2022 IEEE on Conference Virtual Reality and 3D User Interfaces (VR) | 978-1-6654-9617-9/22/$31.00 ©2022 IEEE | DOI: 10.1109/VR51125.2022.00074

Content Presentation on 3D Augmented Reality Windshield Displays in the Context of Automated Driving

Andreas Riegler *
University of Applied Sciences Upper Austria
Johannes Kepler University
Linz, Austria

Andreas Riener †
Technische Hochschule Ingolstadt, Germany

Clemens Holzmann ‡
University of Applied Sciences Upper Austria

Abstract

Increasing vehicle automation presents challenges as drivers of automated vehicles become more disengaged from the primary driving task, as there will still be activities that require interfaces for vehicle-passenger interactions. Windshield displays provide large-content areas supporting drivers in non-driving related tasks. This work addresses user preferences as well as task and safety aspects for 3D augmented reality (AR) windshield displays in automated driving. Participants of a user study ($N = 24$) were presented with two modes of content presentation (multiple content-specific windows vs. one main window), and could freely choose their preferred positions, content types, as well as size, and transparency levels for these content windows using a simulated "ideal" windshield display in a virtual reality driving simulator. We found that using one main content window resulted in better task performance and lower take-over times, however, subjective user experience was higher for the multi-window user interface. These insights help designers of in-vehicle applications to provide a rich user experience in automated vehicles.

Index Terms: Human-centered computing—Visualization—Visualization techniques; Human-centered computing—Visualization—Visualization design and evaluation methods; User Interfaces—User Interfaces—Graphical user interfaces (GUI); Information Interfaces and Presentation—Miscellaneous

1 Introduction

Nowadays, drivers perform an increasing number of activities while driving, such as the primary driving task, as well as interacting with the vehicle's infotainment system (e.g., controlling the music player, entering navigation information, retrieving vehicle information) [25]. Automated driving (AD) further increases drivers' desire for non-driving related tasks (NDRTs) [33]. In highly (SAE level 3 and 4) and fully automated driving (SAE level 5) [6], the primary driving function is performed by the automated vehicle (AV), and new opportunities arise to use AVs as entertainment and office platforms (e.g., [46, 47]).

For many of these non-driving related activities, the driver needs to receive feedback, either visually (e.g., [7]), or otherwise such as auditory (e.g., [22]), and olfactory (e.g., [13]). Currently, there exists a multitude of displays in the vehicle to provide visual output, including dashboard, tablet, and head-up displays [18]. Head-up displays (HUDs) visualize information in the drivers' field of view towards the outside road environment which provides the benefit of quickly retrieving information while observing the road [18, 37]. Going further, windshield displays (WSDs) provide an even larger view and interaction space as they extend HUDs to the entire windscreen, thereby making this display type usable for displaying world-fixed navigation information [15], visualizing nearby points of interest (POIs) [21], and engaging in work, entertainment, and social interaction activites [44], among others. A further potential of WSDs is to enhance user trust by increasing system transparency in AVs [60]. As more and more drivers demand increasing adaptive and personalized interfaces and devices [31], WSDs provide a novel opportunity for the car industry to reduce visual clutter in the instrument cluster and center stack, and provide digital information on the WSD, tailored to each driver's and passenger's needs. Hence, WSDs can be used to create a single user interface (UI) for all in-vehicle infotainment systems [16], and even for outside interactions (e.g., [5]). For automated driving in particular, WSDs may be helpful to inform the driver to take over control of the vehicle in case of so-called take-over requests (TORs) [58]. As customization in smart devices such as smartphones receives increasing attention (e.g., customizable contents through apps, and layouts), in-vehicle interfaces are poised to become more user-centered in terms of adaptation and personalization in the future [23]. Furthermore, the technological advancements in augmented reality (AR) may result in new ways to present information on a WSD, providing world-fixed visualizations (i.e., the content appears to be anchored in the real world) [16]. Accordingly, "floating" 2D or 3D AR objects are an interesting approach towards the realization of such an adaptable interface. Consequently, designers of AR WSD interfaces need to take this trend into consideration by giving drivers the opportunity to customize the content presentation on the WSD. However, although the potentials of WSDs for AVs have been highlighted, little research has been conducted to systematically evaluate user preferences in terms of personalization of content and layout in AR WSDs, and their impact on task and take-over performance. Drivers of SAE level 3 (L3) and level 4 (L4) conditionally AVs may position content in a way that emphasizes entertainment functions, for example, however, such a layout may be considered unsafe from a TOR viewpoint.

Therefore, we investigate and evaluate AR WSDs in terms of user preferences including content and layout, as well as their effect on task and take-over performance for SAE L3 automated vehicles, as a first, to the best of our knowledge. To this end, we let drivers build their own personalized WSD layout in a virtual reality (VR) driving simulator, and compare the possibilities of having multiple content-specific windows with one single main window for content presentation. Based on the analysis of user preferences, task and take-over performances, we discuss the potential implications of personalized windshield display user interfaces.

2 Related Work

In the context of manual driving, the potential of AR applications has already been shown in prototypical user studies. Traditional approaches utilizing HUDs often aim to increase safety. For example, Smith et al. [53] could demonstrate that presenting information directly in a driver's line of sight may lead to increased driving performance and reduced distraction. Another application area for AR HUDs is navigation, where digital arrows are blended into the

*e-mail: andreas.riegler@fh-hagenberg.at
†e-mail: andreas.riener@thi.de
‡e-mail: clemens.holzmann@fh-ooe.at

978-1-6654-9617-9/22/$31.00 ©2022 IEEE
DOI 10.1109/VR51125.2022.00074

outside environment to aid navigation (e.g., [2, 27]). More recent research has directed its attention to NDRTs and passenger experiences, in which drivers/passengers perform office or entertainment activities. However, for conditionally automated vehicles, such tasks must be performed all the while the driver is kept in the loop [12], as they must be able to take over control of the vehicle in case of emergencies [14]. Therefore, it can be very beneficial for the driver to look in the direction of the traffic while utilizing the windshield as a display [52]. Further research on performing in-vehicle work-related tasks shows that participants prefer using a WSD to a head-down display (such as traditional dashboard or center stack displays) [47]. AR content can be visualized to keep a driver's visual focus on the road by reducing or even eliminating glances between the primary driving task and other activities [50]. As a consequence, the implementation of TORs, i.e., notifying the driver to gain control of the vehicle, could benefit from the driver's forward viewing direction and the WSD's large screen space. Applications using WSDs are expected to make in-vehicle experiences for both the driver and passengers more enjoyable, and ease the advancements of vehicles in the transition phase from manual to automated driving [28]. In this research, we focus on automated driving (SAE L3 and higher), as AR functionality is expected to go hand-in-hand with driving automation [39, 56], and can help to establish trust in AD [60]. Currently, however, the realization of AR WSDs is not practicable due to technical and cost issues [16]. Meanwhile, the applicability of AR WSDs as well as future use cases can be demonstrated and evaluated using software simulation, in many cases using virtual reality (VR) technology (e.g., [17, 34]).

2.1 AR WSD Personalization

Initial research on personalization of large head-up as well as windshield display content has been conducted. Häuslschmid et al. [19] explored a generalizable view management concept for manual vehicles (SAE L0–2) that includes drivers' tasks, context, resources, and abilities for efficient information recognition and comprehension. The findings show content-specific areas, for example safety-critical, and personal areas, on the WSD desired by the study participants. Additionally, Häuslschmid et al. [23] further investigated user preferences and safety aspects for 3D WSDs in manual driving. They found that while personalization is desired by users, their customized layouts do not support safe driving, compared to a one-fits-all layout. Therefore, Häuslschmid et al. suggest using a one-fits-all layout as information uptake was found to be higher for these layouts, with the trade-off that individual user preferences are not sufficiently regarded. In the context of automated driving, Riegler et al. [44] investigated windshield display content, window sizes, window transparency, and importance for SAE L3 and L5 AVs. Their experiment aimed at revealing driver-passengers' requirements and preferences for WSDs, and thereby distinguished between different content types, such as warnings, vehicle-related information, work-, entertainment-, and social media content, among others, and levels of vehicle automation. The study was conducted on a simulated 2D WSD, and the content windows were drawn and attributed in a fixed distance from the driver. Results reveal that drivers are aware of the implications of the different levels of vehicle automation, as content windows were utilized in more peripheral areas of the WSD in SAE L3 driving, while the entire WSD was used for SAE L5 driving. However, as their study was focussed on initial exploration of user preferences for WSDs, no task or take-over performance was assessed. Additional findings by Riegler et al. suggest that world-fixed AR visualizations could lead to increased task and take-over performance, compared to screen-fixed content presentations, however, user experience results show no clear preference [43]. Therefore, variable distance in content presentation on the WSD should be evaluated further, from a personalization viewpoint.

Our state-of-the art research suggests that there are two directions for presenting content on a 3D AR windshield display: (1) a single main window, containing all content in sub-menus, utilizing only a single section of the WSD, similar to today's in-vehicle infotainment systems (IVIS) displayed on a tablet in the center console of the vehicle, and (2) multiple content-specific windows, utilizing the entire windscreen design space. In this paper, we identify this research gap pertaining to the personalization of windshield display content in automated driving for SAE L3 AVs, and further evaluate the user-centered WSD design with task and take-over performance measures. Accordingly, we aim to investigate personalization parameters for 3D AR WSDs, and make qualitative and quantitative statements regarding the layout, i.e. a one-fits-all main window vs. multiple content-specific floating windows, as well as subsequent recommendations for designing content for such large displays in the automotive context.

3 Research Questions

As windshield displays enable the driver/passengers to perform NDRTs on a large screen in conditionally and fully automated vehicles, we evaluate visual attributes and their impact on user experience, workload, as well as task and take-over performance for AR-supported 3D WSDs with the following research questions:

- **RQ1:** *Which, and how many areas on 3D WSDs do drivers of conditionally automated vehicles prefer for displaying information?* We hypothesize that drivers would, if provided, personalize content presentation on the 3D WSD, and assign content windows to specific areas of the WSD.
- **RQ2:** *Do drivers have a clear preference regarding window presentation (multiple content-specific windows vs. one main window)?* We hypothesize that drivers have a clear preference regarding the window(s) placement on the 3D WSD.
- **RQ3:** *Which window parameters (such as size, transparency, content types) are desired to be customized?* We hypothesize that drivers have a clear preference regarding window parameters.
- **RQ4:** *How does the driver-selected WSD personalization impact task and take-over performance?* We hypothesize that both task and take-over performance are improved by driver's WSD personalization.

4 Design and Implementation

We utilized the open-source VR driving simulator *AutoWSD* [36, 38], and modified it to enable participants to freely move and adjust content windows on a simulated 3D AR windshield display while driving in a virtual highway scene.

We created four scenarios, one for each WSD condition, in order to avoid learning effects pertaining to traffic scenes and take-over requests. We kept the scenarios short (approx. 8 minutes), in order to reduce the potential simulator sickness to a minimum. We further designed a "warm-up" setting that allowed participants to familiarize themselves with the virtual reality environment. During the scenario, the WSD displayed semantic sentences, one at a time, with the purpose of measuring situational awareness and task performance [8]. These sentences were provided in German and English language, according to the preferred language of the study subjects. An example for a semantically correct sentence would be "After finishing all tests the class celebrated for a whole week". An example for a semantically incorrect sentence would be "The spider goes on vacation by plane". Since we evaluated SAE level 3 automated driving [6], we did not assume subjects to place their hands on the steering wheel during the entire ride, hence, we implemented a speech interface for subjects to perform the task [32]. To this end,

(a) Baseline, screen-fixed 2D WSD content proposed by Riegler et al. [44] for SAE L3.

(b) Example personalization using 3D WSD content for SAE L3.

Figure 1: Condition M: Multiple floating windows displayed on a windshield display for SAE L3 AD.

we accessed the offline version of the Microsoft Speech API, which is able to process and recognize keywords or phrases, such as "Yes" and "No", and their German equivalents.

Additionally, we designed a take-over for each scenario, and subjects had to grasp the steering wheel and/or operate the brake pedal, and steer the vehicle away from the danger zone in order to avoid a collision. Upon occurrence of such a take-over request, the WSD would display a warning message "Take over" along with a warning tone, as such multimodal feedback was found to be preferred by drivers [4]. We placed the warning message for both scenarios at the respective *warnings* window.

Figure 1 shows both presentation variants for condition *M* (multiple content-specific windows), i.e., the flat, screen-fixed 2D baseline (Figure 1a), and the potential personalization of the 3D WSD (Figure 1b). Accordingly, condition *S* refers to the placements and characteristics of a single window used for all content types (see Figure 2).

In case a vehicle in the front was closer than a WSD content window, based on personalized distance parameter, the window would "snap" to the back of the front vehicle, in order to avoid appearing occluded by the front vehicle. In a recent study, Riegler et al. [43] explored anchoring WSD content to real-world objects in SAE L3 AD and found increased task performance and situation awareness, as compared to screen-fixed content. To this end, we dynamically snap the content window to the front vehicle for the purposes of (1) reducing visual clutter between the real and virtual objects, and (2) increase the driver's perception of the front vehicle's movements by adjusting the content window to move accordingly.

5 Driving Simulator Study

We designed our user study as 2×2 within-subject design, where each study participant would try both content presentation modes (i.e., multiple windows, condition M, and one single main window, condition S) for both the baseline and personalized content presentation, Additionally, we used a counterbalanced design to reduce the bias caused by the order in the variables.

5.1 Procedure

First, the subjects were given an introduction to the purpose of the study. This included the explanation of the virtual reality driving simulator (see Figure 3), automated driving at SAE level 3. We further explained the concept of a windshield display and emphasized the precedence of a safe but also comfortable drive. Additionally, we gave an overview of the scenario procedure. Next, participants were asked to answer a demographic questionnaire, as well as the Affinity for Technology Interaction (ATI) questionnaire which is used to determine subjects' attitudes and engagements towards technology interplay [1], and finally the pre-study Simulator Sickness Questionnaire (SSQ) [24] to determine the initial level of nausea before proceeding. After each of the two scenario in the virtual reality environment, participants had to fill in the Technology Acceptance Model (TAM) [10], NASA Raw Task Load Index (NASA RTLX) [20], and User Experience (UEQ-S) [48] questionnaires. Finally, subjects were asked to complete the post-study Simulator Sickness Questionnaire (SSQ) [24] and to describe their experience in a short interview. The entire procedure took approximately 75 minutes per participant. Subjects did not receive any compensation for participating in the study.

5.1.1 WSD Personalization

For both conditions M and S, participants were given the opportunity to adjust the initial baseline condition (content windows on a flat 2D WSD). With assistance of our experimenters, participants were asked to position multiple content windows (condition M, "multiple windows") on the WSD according to their personal preferences, and afterwards associate each content window with further attributes such as their transparency and size. We set the initial WSD layout and content windows according to the qualitative findings by Riegler et al. [44].

For each window, participants had to specify the desired content type (by drag and drop). Therefore, we offered a list containing potential media types:

- *Warnings (**W**)*, such as a potentially short headway, mechanical failures, etc.
- *Vehicle information (**V**)*, such as the current speed, or distance/time to destination
- *Work/office related information (**O**)*, such as emails or calendar
- *Entertainment (**E**)*, such as music playlists, videos, etc.
- *Social Media (**S**)*, such as Facebook, Twitter, etc.
- *Custom/Other (**C**)*, such as notifications, weather information, smarthome control, etc.

Consequently, the participants started with the personalization of the provided content windows (e.g., warnings, vehicle-related information, entertainment, social media, work-related information, etc.) on the 3D WSD on a large monitor, using a computer mouse, and subsequently refining the layout in the virtual environment, using the directional-pad buttons on the steering wheel. The reason

(a) Baseline, screen-fixed 2D WSD content proposed by Riegler et al. [44] for SAE L3.

(b) Example personalization using 3D WSD content for SAE L3.

Figure 2: Condition S: Single main window displayed on a windshield display for SAE L3 AD.

we chose to let subjects first generate a coarse layout on a monitor was because of its ease to move the content windows, and quickly modify the layout to one's preference. Additionally, we instructed participants that speech commands to adjust the content windows were possible, such as "place the social media window more to the right", in which case the study organizer would perform the changes with the Wizard-of-Oz technique. For condition S ("single window"), the participants could only place that one-fits-all window on the WSD. We have chosen to use only rectangles as content windows, since this shape is most commonly used in applications in many areas, such as desktop computers, tablets, or smartphones. Following the initial positioning and sizing of the windows, participants were then asked to put on the HTC Vive Pro Eye and the study organizer started the VR application with the subject's initial WSD layout. Participants could familiarize themselves with the VR environment and their WSD personalization on a short warm-up track, and fine-tune the WSD layout further. Subsequently, the instructions for the current task were given, and the scenario began with the vehicle starting to drive automatically. During the ride, subjects were also allowed to adjust their WSD personalization, however, we noted that this could negatively affect their task and take-over performance.

5.1.2 Non-Driving Related Task (NDRT)

For the cognitive task engagement, we chose a reading comprehension task, which is based on the reading-span task by Daneman and Carpenter [9], in which subjects had to determine whether a given sentence is semantically correct or incorrect. We used this particular task as NDRT as it is commonly used in office and social media tasks, such as proofreading, and reading text messages, and can be compared between conditions and users. Participants were requested to rate the sentences as quickly but also as correct as possible on their semantic correctness.

For condition S, the text was displayed on the one main window on the WSD, and for condition M, the text was displayed in the *work* window. Only one sentence was shown to the participant at once. In case the sentence was semantically correct, participants were asked to say "Yes", otherwise "No". Upon the affirmative or negative answer, correct or not, the next sentence would be displayed. We recorded the task completion time as well as correctness of the answer. If the participant took more than 10 seconds to answer the given sentence, it was counted as incorrectly answered, and the next sentence was displayed.

5.1.3 Take-Over Task

Participants drove on a two-lane highway road, and always started with activated AD mode. As we used SAE L3 scenarios, we designed two TORs where the driver would need to take control of the vehicle and steer it manually away from the danger zone. In case a TOR occurred, the warning was displayed in the "warning" window in condition M, and in the single main window in condition S. In that case, all other WSD contents were faded out to emphasize the importance of the TOR warning. Additionally, the TOR display message was accompanied by an auditory "beep". A TOR was displayed when an accident occurred in front of the vehicle, representing an emergency TOR as the time to collision was approx. 5s [59]. At this time, participants had to take over control of the vehicle, either by pressing a pedal for $> 5\%$ or a steering angle change of $> 2°$ [57], to activate the manual driving mode and subsequently to avoid a collision. After steering the vehicle away from the danger zone, the vehicle resumed automated driving, and the WSD content was faded back in.

5.1.4 Measurements for Safety, Usability, User Experience, Workload, and Acceptance

To assess safety, we determine TOR reaction times. For usability, we assessed drivers' NDRT performance. For evaluating the workload, we used self-ratings using the NASA RTLX questionnaire. Acceptance of the investigated technologies was measured with self-ratings based on the Technology Acceptance Model questionnaire. Usability and user experience was determined using the self-rated User Experience Questionnaire.

5.2 Participants

We recruited 24 participants (14 male, 10 female) aged between 21 and 52 ($Mean = 27.1$, $SD = 7.1$) years with no knowledge of the project from the general population of our university, using mailing lists and posted flyers. All subjects were in possession of a valid driver's license. In terms of annual mileage, nine participants drove less than 2,000km, and (36%) 10 participants between 2,000km and 10,000km (40%). The remaining five respondents reported a higher mileage (24%). Furthermore, 17 participants were already familiar with virtual reality. Participants had normal or corrected to normal vision. Participants with glasses were able to keep them on while wearing the HTC Vive Pro Eye HMD. The questionnaire on interaction-related technical affinity (ATI scale) provided a mean value of $4.24 (SD = 1.19)$ for the sample, which means that the participants assessed themselves as having a high affinity for technology [1].

6 Results

In the following, we present a detailed analysis of the collected data with respect to our research questions. To evaluate differences in

Figure 3: The study setting. The study participant is wearing the HTC Vive Pro Eye Virtual Reality headset, which includes speakers for audio output. The Logitech steering wheel and pedals are used for take-overs and manual driving. The microphone next to the steering wheel is used for speech input. The monitor is used by the study organizer to follow along.

task and take-over performance for the conditions M and S, we performed analyses of variance (ANOVAs) with Bonferroni correction considering a 5% threshold for significance. In case of multiple comparisons, we adjusted the significance level from $\alpha = 0.05$ to the Bonferroni-corrected α'. For multi-item self-rating scores, we computed Cronbach's α, resulting in satisfying reliability scores for all NASA RTLX, UEQ-S, and TAM dimensions. Throughout this paper, we use the abbreviations Mdn for median, SD for standard deviation, and SE for standard error.

6.1 Windshield Display Characteristics

For both conditions, we determined the window properties position, width, height, tilt, distance, and transparency. For condition M, we additionally counted the number of utilized windows for each content type. This was not the case for condition S, as the single WSD window contained all content types. The overview of the personalized WSD window properties for both conditions is provided in Table 1, where both the mean values and standard deviations are provided for each metric.

6.1.1 Condition M: Multiple Content-Specific Windows

Counts The *Counts* metric is only relevant for condition M, as condition S always consists of a single main window. For condition M, the number of utilized windows differs with its associated content type. Participants seem to be well aware of the limitations of conditionally automated vehicles (SAE L3), as they provided a mean number of 1.208 warning windows (**W**) on the WSD. This signifies the importance of receiving feedback from the AD system, especially in safety-relevant situations. Also, vehicle-related information windows (**V**) were utilized commonly, and work (**O**), entertainment (**E**) as well as social media (**S**) windows were not used as often. Finally, custom content windows (**C**) that do not include any of the aforementioned information, for example smarthome information, were used more sparingly.

Position We also looked at the prominent positions for each content-specific window. While warning and vehicle-related windows were mostly placed on the left section of the WSD, work, entertainment and social media windows were positioned in the center location of the WSD. Warnings were prominently placed at the bottom of the WSD, similar to currently available HUDs, vehicle-related information were placed both at the bottom and top left side of the WSD. Further, custom-information windows were mostly placed in peripheral sections of the WSD.

Width and Height We calculated the width and height of each content window as a ratio of the entire windscreen dimensions. Work, entertainment and social media windows received the largest area of the windshield for their content. Warnings and vehicle-related information, and particularly custom-content windows, did not receive as much screen space from the participants.

Tilt As study subjects had the option to rotate/tilt the content windows, we also measured these individual preferences. Interestingly, warnings and vehicle-related information were not rotated at all, which makes sense as these windows were prominently placed on the left side of the vehicle where the driver is situated. Additionally, custom-content windows were rarely tilted as subjects did not suppose to look at these windows often or for longer periods of time. In contrast, the remaining content windows, as they were located in the center of the WSD, as opposed to the driver's side, were tilted towards the driver with a mean angle of approx. 17 degrees.

Distance The distance parameter shows that warnings and vehicle-related information, as well as custom-content windows, were placed more closely to the driver, similar to currently available HUDs, with approx. 2 meters distance from the driver. Contrarily, work, entertainment, and social media windows were placed at larger distances of approx. 12 meters. Therefore, it seems that driving-related information should be presented in closer proximity to the driver as opposed to non-driving related content.

Opacity We also investigated differences regarding the provided opacity for each content window, and found that warnings received the highest opacity (approx. 80%), while other content types showed more transparency. These findings indicate that warnings are considered important to the users, hence the low transparency, and other media types, where immediate actions might be perceived as not as important, were designed to be more transparent.

6.1.2 Condition S: Single Main Window

Position The single main window was prominently placed in the horizontal and vertical center of the windshield. While some participants started to position it either on the driver's side, or on the passenger's side, they realized during the drive that both these setups were not ideal in terms of see-through capabilities, and visual attention in case of take-over requests.

Width and Height The main window was designed to be larger than any single content window in condition M, spanning approx. 35% of the windscreen's width, and 70% of the windscreen's height. We found that some participants had troubles finding the "right" dimensions to accommodate the media types, and would therefore design the window larger.

Tilt As the window was mainly positioned in the center of the windscreen, participants chose to tilt it towards the driver's direction for better readability and reduced perspective distortion of the content.

Distance Distance-wise, we found user-specific differences as participants on the one hand intended to use the main window as a replacement for nowadays common tablet interfaces located at the center stack of the vehicle. On the other hand, similar to condition M, where users placed work, entertainment, and social media windows farther away, the single main window was placed such that all potential content types would be appropriately visible, according to the participants. To this end, most participants opted to place the window at a distance of approx. 10 meters, which puts it farther away and today's HUDs, but not as distant as some content windows in condition M.

	M						S
Content Type	W	V	O	E	S	C	All-in-One
Counts	1.208 (0.415)	1.125 (0.337)	1.083 (0.583)	0.958 (0.751)	0.833 (0.702)	0.708 (0.464)	1.000 (0.000)
Width (%)	16.708 (4.418)	15.333 (4.331)	26.333 (5.483)	27.750 (6.117)	22.125 (5.102)	14.083 (4.925)	35.525 (5.055)
Height (%)	11.250 (4.067)	10.375 (3.876)	25.833 (4.869)	25.542 (5.090)	19.375 (2.856)	9.250 (3.930)	71.110 (10.455)
Tilt (deg)	0.000 (0.000)	0.000 (0.000)	17.000 (7.929)	17.375 (6.883)	16.500 (6.129)	3.750 (5.758)	14.385 (3.667)
Distance (m)	2.363 (0.894)	2.523 (0.729)	12.083 (3.361)	13.000 (3.093)	11.625 (3.187)	2.701 (1.001)	10.075 (3.825)
Opacity (%)	80.417 (19.219)	61.875 (16.538)	52.917 (10.099)	51.458 (16.647)	46.667 (11.578)	49.791 (12.552)	63.775 (15.850)

Table 1: Overview of the different content types and their window properties as specified by the study participants.

Opacity The mean opacity of the single main window was set to approx. 63%, which, again, similar to the above metrics, is an intermediate value compared to the content windows in condition M. As the main window is quite large, and placed in the center of the WSD, on average, the transparency reflects this circumstance. Participants seem to be aware that in SAE L3 AD, drivers should still monitor the outside environment from time to time, and take-over requests can occur at any time, and hence designed a semi-transparent user interface.

6.2 Quantitative Measures

As quantitative measures, we assessed the error rates, task completion times, as well as take-over request (TOR) times for both conditions, for both the baseline and personalized designs. Table 2 gives an overview of the overall task performances and take-over times. Since the results are normally distributed, we applied a paired two-samples t-test for our further analysis.

6.2.1 Task Performance and Error Rate

The mean task completion time (i.e., giving a reply regarding the semantic correctness of a given sentence) for condition M (baseline) was $6.784s$ ($SD = 0.955$) and for condition S (baseline) $6.204s$ ($SD = 0.988$) (see Table 2). The respective personalized user interfaces led to a mean task completion time of $6.168s$ ($SD = 1.079$) for condition M, and $5.810s$ ($SD = 1.266$) for condition S. As expected, the user-defined personalized UIs achieved better results than their pre-defined baseline counterparts. Regarding statistical significance, the personalized single-window UI achieved a significantly better task performance than the baseline multi-window solution ($t(23) = 4.482, p = 0.01$, Cohen's $d = 0.98$).

The mean error rate for condition M (baseline) was 0.225 ($SD = 0.184$) and for condition S (baseline) 0.277 ($SD = 0.158$). Again, the personalized WSD UIs resulted in lower error rates than the baseline layouts. However, we did not find a statistically significant differences between all conditions.

6.2.2 Take-over Performance

Regarding the mean take over time, we identified a statistically significant difference between the multi-window baseline and personalized UIs (baseline: $Mean = 3.358s, SD = 1.426$, personalized: $Mean = 2.451s, SD = 1.040, t(23) = 2.320, p = 0.025$, Cohen's $d = 1.0$). Additionally, we found a statistically significant difference between the single-window personalized UI and the multi-window baseline UI ($t(23) = 2.779, p = 0.021$, Cohen's $d = 1.05$).

6.3 Qualitative Measures

To validate the VR driving simulator setup, we report on simulator sickness based on the Simulator Sickness Questionnaire (SSQ) used before and after the VR drive. We further assessed the Technology Acceptance Model (TAM), the User Experience Questionnaire (UEQ-S), as well as the NASA Raw Task Load Index (NASA RTLX). Additionally, we report interview results based on semi-structured interviews conducted after the experiment.

6.3.1 Technology Acceptance Model

Considering the TAM, we evaluated the subscales Perceived Usefulness (PU), Perceived Ease of Use (PEOU), Attitude towards Use (ATT), Intent of the system, and Trust in the system. Considering the means of the evaluated TAM subscales we can see that condition M (multi-window UI) received higher ratings than condition S (single-window UI) in the scales PU, PEOU, ATT, and Trust when comparing the personalized variants. The comparative analysis of the inter-condition variants (baseline vs. personalized UIs) reveals that the personalized variants received equal or better ratings by the subjects (see Table 3). Overall, the highest subjective ratings were given to the personalized multi-window user interface. Friedman ANOVA reported significant differences between PU ($F(2,23) = 4.560, p = 0.030$), PEOU ($F(2,23) = 5.087, p = 0.022$), and ATT ($F(2,23) = 3.310, p = 0.034$) between both personalized UIs.

6.3.2 User Experience Questionnaire

The User Experience Questionnaire Short (UEQ-S) allowed us to calculate the pragmatic quality (usability) and hedonic quality (user experience) of the two WSD conditions. The UEQ-S has a range from -3 to 3. Table 4 shows the mean values depending on the two WSD conditions M and S in both the baseline and customized variants. Values greater than 0.8 indicate a positive evaluation.

Table 4 gives an overview of the UEQ-S results. For the pragmatic quality a mean value of 2.003 ($SD = 1.355$) was achieved for condition M (baseline) and 2.124 ($SD = 1.048$) for condition M (personalized). For conditions S, we calculated for the pragmatic quality a mean value of 1.537 ($SD = 1.412$) (baseline) and 1.881 ($SD = 1.920$) (personalized), respectively. Accordingly, a mean value of 1.820 ($SD = 1.409$) for condition M (baseline) and a value of 1.953 ($SD = 1.336$) for condition M (personalized) was determined for the hedonic quality, and 1.457 ($SD = 0.940$) for condition S (baseline) and 1.991 ($SD = 1.027$) for condition S (personalized). Friedman ANOVA revealed significant effects for the overall UEQ-S scores of the baseline and personalized single-window conditions ($F(2,23) = 5.125, p = 0.009$). The comparative analysis of both multi-window variants resulted in no statistically significant differences.

6.3.3 NASA RTLX

Figure 4 shows the aggregated NASA RTLX results for the WSD conditions in both baseline and personalized variants. The scales physical and temporal demand were on average rated higher as the other categories. As expected, the default baseline configurations received a higher subjective workload than the custom user-defined setups. However, comparing the two personalized variants provides interesting insights. While mental demand and frustration were rated lower for condition M, the metrics performance and effort received more positive ratings for condition S. We also calculated the total mean score for the WSD conditions. For condition M (baseline), we determined a total mean score of 25.00 ($SD = 5.58$), and for the personalized counterpart 20.14 ($SD = 9.64$). In contrast, the total mean score for condition S (baseline) is 24.51 ($SD = 4.82$), and for the personalized variant 19.23 ($SD = 5.67$). They represent the subjectively experienced stress and were calculated from the

Variable	M (Baseline) Mean (SD)	M (Personalized) Mean (SD)	S (Baseline) Mean (SD)	S (Personalized) Mean (SD)
Error Rate	0.225 (0.184)	0.210 (0.140)	0.277 (0.158)	0.241 (0.190)
Task Completion Time (s)	6.784 (0.955)	6.168 (1.079)	6.204 (0.988)	5.810 (1.266)
TOR Time (s)	3.358 (1.426)	2.451 (1.040)	3.040 (1.005)	2.170 (1.140)

Table 2: Paired two-samples t-test for NDRT and take-over performance for the baseline and personalized variants of conditions M and S.

	M		S	
Variable	Baseline	Personalized	Baseline	Personalized
PU	5.012 (0.847)	6.113 (0.923)	5.012 (0.446)	5.009 (0.587)
PEOU	4.899 (0.665)	5.874 (0.812)	4.563 (0.316)	5.154 (0.634)
ATT	5.676 (1.120)	6.125 (0.288)	4.333 (0.987)	5.569 (0.553)
Trust	5.002 (0.777)	5.888 (0.598)	5.517 (0.860)	5.214 (0.821)
Intent	5.963 (1.134)	6.022 (1.369)	5.295 (0.945)	5.991 (1.078)

Table 3: Overview of the mean values of the TAM scores for the multi-window (M) and single-window (S) conditions. The standard deviations are given in brackets.

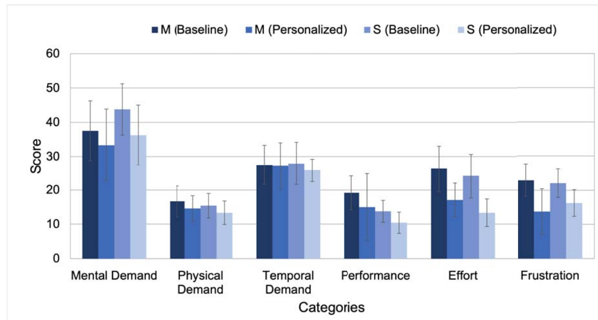

Figure 4: NASA RTLX scores for both WSD conditions, in baseline and personalized configurations.

	M		S	
Variable	Baseline	Personalized	Baseline	Personalized
Pragmatic	2.003 (1.355)	2.124 (1.048)	1.537 (1.412)	1.881 (1.920)
Hedonic	1.820 (1.409)	1.953 (1.336)	1.457 (0.940)	1.991 (1.027)
Overall	1.911 (1.370)	2.077 (1.222)	1.483 (1.225)	1.934 (1.414)

Table 4: UEQ-S scores for both WSD conditions, in baseline and personalized configurations. The standard deviations are given in brackets.

mean values of the six subscales. Using the t-test for independent samples, we did not find a statistically significant difference between the two personalized variants. However, we calculated a statistically significant difference between the baseline and personalized variant in condition S ($t(23) = 5.270, p = .007$).

6.3.4 Simulator Sickness Questionnaire

In order to validate the VR driving simulation, we assessed the participants' simulator sickness using the standardized Simulator Sickness Questionnaire (SSQ). We used the SSQ before and after the VR scenarios for each subject. Results show that nausea among all participants received a mean value of $0.147(SD = 0.233)$; oculomotor sickness amounted to a mean value of $0.245(SD = 0.515)$; and disorientation sickness received a mean score of $0.265(SD = 0.410)$ before the VR exposure. After the VR scenarios, SSQ results revealed that nausea among all participants received a mean value of $.385(SD = 0.350)$; oculomotor sickness amounted to a mean value of $0.390(SD = 0.625)$; and disorientation sickness received a mean score of $0.344(SD = 0.500)$ When interpreting a given score of zero as no VR sickness, and 1 as slight VR sickness, these results suggest that the VR driving simulator caused very little VR sickness. The items that were most graded as moderate or severe were "Eye strain" ($Mean = 0.890, SD = 0.855$) and "Difficulty focusing" ($Mean = 0.769, SD = 0.896$), and "Blurred vision" ($Mean = 0.713, SD = .800$). Since no participant felt moderate or even severe overall VR sickness, we were able to use all participant data for analysis.

6.3.5 Interviews

In the post-experiment interview, we asked participants to express their general experience, attitude, and preference towards the system, including each display mode.

Participants favored condition M over condition S in terms of customization and personalization. As participants were free to move individual content windows for different purposes, one could "design the windshield display as large command center". Five participants also stated that collaborative aspects would be increasingly supported by the multi-window UI, as passenger-specific content could be placed on the passenger side of the vehicle, rather than the large AR interface in the middle of the WSD (condition S). It was also mentioned that the single-window interface would be bad for micro-tasks, such as quickly checking notifications, or skimming over a few emails, while longer tasks, such as reading the news, or watching videos could be better consumed by having a single point of focus on the WSD. This insight from half the participants was also reflected in the better task performance of condition S as compared to condition M, where subjects had to focus on the cognitive non-driving related task. Participants stated that an option to have the "best of both worlds" would be to provide the possibility of multi-window customizations (condition M), and providing some sort of "focus/performance mode" that emphasizes the visualization of the desired task, while the other tasks move into the background. Furthermore, safety aspects were discussed. When asked about whether they felt more in control with either condition M or S, most subjects stated that condition M provided more overall feeling of safety ("better overview of the outside road environment"), as most content windows were designed to be smaller and more transparent as well as in more peripheral areas of the WSD as compared to the single-window UI. Subjects further noted that a potential large window targeted for consuming work or entertainment tasks might be better suited for fully automated vehicles for a more immersive environment, while simple, quick tasks might be better visualized using smaller, scattered windows as provided in condition M.

7 Discussion

Three-dimensional augmented reality windshield displays are an interesting concept in the context of conditionally automated driving. Answering **RQ1**, and extending initial research by Riegler et al. [44] on two-dimensional WSDs for semi-automated vehicles, our findings show that the added distance parameters for displaying continuous-depth content on the WSD has been utilized by our participants. While there are some common areas for specific content types in both setups, we found that more peripheral windows were not only placed at a greater distance, but also tilted towards the driver, which screen-fixed two-dimensional layouts did not account for. Overall, the personalized user interfaces differed from the baseline concepts in some aspects such as placement on the WSD, mainly influenced by the distance parameter. While current HUDs are screen-fixed, recent concepts by automobile manufacturers utilize continuous-depth AR, which, combined with higher levels of vehicle automation, opens up a new design space for in-vehicle immersive experiences [40,41,56].

As for **RQ2**, our study subjects seemed to be well aware of the limitations of conditionally automated driving, and placed, in case of the multi-window UI, warning messages in the driver's side of the WSD, and less critical content types in the peripheral sections of the WSD. As Topliss et al. [54] found, manual driving behavior worsens for WSD content being displayed further from the driver's forward view. For the single-window presentation mode, participants had to find an acceptable intermediate solution between being able to monitor the roadside activity, and performing the non-driving related task. As such, window size, distance, and transparency parameters were adjusted, accordingly. We investigated a variety of self-rated usability, user experience, and workload metrics for analyzing user preferences. While the personalized solutions received better ratings than their baseline screen-fixed counterparts, comparison of both personalized interfaces show mixed results. Results of the TAM showed that the multi-window customization received a higher acceptance, however, subjective user experience and workload findings revealed no significant differences. The post-experiment interviews gave further insights in terms of potential use cases for either WSD presentation mode, such as multi-window setups with peripheral content windows for conditionally automated driving for an increased situational awareness. However, larger, more immersive content windows could be better suited for fully automated driving scenarios, which is supported by Riegler et al. [45]. Therefore, context awareness such as the vehicle's capabilities, and the possibility for users to customize in-vehicle interfaces, such as the WSD content, need to be considered in future automotive UIs (**RQ3**). While warning and vehicle-related information windows were mainly placed similarly as today's screen-fixed HUDs, other content windows, such as work, entertainment and social media windows, were placed with customized distance and tilt values such that subjects considered the benefits and limitations of a larger UI design space in the forward viewing direction. Research (e.g., [17,47,49]) is already considering utilizing WSDs for both ensuring situational awareness while performing work or entertainment activities.

Regarding task performance (**RQ4**), we found that the use of a single main window encompassing all media types significantly improved task performance for the text comprehension task. As we found in post-study interviews, many subjects stated that they could concentrate more on the task rather than having multiple potentially distracting windows in their field of view. Furthermore, we found that take-overs were performed significantly faster for the single-window mode. One possible reason as to the better TOR performance could be the warning message being shown directly in the driver's visual view of attention, as opposed to the dedicated warning window location in condition M, which may have required a focus change from the driver. This is supported by Langlois et al. [29], as AR can improve drivers' situational awareness by aiding the driver in anticipating lane change maneuvers, for example. Feedback design should therefore consider the driver's viewing direction, maybe regardless of the driver's personal preference towards a specified area of the WSD to display notifications/warnings. Furthermore, a possible way to reduce take-over times with AR interfaces might be to both utilize multimodal warning messages (e.g., [61]) and highlighting outside information that could cause a takeover (e.g., inattentive pedestrians) [26].

7.1 Limitations and Future Work

We are aware that our experiment has some limitations. First, the study was conducted in a VR driving simulator environment. We utilized VR in order to keep the experiment in a safe and controlled environment [11,42], and thus intended to create a realistic VR experience (e.g., ambient sound effects, adequate visuals, etc.). Research indicates that participants' subjective and psychological responses in VR environments are closely coupled to their experience and behaviors in a real-world setting [51], and that VR can adequately simulate AR content (e.g., [27, 30]). However, user preferences and perceptions might differ in a real driving scene. Furthermore, our study involved only a limited population, that is mostly young university students and staff in Europe. Other users might behave and perform different from our results [3]. We would also like to note that participants' responses might change as time passes as new technologies, and people's attitude and acceptance towards them.

In upcoming studies, we want to include and evaluate an interaction management system for multimodal user engagements with windshield displays. In particular, we intend to unify gaze, voice and gesture input for interacting with WSDs in order to establish context-aware cooperative interfaces [35,55]. Additionally, the role of simulator and motion sickness when driver/passengers interact and get immersed with AR WSD content should further be explored.

8 Conclusion

In this paper, we let drivers of conditionally and fully automated vehicles design their own 3D WSD layout in a VR driving simulator. We further investigated both subjective preferences and objective task and take-over performance for utilizing such WSDs. Our aim was to explore how WSDs can be used to provide higher productivity and user experience for future drivers and passengers. To this end, we determined an initial design space for 3D WSD window parameters (such as content types, distance, and transparency) by comparing two display modalities (multiple windows vs. one main window) in conditionally automated driving scenarios. Our results lead to several implications and recommendations for the use of 3D AR WSDs in SAE level 3 AVs:

- Customization and personalization of in-vehicle interfaces needs more research attention, and conventional one-fits-all solutions should be challenged. Certain levels of in-vehicle user interface customizations according to the level of vehicle automation should be addressed.
- WSD personalization (content windows, size and distance parameters, etc.) positively impacts objective task performance and subjective user experience in the evolution from screen-fixed HUDs towards world-relative AR interfaces for future in-vehicle experiences.
- The provision of a focus/performance mode for certain visually demanding tasks displayed on AR WSDs should be investigated. Quantitative and qualitative findings show that 3D AR interfaces have the potential to increase productivity and user satisfaction in vehicles, and further context-specific experiments should investigate their viability for increased automotive use cases.

Acknowledgments

This project is financed by research subsidies granted by the government of Upper Austria, and research subsidies granted for the project AutoSimAR by the Austrian Research Promotion Agency (FFG).

References

[1] C. Attig, S. Mach, D. Wessel, T. Franke, F. Schmalfuß, and J. Krems. Technikaffinität als ressource für die arbeit in industrie 4.0. 09 2018.

[2] K. Bark, C. Tran, K. Fujimura, and V. Ng-Thow-Hing. Personal Navi. pp. 1–8, 2014. doi: 10.1145/2667317.2667329

[3] L. Barkhuus and J. A. Rode. From mice to men - 24 years of evaluation in chi. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '07. ACM, New York, NY, USA, 2007. doi: 10.1145/1240624.2180963

[4] P. Bazilinskyy, S. M. Petermeijer, V. Petrovych, D. Dodou, and J. C. de Winter. Take-over requests in highly automated driving: A crowdsourcing survey on auditory, vibrotactile, and visual displays. *Transportation research part F: traffic psychology and behaviour*, 56:82–98, 2018.

[5] A. Colley, J. Häkkilä, M.-T. Forsman, B. Pfleging, and F. Alt. Car Exterior Surface Displays. pp. 1–8, 2018. doi: 10.1145/3205873.3205880

[6] S. O.-R. A. V. S. Committee. Taxonomy and definitions for terms related to on-road motor vehicle automated driving systems, 2018.

[7] D. Damböck, T. Weißgerber, M. Kienle, and K. Bengler. Evaluation of a contact analog head-up display for highly automated driving. In *4th International Conference on Applied Human Factors and Ergonomics. San Francisco. USA*. Citeseer, 2012.

[8] M. Daneman and P. A. Carpenter. Individual differences in working memory and reading. *Journal of Verbal Learning and Verbal Behavior*, 19(4):450 – 466, 1980. doi: 10.1016/S0022-5371(80)90312-6

[9] M. Daneman and P. A. Carpenter. Individual differences in working memory and reading. *Journal of verbal learning and verbal behavior*, 19(4):450–466, 1980.

[10] F. D. Davis. User acceptance of information technology: System characteristics, user perceptions and behavioral impacts. *Int. J. Man-Mach. Stud.*, 38(3):475–487, Mar. 1993. doi: 10.1006/imms.1993.1022

[11] J. De Winter, P. M. van Leeuwen, and R. Happee. Advantages and disadvantages of driving simulators: A discussion. In *Proceedings of measuring behavior*, 2012.

[12] J. Dillmann, R. den Hartigh, C. Kurpiers, F. Raisch, D. de Waard, and R. Cox. Keeping the driver in the loop in conditionally automated driving: A perception-action theory approach. *Transportation Research Part F: Traffic Psychology and Behaviour*, 79:49–62, 2021.

[13] D. Dmitrenko, E. Maggioni, and M. Obrist. Towards a framework for validating the matching between notifications and scents in olfactory in-car interaction. In *Extended Abstracts of the 2019 CHI Conference on Human Factors in Computing Systems*, pp. 1–6, 2019.

[14] A.-K. Frison, P. Wintersberger, C. Schartmüller, and A. Riener. The real t (h) or: Evaluation of emergency take-over on a test track. In *Proceedings of the 11th international conference on automotive user interfaces and interactive vehicular applications: Adjunct proceedings*, pp. 478–482, 2019.

[15] W.-T. Fu, J. Gasper, and S.-W. Kim. Effects of an in-car augmented reality system on improving safety of younger and older drivers. *2013 IEEE International Symposium on Mixed and Augmented Reality (ISMAR)*, pp. 59–66, 2013. doi: 10.1109/ismar.2013.6671764

[16] J. L. Gabbard, G. M. Fitch, and H. Kim. Behind the Glass: Driver Challenges and Opportunities for AR Automotive Applications. *Proceedings of the IEEE*, 102(2):124–136, 2014.

[17] M. A. Gerber, R. Schroeter, L. Xiaomeng, and M. Elhenawy. Self-Interruptions of Non-Driving Related Tasks in Automated Vehicles: Mobile vs Head-Up Display. *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems, CHI '20*, pp. 1–9, 2020. doi: 10.1145/3313831.3376751

[18] R. Haeuslschmid, B. Pfleging, and F. Alt. A Design Space to Support the Development of Windshield Applications for the Car. In *the 2016 CHI Conference*, pp. 5076–5091. ACM Press, New York, New York, USA, 2016.

[19] R. Haeuslschmid, Y. Shou, J. O'Donovan, G. Burnett, and A. Butz. First Steps towards a View Management Concept for Large-sized Head-up Displays with Continuous Depth. In *the 8th International Conference*, pp. 1–8. ACM Press, New York, New York, USA, 2016.

[20] S. G. Hart and L. E. Staveland. Development of nasa-tlx (task load index): Results of empirical and theoretical research. In *Advances in psychology*, vol. 52, pp. 139–183. Elsevier, 1988.

[21] R. Häuslschmid, S. Osterwald, M. Lang, and A. Butz. *Augmenting the Driver's View with Peripheral Information on a Windshield Display*. ACM, New York, New York, USA, Mar. 2015.

[22] M. S. Horswill and A. M. Plooy. Auditory feedback influences perceived driving speeds. *Perception*, 37(7):1037–1043, 2008.

[23] R. Häuslschmid, D. Ren, F. Alt, A. Butz, and T. Höllerer. Personalizing Content Presentation on Large 3D Head-Up Displays. *PRESENCE: Virtual and Augmented Reality*, 27(1):80–106, 2019.

[24] R. S. Kennedy, N. E. Lane, K. S. Berbaum, and M. G. Lilienthal. Simulator sickness questionnaire: An enhanced method for quantifying simulator sickness. *The International Journal of Aviation Psychology*, 3(3):203–220, 1993.

[25] D. Kern and A. Schmidt. *Design space for driver-based automotive user interfaces*. ACM, New York, New York, USA, Sept. 2009.

[26] H. Kim, A. Miranda Anon, T. Misu, N. Li, A. Tawari, and K. Fujimura. Look at me: Augmented reality pedestrian warning system using an in-vehicle volumetric head up display. In *Proceedings of the 21st International Conference on Intelligent User Interfaces*, pp. 294–298, 2016.

[27] S. Kim and A. K. Dey. Simulated augmented reality windshield display as a cognitive mapping aid for elder driver navigation. p. 133, 2009. doi: 10.1145/1518701.1518724

[28] A. L. Kun, M. Tscheligi, A. Riener, and H. van der Meulen. Arv 2017: Workshop on augmented reality for intelligent vehicles. In *Proceedings of the 9th International Conference on Automotive User Interfaces and Interactive Vehicular Applications Adjunct*, AutomotiveUI '17, pp. 47–51. ACM, New York, NY, USA, 2017.

[29] S. Langlois and B. Soualmi. Augmented reality versus classical hud to take over from automated driving: An aid to smooth reactions and to anticipate maneuvers. In *2016 IEEE 19th international conference on intelligent transportation systems (ITSC)*, pp. 1571–1578. IEEE, 2016.

[30] S. Langlois, T. N. That, and P. Mermillod. Virtual Head-up Displays for Augmented Reality in Cars. pp. 1–8, 2016. doi: 10.1145/2970930.2970946

[31] G. Meixner, C. Häcker, B. Decker, S. Gerlach, A. Hess, K. Holl, A. Klaus, D. Lüddecke, D. Mauser, M. Orfgen, et al. Retrospective and future automotive infotainment systems—100 years of user interface evolution. In *Automotive user interfaces*, pp. 3–53. Springer, 2017.

[32] F. Naujoks, Y. Forster, K. Wiedemann, and A. Neukum. Speech improves human-automation cooperation in automated driving. In B. Weyers and A. Dittmar, eds., *Mensch und Computer 2016 – Workshopband*. Gesellschaft für Informatik e.V., Aachen, 2016.

[33] B. Pfleging, M. Rang, and N. Broy. Investigating user needs for non-driving-related activities during automated driving. In *Proceedings of the 15th International Conference on Mobile and Ubiquitous Multimedia*, MUM '16, pp. 91–99. ACM, New York, NY, USA, 2016. doi: 10.1145/3012709.3012735

[34] A. Riegler, B. Aksoy, A. Riener, and C. Holzmann. Gaze-based Interaction with Windshield Displays for Automated Driving: Impact of Dwell Time and Feedback Design on Task Performance and Subjective Workload. *12th International Conference on Automotive User Interfaces and Interactive Vehicular Applications, AutomotiveUI '20*, pp. 151–160, 2020. doi: 10.1145/3409120.3410654

[35] A. Riegler, C. Anthes, C. Holzmann, A. Riener, and S. Mohseni. Autosimar: In-vehicle cross-virtuality transitions between planar displays and 3d augmented reality spaces. In *ISS'21: Interactive Surfaces and Spaces*, 2021.

[36] A. Riegler, A. Riener, and C. Holzmann. Autowsd: Virtual reality automated driving simulator for rapid hci prototyping. ACM, New York, NY, USA, 2019. doi: 10.1145/3340764.3345366

[37] A. Riegler, A. Riener, and C. Holzmann. Towards dynamic positioning

of text content on a windshield display for automated driving. In *25th ACM Symposium on Virtual Reality Software and Technology*, VRST '19. Association for Computing Machinery, New York, NY, USA, 2019. doi: 10.1145/3359996.3364757

[38] A. Riegler, A. Riener, and C. Holzmann. Virtual reality driving simulator for user studies on automated driving. In *Proceedings of the 11th International Conference on Automotive User Interfaces and Interactive Vehicular Applications: Adjunct Proceedings*, AutomotiveUI '19, p. 502–507. Association for Computing Machinery, New York, NY, USA, 2019. doi: 10.1145/3349263.3349595

[39] A. Riegler, A. Riener, and C. Holzmann. A Research Agenda for Mixed Reality in Automated Vehicles. *19th International Conference on Mobile and Ubiquitous Multimedia, MUM 2020*, pp. 119–131, 2020. doi: 10.1145/3428361.3428390

[40] A. Riegler, A. Riener, and C. Holzmann. Augmented reality for future mobility: Insights from a literature review and hci workshop. *i-com*, 20(3):295–318, 2021.

[41] A. Riegler, A. Riener, and C. Holzmann. A systematic review of augmented reality applications for automated driving: 2009–2020. *PRESENCE: Virtual and Augmented Reality*, pp. 1–80, 2021.

[42] A. Riegler, A. Riener, and C. Holzmann. A systematic review of virtual reality applications for automated driving: 2009–2020. *Frontiers in Human Dynamics*, p. 48, 2021.

[43] A. Riegler, K. Weigl, A. Riener, and C. Holzmann. StickyWSD: Investigating Content Positioning on a Windshield Display for Automated Driving. *19th International Conference on Mobile and Ubiquitous Multimedia, MUM 2020*, pp. 143–151, 2020. doi: 10.1145/3428361.3428405

[44] A. Riegler, P. Wintersberger, A. Riener, and C. Holzmann. Investigating User Preferences for Windshield Displays in Automated Vehicles. In *Proceedings of the 7th ACM International Symposium on Pervasive Displays*, pp. 1–7. ACM Press, New York, New York, USA, 2018.

[45] A. Riegler, P. Wintersberger, A. Riener, and C. Holzmann. Augmented reality windshield displays and their potential to enhance user experience in automated driving. *i-com*, 18(2):127–149, 2019.

[46] A. Riener, S. Boll, and A. L. Kun. Automotive User Interfaces in the Age of Automation (Dagstuhl Seminar 16262). *Dagstuhl Reports*, 6(6):111–159, 2016. doi: 10.4230/DagRep.6.6.111

[47] C. Schartmüller, A. Riener, P. Wintersberger, and A.-K. Frison. Workaholistic. pp. 1–12, 2018. doi: 10.1145/3229434.3229459

[48] M. Schrepp, A. Hinderks, and J. Thomaschewski. Design and evaluation of a short version of the user experience questionnaire (ueq-s). *International Journal of Interactive Multimedia and Artificial Intelligence*, 4:103, 01 2017. doi: 10.9781/ijimai.2017.09.001

[49] R. Schroeter and F. Steinberger. Pokémon drive: towards increased situational awareness in semi-automated driving. In *Proceedings of the 28th australian conference on computer-human interaction*, pp. 25–29, 2016.

[50] R. Schroeter and F. Steinberger. Pokémon DRIVE. pp. 25–29, 2016. doi: 10.1145/3010915.3010973

[51] M. Slater, A. Antley, A. Davison, D. Swapp, C. Guger, C. Barker, N. Pistrang, and M. V. Sanchez-Vives. A virtual reprise of the stanley milgram obedience experiments. *PloS one*, 1(1):e39, 2006.

[52] M. Smith, J. L. Gabbard, and C. Conley. Head-up vs. head-down displays: examining traditional methods of display assessment while driving. In *Proceedings of the 8th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*, pp. 185–192. ACM, 2016.

[53] M. Smith, J. Streeter, G. Burnett, and J. L. Gabbard. Visual search tasks. In *the 7th International Conference*, pp. 80–87. ACM Press, New York, New York, USA, 2015.

[54] B. H. Topliss, S. M. Pampel, G. Burnett, and J. L. Gabbard. Evaluating head-up displays across windshield locations. In *Proceedings of the 11th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*, AutomotiveUI '19, p. 244–253. Association for Computing Machinery, New York, NY, USA, 2019. doi: 10.1145/3342197.3344524

[55] M. Walch, K. Mühl, J. Kraus, T. Stoll, M. Baumann, and M. Weber. From car-driver-handovers to cooperative interfaces: Visions for driver–vehicle interaction in automated driving. In *Automotive user interfaces*, pp. 273–294. Springer, 2017.

[56] G. Wiegand, C. Mai, K. Holländer, and H. Hussmann. InCarAR. pp. 1–13, 2019. doi: 10.1145/3342197.3344539

[57] P. Wintersberger, P. Green, and A. Riener. Am i driving or are you or are we both? a taxonomy for handover and handback in automated driving. 2017.

[58] P. Wintersberger, A. Riener, C. Schartmüller, A.-K. Frison, and K. Weigl. Let me finish before i take over: Towards attention aware device integration in highly automated vehicles. In *Proceedings of the 10th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*, AutomotiveUI '18, pp. 53–65. ACM, New York, NY, USA, 2018. doi: 10.1145/3239060.3239085

[59] P. Wintersberger, C. Schartmüller, and A. Riener. Attentive user interfaces to improve multitasking and take-over performance in automated driving: the auto-net of things. *International Journal of Mobile Human Computer Interaction (IJMHCI)*, 11(3):40–58, 2019.

[60] P. Wintersberger, T. von Sawitzky, A.-K. Frison, and A. Riener. Traffic Augmentation as a Means to Increase Trust in Automated Driving Systems. In *the 12th Biannual Conference*, pp. 1–7. ACM Press, New York, New York, USA, 2017.

[61] H. Yun and J. H. Yang. Multimodal warning design for take-over request in conditionally automated driving. *European transport research review*, 12:1–11, 2020.