (W) in ° and depth (Z) in m of the personalized layouts. Furthermore, the areas of the one-fits-all layout and their eccentricities and the response times, response time (RT in s) and response rate (RR in %) for both layout variants are depicted. We assigned the information to the correct areas of the one-fits-all layout; we specified the exact position with (r) for right and (l) for left if two items would be assigned to one area (also shown in figure 10).*

Task Level	**Information (Icon)**	**Personal Layouts**							**One-fits-all Layout**			
		X	**Y**	**Ecc.**	**Z**	**W**	**RT**	**RR**	**Area**	**Ecc.**	**RT**	**RR**
1	Warning (Caution)	1.6	-4.9	5.2	10.40	5.33	1.32	50	Warning	4.9	1.15	78
1	Current Speed	0.0	-8.1	10.10	10.59	4.90	1.36	69	Vehicular I. (r)	8.1	1.31	84
2	Warning (Low Gas)	-8.9	-8.9	9.91	11.39	4.92	1.55	35	Vehicular I. (l)	8.1	1.41	49
2	Navigation	0.8	-4.1	7.98	10.23	5.61	1.31	55	Environmental I.	7.3	1.15	55
3	Personal Message	7.3	-4.1	17.68	9.65	5.09	1.34	35	Text	8.1	1.42	65
3	Incoming Call	-1.6	-2.5	17.2	10.67	4.69	1.47	50	Personal I. (l)	17.4	1.59	42
3	Music Playback	9.7	-4.9	16.78	10.49	5.27	1.35	35	Personal I. (r)	23.9	1.34	57
3	Point of Interest	15.9	-4.9	18.79	10.23	3.80	1.84	52	Environmental I.	7.3	1.27	66
3	Time & Date	25.2	0.0	20.46	9.55	3.85	1.82	46	Ambient I. (r)	12.1	1.76	39
3	Weather	23.2	0.0	22.81	9.49	4.43	1.72	31	Ambient I. (l)	12.1	1.77	50

Table 3

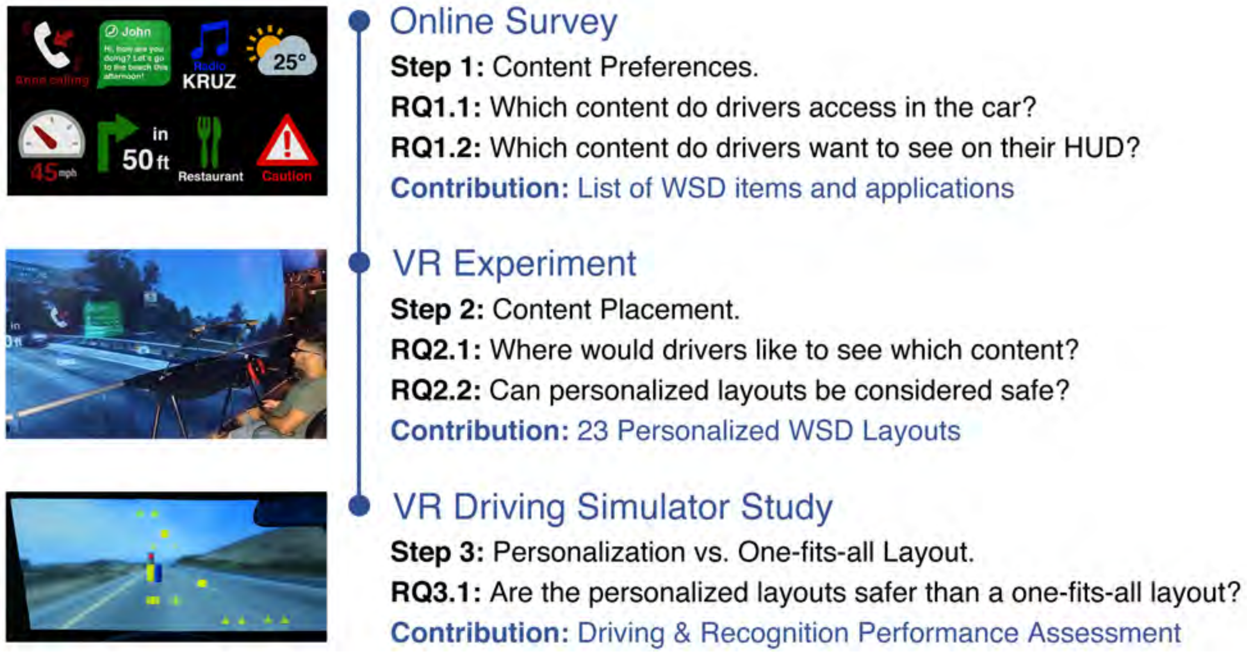
New Table: Part 1 presents the mean eccentricity of all icons of the two layout variants. Part 2 depicts the participants' driving performance when driving with the either of the two layout variants or without WSD. Part 3 reports the driver's response performance in detecting and responding to the stimuli.

Metric	**Condition**	**One-fits-all Layout**		**Personal Layout**	
		Mean	**SD**	**Mean**	**SD**
Item Placement					
Eccentricity		11.74°	7.74°	10.93°	5.76°
Driving Performance					
Lateral deviation	Baseline	0.61 m	0.01 m	0.56 m	0.01 m
	Intervention	0.63 m	0.02 m	0.66 m	0.02 m
Response time	Baseline	1.00 m	0.12 m	0.98 m	0.09 m
	Intervention	1.10 m	0.19 m	1.18 m	0.31 m
Missed ConTRe lights	Baseline	0.69 m	2.41 m	2.78 m	5.42 m
	Intervention	5.21 m	14.70 m	9.38 m	19.82 m
Response Performance					
Response rate	Intervention	64.2%	13%	49.5%	12%
Response time	Intervention	1.42 s	0.22 s	1.51 s	0.11 s

Table 4

New Table: The response rate and performance for stimuli placed at locations for urgent & primary task-related, secondary task-related and tertiary task-related information.

Information Type	**One-fits-all Layout**		**Personal Layout**	
	Response time	**Response rate**	**Response time**	**Response rate**
Urgent & primary information	1.23 s	81%	1.34 s	59%
Secondary information	1.28 s	52%	1.43 s	45%
Tertiary information	1.52 s	53%	1.59 s	42%



Online Survey

Step 1: Content Preferences.

RQ1.1: Which content do drivers access in the car?

RQ1.2: Which content do drivers want to see on their HUD?

Contribution: List of WSD items and applications

VR Experiment

Step 2: Content Placement.

RQ2.1: Where would drivers like to see which content?

RQ2.2: Can personalized layouts be considered safe?

Contribution: 23 Personalized WSD Layouts

VR Driving Simulator Study

Step 3: Personalization vs. One-fits-all Layout.

RQ3.1: Are the personalized layouts safer than a one-fits-all layout?

Contribution: Driving & Recognition Performance Assessment

Figure 1. New Figure: Overview of our research steps, questions and contributions.

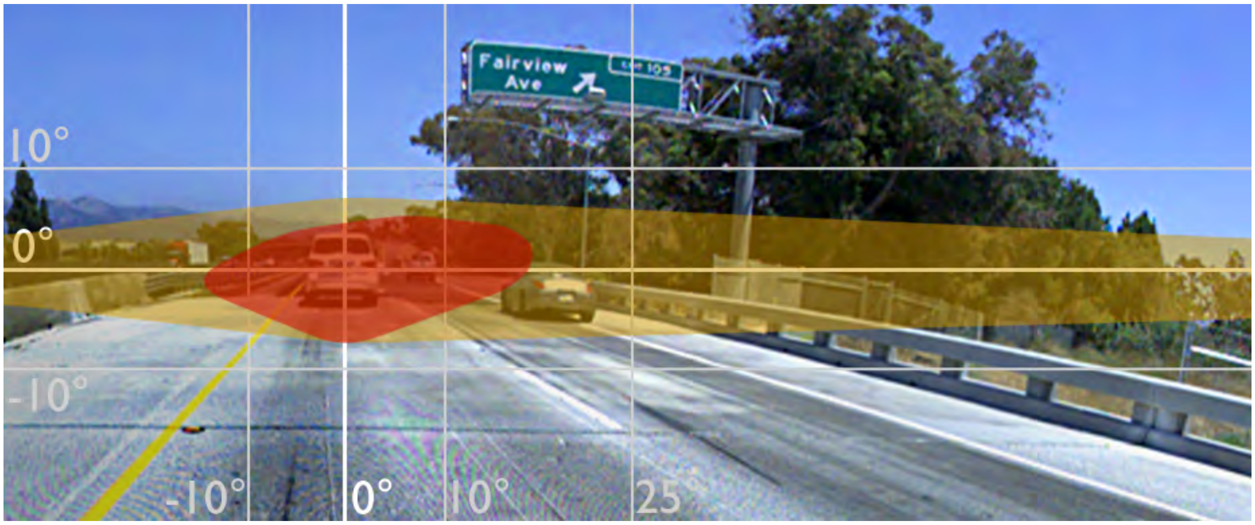


Figure 2. We identified two critical areas for safe driving, where content should be avoided or placed wisely: Drivers direct their visual attention mostly to the red area. The yellow area covers the own and other lanes, but also crossroads at distances suitable for timely reaction. It is mostly monitored with peripheral vision, but drivers also fixate within this area to identify hazards. Both areas are critical, but their relative importance depends on the driving situation.

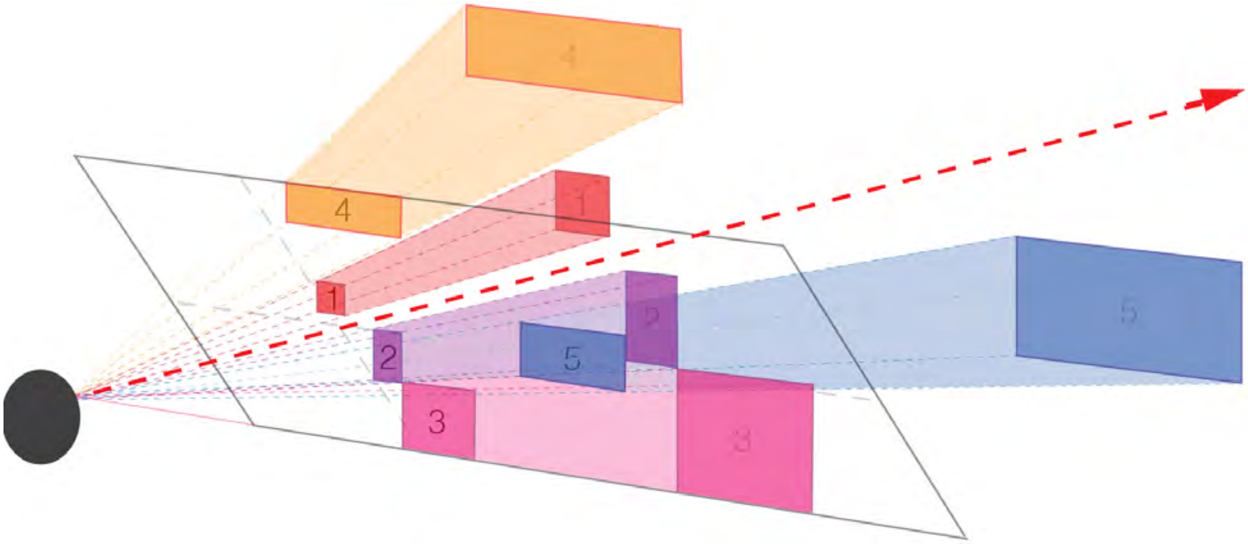


Figure 3. The one-fits-all concept for large HUDs from (Häuslschmid, Shou, O'Donovan, Burnett, & Butz, 2016). The areas contain (1) urgent warnings, (2) text (alternatively in area 5), (3) personal and entertainment content, (4) ambient information, (5) information about the car.

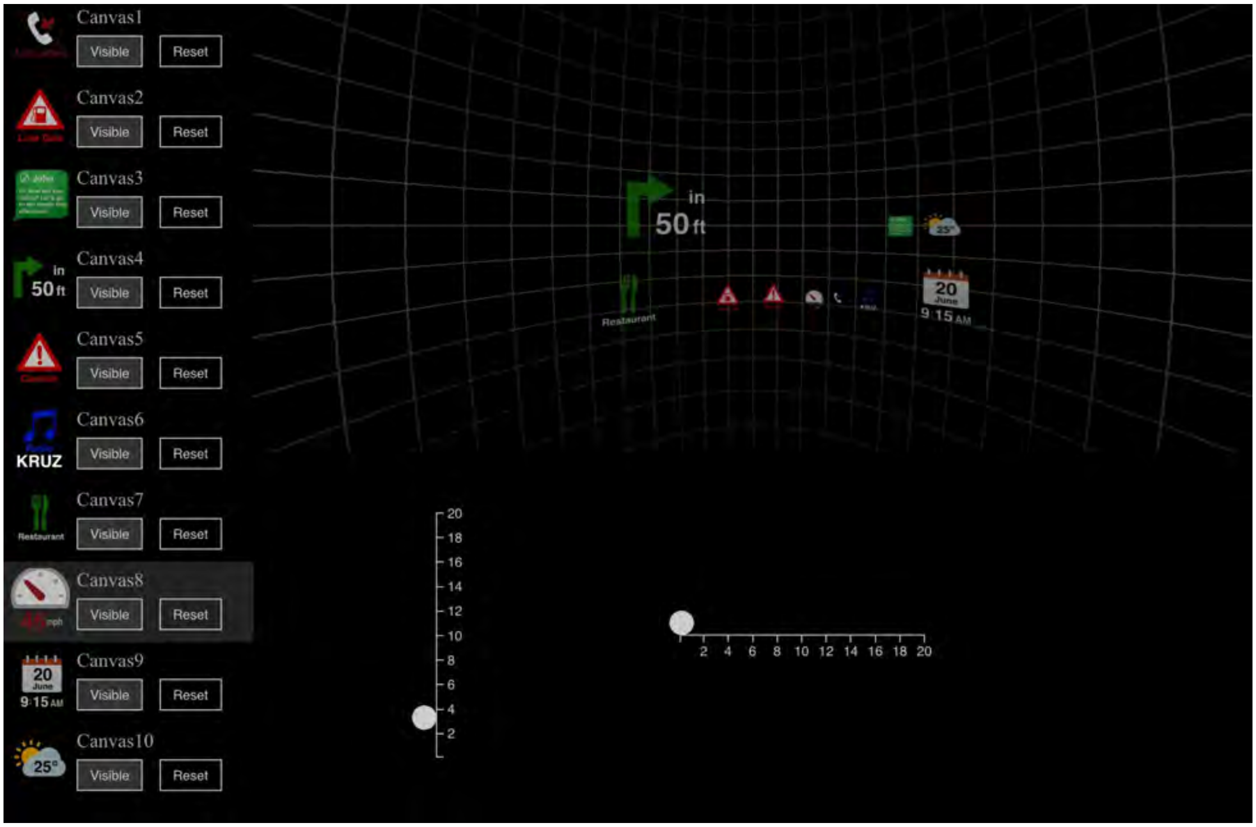


Figure 4. The touch interface for the creation of the personal layouts. It shows an example layout of one participant. Like many other participants also this one lined up many icons along the bottom edge of the windshield.

Hi, how are you doing? Let's go to the beach this afternoon!

Figure 5. A participant creating his personal layout. The participant placed items within areas relevant for safe driving. Thus, we do not consider this layout safe.

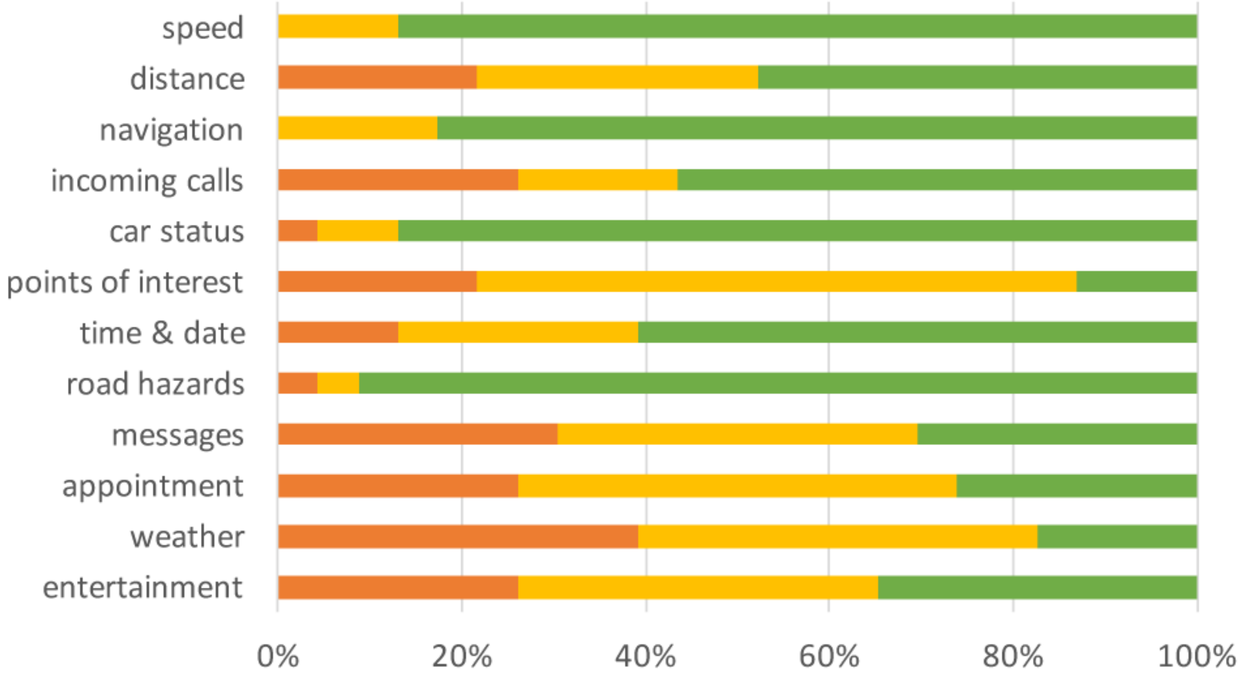


Figure 6. Participants selected median=6 of the above types of information to be displayed on their personal HUD (green=yes, yellow=sometimes, orange=no). They clearly gave priority to driving-related content.

Figure 7. Examples of personalized layouts. The background shows the driving scene in which the final layout was created. Based on the AOIs (defined in figure 2), we would not recommend to use these layouts on the road.

Figure 8. The top left image shows the mean locations derived from the personal layouts of our participants. The bottom left image shows a pattern that we found within several personal layouts (here 8): Participants placed only few icons in the driving scene and lined up the remaining icons along the bottom edge of the windshield. The images to the right show the locations chosen for the different types of information. The shape and dimensions of each image correspond to the entire windshield.

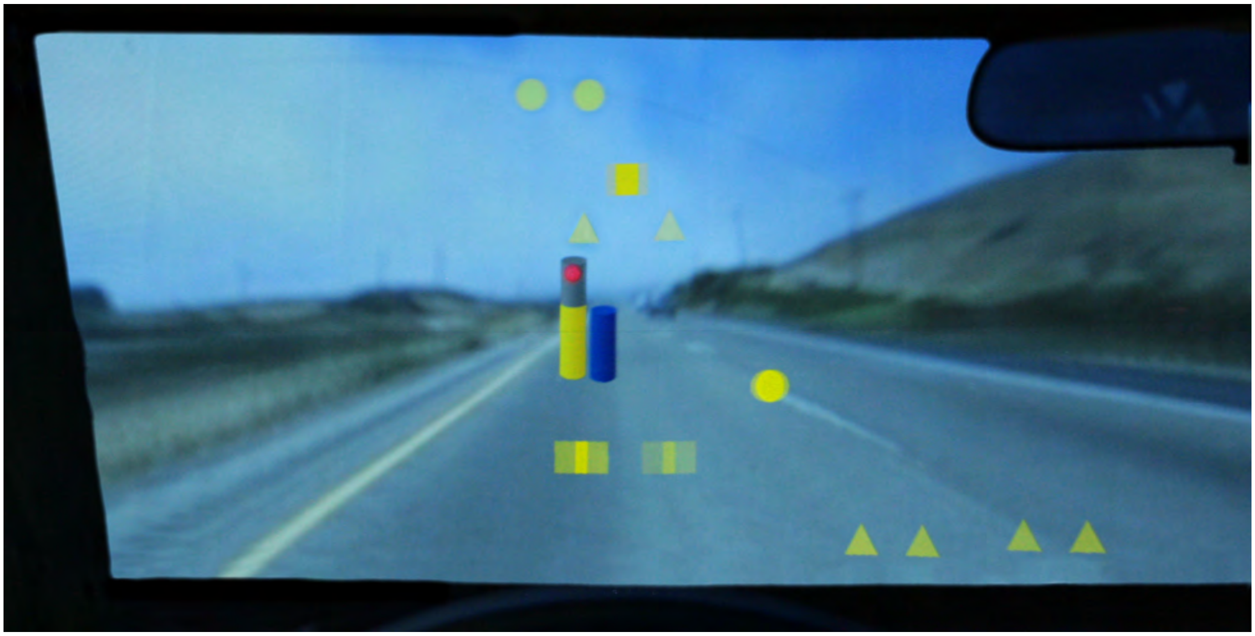


Figure 9. Snapshot of the driver's view during the second study, showing the image for the left and right eye. Participants wear shutter glasses to perceive a 3D scene (shapes with less intense color will be perceived as one shape). Participants had to react to appearing and changing stimuli by pressing buttons on the steering wheel.

Hi, how are you doing? Let's go to the beach this afternoon!

Figure 10. Example information layout according to the one-fits-all concept (Häuslschmid, Shou, O'Donovan, Burnett, & Butz, 2016). Content is primarily placed above and below the areas relevant for driving, apart of the only temporarily visible textual content.