Contact-analog Warnings on Windshield Displays promote Monitoring the Road Scene

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ABSTRACT
Drivers attend to a lot of information at various locations inside and outside the car as well as on external devices (e.g. smart phones). Head-Up Displays (HUDs) support keeping drivers' visual focus directed towards the street; as they present virtual information in the windshield area on top of the physical world within the field of view of the driver. Displayed information, however, is often spatially dissociated with its cause in the physical world: for example a warning is displayed, yet drivers still require time searching for the hazard causing it. Windshield displays (WSDs) allow virtual warnings being displayed at the position of the hazard. We compared HUD and WSD with the baseline no-display and found that drivers demonstrate a calm gaze behavior with WSDs; they keep their visual attention in average 1.5 s longer focused on the leading car. However, we also found no significant faster reaction time compared to HUDs. We discuss our findings comparing HUDs to WSDs, present potential limitations of our study and point out future steps in order to further investigate the advantages of WSDs.

ACM Classification Keywords
H.5.2 User Interfaces: Information Systems H.1.2. User/Machine Systems: Human Factors

Author Keywords
Windshield Display (WSD), Head-Up Display (HUD), contact-analog, world-stabilized, hazard warning, Augmented Reality (AR), in-vehicle interfaces (IVIS)

INTRODUCTION
While driving a car, it is crucial to remain visually focused on the street in order to quickly react to changing driving situations. However, drivers also consume a lot of secondary information on various spatial locations: e.g., driving performance feedback is displayed in the car's dashboard (e.g. speed) or incoming calls and emails on smart phones. To facilitate drivers' visual attention on the street while consuming digital information, researchers explore the visual overlay of virtual feedback on top of the physical world [3, 12, 19]: Head-Up Displays show a graphical user interface overlay within the limited lower windshield area; windshield displays (WSD) can blend in graphical elements anywhere on the windshield.

Most information displayed on HUDs or WSDs are positioned at specific locations at the border of drivers' field of view with no spatial relationship between virtual and real-world information (e.g. [2, 4]). Some information simply has no spatial relationship, e.g. speed; some information does, e.g. a turn left instruction. Gestalt principles suggest that spatial '*closeness*' between virtual and physical stimuli (a.k.a. contact-analog or registered display) are easier and faster understood. In the context of driving, it was found that drivers translate spatial binding into logical binding and thereby reach faster recognition times [8]. However, virtual stimuli appearing anywhere in the drivers' peripheral view can also be distracting [17]. It is argued that the drivers' locus of attention might shift towards the stimulus leading to reflexive shifts. Some argue that users only attend this information when the current driving situation permits (zoom-lens model of attention or useful field of view [7, 11]).

We compared two types of information displays, registered (contact-analog) (WSD) and un-registered information (HUD), and compared both to a baseline condition with no graphical information displayed (standard windshield). In the context of a standard car-following task, participants were asked to judge hazards on the street in combination with a displayed warning (in WSD and HUD), or – in the baseline – no displayed warning. We investigated the effect of information display on driving and glance behavior and found that drivers keep their gaze longer focused on the street when graphical warnings are displayed over the hazard instead of fixed positions in HUDs.

RELATED WORK
The gestalt principle of proximity suggests that two stimuli are easier understood as related when they are spatially close to each other. Related research (e.g. [18, 21]) works on the technical realisation of windshield displays to display virtual information on a larger space in the field of view (FOV) of a driver which enables to implement the concept of proximity between virtual information and the physical world.

Head-Up Displays cover a small area in the drivers' field of view; it had been already shown [15] that displaying information inside the FOV leads to better reaction times and to improved driving performance (e.g. quicker appliance of the break) compared to Head-Down Displays (HDDs). However, since HUDs cover a limited area they cannot guarantee a spatial relationship between displayed and real information. Contact-analog information display had been explored in the context of car navigation [19] using HUDs: they showed arrows on the HUD and made them appear as 'being on the road'. However, this works as long as the information in the world (e.g. streets) is within the display area of a HUD.

Kim et al. [12] displayed crash warnings on a HUD in a manner which are contact-analog but still fixated in position. The designed interface provides icons at the top, left and right sides of a HUD, pointing at the direction of the hazard. Participants had to detect and verbally locate these hazards. The authors compared the HUD interface to a conventional warning system which provides text in a HDD and icons at the side view mirrors. They found that the HUD interface can provide a safety benefit as well as a good user acceptance. In the areas in front and to the right of the driver, reaction time was decreased when using the HUD interface. As the invented HUD interface was not compared to a simple warning sign on a HUD, it remains unclear if giving hints about the position of a hazard leads to faster reaction times.

Peripheral perception

Environmental objects can be far off the drivers focus point, placed within the peripheral field of view, when looking straight to the road. This would require placing the related information also in the periphery which is widely refused in the context of driving. As already discussed in [10], the driver has to move his eyes or head to perceive information [6, 20] and might react with a reflexive shift of the locus of attention towards an appearing peripheral stimulus [17]. Such sudden shifts of attention can be very safety-critical. But Houtmans et al. [11] suggests that peripheral perception is a controlled and not an automatic process. Then, the probability that driver reflexively shift attention towards the periphery might be low. They also found that participants were able to identify highly peripheral signals while they focused on other stimuli. Information was gained about spatial characteristics such as position and shape. Transferring this to our study, this means a driver is able to already acquire information about the potential hazard when still focusing on the leading vehicle. Then, a driver would not even have to visually focus on a peripheral object to identify and judge it.

Peripheral vision is crucial for the direction of attention towards safety-relevant objects in the surroundings [22]. However, human perceptional capabilities strongly depend on the situational demand. The applied zoom-lens model of attention and also the theory of the *useful field of view* (UFOV) suggest that a driver will only perceive the peripheral information when the current road situation allows an attention shift. The zoom-lens model of attention describes that the FOV a driver can attentively observe shrinks to increase resources in the center [7]. This corresponds to the theory of the useful field of view: the area within one can obtain visual information by a brief glance, without any eye or head movements. Within this area information in the driving scene can be identified and extracted very fast. Therefore, a large UFOV also covering the periphery is desirable. The humans state, the task eccentricity, and the driving speed, but especially a high mental load, e.g. caused by attention sharing, decrease the size of the useful field of view and thereby performance in the periphery [10, 11, 20]. Allahyari et al. [1] concluded that a reduction of the UFOV is a strong predictor for accident rate. Applied to peripheral hazard detection, in a highly demanding driving situation driver would be more focused on the road to increase primary task performance. Secondary task performance would be deteriorated.

Crundall et al. [5] challenged subjects to search for dangers in a driving video and found evidence for the deterioration in peripheral perception in driving scenes with increasing demand. Moreover, subjects performed worse in detecting hazards placed at more eccentric positions.

In a demanding driving situation, a driver may oversee hazards in the periphery. As peripheral vision plays an important role in safety and driving performance [1], drivers may even need support to perceive hazards and to keep peripheral awareness high.

STUDY

In this study we compared the registered display of a warning sign on a WSD with the unregistered display on a HUD and a baseline without any warning aid. We were particularly interested in the time to perceive and understand potential hazards as well as its relation to the position of the hazard and the current situational demand. Also, we investigated on the driving performance and the gaze behavior to monitor the drivers' reaction on occurring warning signs. We expected to find increasing reaction times with higher eccentricities and in more demanding road situations, but also expected the registered warnings to constantly lower these values compared to the unregistered and no-warning conditions. As we also anticipated a more structured and faster search which corresponds to a more constant visual focus on the car in front, we also assumed driving performance will be improved.

Participants

18 volunteers aged between 22 and 44 (2 female, Mean = 29.9, SD = 5.7) with valid driver's licence participated in our study; 11 had previous experience with HUDs.

Study Design

We conducted a controlled experiment in a 3×2×2×5 repeated measures within-subjects design. We compared 3 DISPLAYS (no display (NOD), Head-Up Display (HUD), Windshield Display (WSD)) in 2 DEMANDS (EASY and HARD). In addition we tested 2 HAZARDS (hazard and no hazard) at 5 HAZARD LOCATIONS (-7°, 0°, 7°, 14° , 21°).

Trials were blocked by DISPLAY and embedded into a continuous driving experience of 15 minutes consisting of a (1) 1-minute training phase and a (2) 14-minute experiment phase.

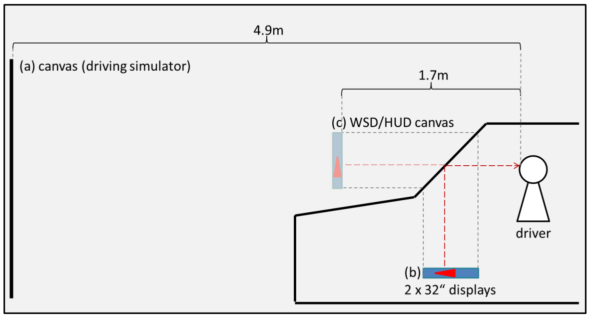

Figure 1. Dimensions of our test setup

The order of DISPLAYS was counter-balanced using a Latin-square. The general task during both phases was a standardized car-following task [16]. Drivers were seated in a driving simulator (see Fig. 1) and asked to follow a leading vehicle on a straight street without curves. The leading car breaks and accelerates with varying frequency without lane changing or turning. Drivers need to keep constant distance to the vehicle with stable lateral control by remaining in the middle of the lane. Visual feedback during the training phase communicated the correct position of the vehicle with respect to the leading vehicle and the lane: green or red signs displayed in the right area provide visual feedback and drivers were asked to adapt their driving behavior accordingly. During the experimental phase, no such feedback was provided.The leading car's distance is derived from 2 dimensional size cues of the simulator's screen. Breaking is additionally visualized by standard back lights.

In EASY DEMAND conditions, participants drove slowly with a speed of 40 to 50 km/h. The leading car changed its speed repeatedly at 100 m; this corresponds to 44 times. In DEMAND HARD the leading vehicle changed its speed 86 times between 20 and 110 km/h. We defined our driving tracks according to the recommendations of [9]. It was not possible for participants to develop a feeling of rhythm, as the time between speed changes varied strongly due to the current speed.

As secondary task, we asked participants to consciously judge two types of HAZARDS: we chose a rolling football, either towards the street (hazard, a kid might follow) or away of it (no hazard). Participants were asked to push a button on the steering wheel in case there is a hazard. During one block appeared 40 hazards, 50% were false alarms. Hazards can occur at a constant distance of 70 m at 5 different HAZARD LOCATIONS with respect to the drivers' straight eye focus: -7° , 0° , 7° , 14° , 21° (see Fig. 2).

On the DISPLAY HUD, a visual feedback about hazards is located within the display area of a HUD (see Fig. 3) at a stable position. On the WSD, feedback was provided at the position of the hazard (in world-coordinates from the drivers head) (see Fig. 4); NOD is the baseline condition with no visual warning feedback about hazards.

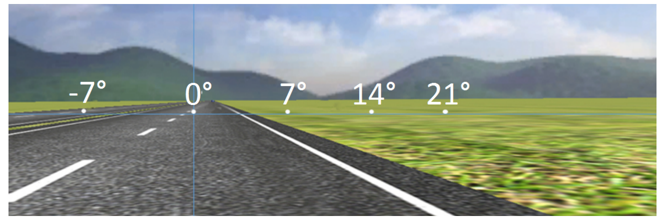

Figure 2. Hazard locations at a distance of 70m

Apparatus

Similar to [10], we integrate an acrylic windshield, a steering wheel (with buttons), and a car seat into a wooden box covered with fabric. Room lights are dimmed to ensure visibility of virtual projections and the simulator scene.

Driving simulator: hardware and software setup

In all DISPLAY conditions, we used the same software and hardware setup to simulate the driving scene: the simulated driving scene was projected on a canvas (4.1 × 2.3 m) in 4.9m distance to the driver.

The car-following task was implemented based on openDS[1]'s three vehicle platooning task; we added appearing obstacles to the task: an animated ball either moving towards the street or moving away from the street. Obstacles appear at the controlled angle, move however – due to locomotion of the simulated car – towards the border of the windshield.

Displaying warnings in HUD and WSD conditions

In both DISPLAY conditions, HUD and WSD, we display hazard warning on top of the driving simulation using a separate display (see Fig 1): two 32″ displays (1360 × 768 px) are aligned below the windshield (see Fig. 1 (b)). Virtual content is reflected on the windshield and perceived by the driver as floating in 1.7 m distance (see Fig. 1 (c)). The full reflection of the two displays covers 70% width and 40% height of the driver's field of view; a good compromise between windshield coverage and distance to the reflected image [10]. One limitation of this setup is that virtual images get reflected to both, inner and outer, sides of the windshield acrylic sheet leading to two reflections being slightly misaligned (double-image effect). However, since the appearing warning symbols are simple (no text, simple triangle shapes), this effect is hardly visible and not disturbing.

Warnings in HUD condition are displayed within a rectangle with white borders (294 × 137 px) at the standard HUD position 5° below the meridian [2, 4] of the field of view since people showed faster reaction times [14]. Warnings are displayed (see Fig. 3). The warning is positioned in the center of the rectangle and does not give any indication on the obstacle's position in the driving scene. Obstacles and warnings appear at the same time.

Warnings in WSD condition appear directly on the hazard following its movement (registered feedback). Since HUD and WSD reflections are semi-transparent, the obstacles in the simulator scene are still visible (see Fig. 4). Warnings

[1] www.opends.eu

Figure 3. An example of an unregistered warning sign on HUDs (photo taken from the driver's point of view)

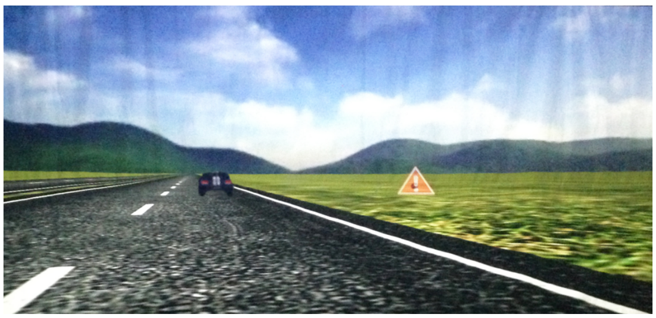

Figure 4. An example of a registered warning sign on WSDs (photo taken from the driver's point of view)

had the same size as in HUD conditions. The WSD was calibrated to each driver; the driver's head position is required in order to match the position of the warning with the position of obstacles in the scene. The calibration process consists of colored grids displayed on the canvas (see Fig. 1 (a)) and the WSD canvas (see Fig. 1 (b)). Participants were asked to move the grid on the WSD using a keyboard to match the grid on the simulator canvas; during the experiment, we asked participants to keep their head at a constant position. As we found in pilot studies that subjects maintained a quite stable position during the entire test, we did not see any reason to use head-tracking or to recalibrate the system during the experiment. Neither it was necessary to calibrate the HUD.

Data collection

When participants arrived they filled out a demographic questionnaire. Eye-tracker and Windshield Display were calibrated.

Driving performance average deviation from the required distance to the leading car (40 m) in meters.

Judgment success rate the number of correctly identified hazards/no hazards

Judgment time time between hazard stimulus appearance and the driver's button press

Glance duration time from entering to leaving a windshield area (see all areas in Fig. 5).

Glance count number of glances within a windshield area.

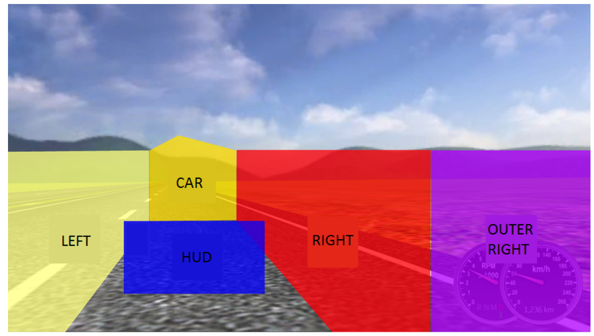

Figure 5. Simulator scene was split into five areas; three of them are driving-relevant in NOD and WSD condition (CAR, LEFT, RIGHT); four of them are driving-relevant in HUD condition (CAR, LEFT, RIGHT, HUD)

RESULTS AND DISCUSSION

We ran repeated measures ANOVA and used corrections for the F-ratio if the assumption of sphericity is violated (significant Maulchy's Test of Sphericity): we used Huynh-Feldt (sphericity estimate ≥ 0.75) or Greenhouse Geisser correction (otherwise) depending on estimates of Maulchy's test. Further, we report Tukey post-hoc tests.

Driving performance

We found no significant effect of DISPLAY on driving performance ($F_{2,34} = 0.279$, $p = 0.0758$): participants varied the distance to the leading car in average $mean = 14.49\ m, CI[12.18, 16.80]$ in NOD, $mean = 14.17\ m, CI[11.90, 16.43]$ in HUD and $mean = 13.95\ m, CI[11.46, 16.43]$ in WSD condition. The DEMAND has a significant effect on driving performance ($F_{1,17} = 106.5$, $p < 0.0001$): participants varied significantly less meters in distance in easy ($mean = 11.87\ m, CI[9.66, 14.07]$) than in hard driving situations ($mean = 16.54\ m, CI[14.28, 18.79]$). Driving performance mean and confidence interval for DISPLAYS differ within centimeter range; participants demonstrated a constant performance with all displays and concentrated on the primary task even with appearing visual feedback. Our choice of DEMAND difficulty showed to be legitimate; users showed significantly different driving behavior in easy and hard driving situations.

Hazard judgment

During one DISPLAY condition, we showed 20 hazards and 20 false alarms to participants. We measured hazard judgment by judgment success rate and judgment time.

Judgment success rate

We found no significant effect of DISPLAY on judgment success rate ($F_{2,34} = 0.477$, $p = 0.625$): participants correctly judged in avg. 89% $CI[84.81, 92.69]$ of cases with no display, 90.42% $CI[86.67, 94.16]$ of cases with HUD, and 89.31% $CI[85.77, 92.84]$ of cases with WSD. The judgment success rate is generally high ($\geq$89.31%): neither HUDs nor WSDs did improve judgment success rate, neither in EASY nor in HARD condition.

Judgment time

Figure 6 shows the judgment time for all DISPLAYS at all angles and illustrates a strong difference between displays for angle

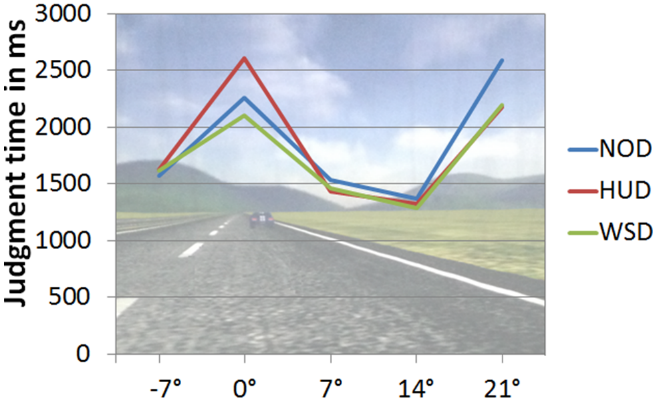

Figure 6. Judgment times in relation to hazard angle position.

0°. Since hazards were visible at all angles but could have been covered by the leading car at angle 0°, we decided to take out this angle for the following analysis and refer to the discussion on advantages of WSD for occluded hazards (see conclusions).

DISPLAY had no effect on the judgment time ($F_{1.172,19.93} = 0.963$, $p = 0.353$). Post-hoc analysis revealed that the HUD ($mean = 1640$ ms, $CI[1398, 1882]$) significantly improved the judgment time compared to driving without display ($mean = 1767$ ms, $CI[1515, 2020]$). Values of HUD and WSD ($mean = 1641$ ms, $CI[1384, 1898]$) are practically equal. Though, we did not find WSD to be significantly different to both others.

We also found a significant effect of DEMAND on judgment time ($F_{1,17} = 4.69$, $p = 0.045$): participants responded faster in easy than difficult driving situations ($mean = 1638$ ms, $CI[1437, 1839]$ vs. $mean = 1727$ ms, $CI[1491, 1964]$).

The variable HAZARD LOCATION also had a significant effect on judgment time ($F_{2.354,40.01} = 46.181$, $p < 0.0001$). A Tukey test revealed three significant groups:

(G1) -7° ($mean = 1606$ ms, $CI[1343, 1869]$) and 7° ($mean = 1479$ ms, $CI[1322, 1637]$),

(G2) 14° ($mean = 1323$ ms, $CI[1167, 1479]$), and

(G3) 21° ($mean = 2323$ ms, $CI[1971, 2674]$).

Participants judged an appearing hazard faster at angle 14° than the less distant angle (7°,-7°) from the initial head position at 0°, an effect already reported elsewhere [13]. They recommended to place displays at an eccentricity of 15 to 20° as driving performance remained best when the driver performed a secondary task at this eccentricity. Due to our test results, we recommend to place them closer than 20°.

We found an interaction effect of DISPLAY × HAZARD LOCATION on judgment time ($F_{6,56.721} = 3.194$, $p = 0.026$, see Fig. 8): post-hoc revealed that for hazards appearing at 21°, participants reacted significantly slower when driving without display aid ($mean = 2595$ ms, $CI[2186, 3004]$) than with HUD ($mean = 2180$ ms, $CI[1846, 2514]$) or WSD ($mean = 2193$ ms, $CI[1740, 2646]$); no significant difference between HUD and WSD was found.

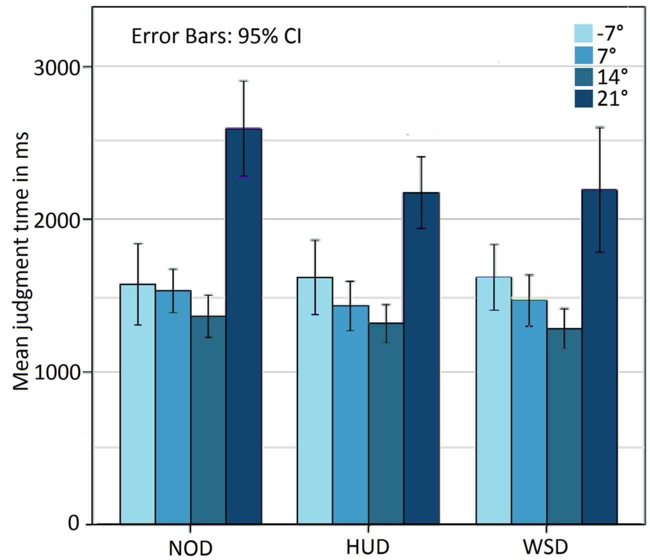

Figure 7. Judgment times and confidence intervals (95%)

Gaze behavior

We measured gaze behavior by calculating gaze duration and glance count.

Glance duration

We found significant main effects on glance duration by DISPLAY ($F_{1.592,27.064} = 6.615$, $p = 0.07$) and AREA ($F_{1.010,17.176} = 78.183$, $p < 0.0001$). We also found an interaction effect for DISPLAY × AREA ($F_{1.382,23.490} = 4.268$, $p = 0.039$). Post-hoc tests on DISPLAY reveal different gaze behaviors: participants kept their gaze significantly longer focused on one area with WSD ($mean = 1748$ ms, $CI[1533, 1963]$) than with both, NOD ($mean = 1330$ ms, $CI[961, 1700]$) and HUD ($mean = 1405$ ms, $CI[1075, 1735]$). The gaze duration is not significantly different for HUD and NOD. Post-hoc tests on AREA reveal 3 significantly different groups:

(G1) the CAR ahead ($mean = 5814$ ms, $CI[4514, 7114]$),

(G2) the RIGHT ($mean = 504$ ms, $CI[451, 557]$), and

(G3) the HUD ($mean = 365$ ms, $CI[297, 433]$) and OUTER_RIGHT ($mean = 336$ ms, $CI[302, 369]$) areas.

Post-hoc tests on the interaction of DISPLAY × AREA showed that subjects focused the longest on the area car in all display conditions (NOD: $mean = 5061$ ms, $CI[3269, 6853]$, HUD: $mean = 5438$ ms, $CI[3777, 7099]$, WSD: $mean = 6943$ ms, $CI[5957, 7928]$). Subjects using a HUD looked longer at the vehicle ahead during one visit compared to driving without display. Using the WSD allowed participants to observe the car in front for on average 1.5 seconds longer compared to the HUD use. However, this difference did not appear to be significant in our statistical tests. The observation of the driving situation in front is important for safe driving. Therefore, a driver using the WSD might be less involved in rear-end collisions. For the surrounding areas the mean glance duration is a not very meaningful measurement.

Glance count

We also analyzed the gaze behavior by looking at the glance counts in a repeated measure ANOVA. We found a significant effect for DISPLAY, DEMAND, and AREA as well as all interactions. The main effect for DISPLAY ($F_{2,34}$ = 10.856, p = 0.0002) shows that participants had a different glance behavior in the three DISPLAY conditions. A Tuckey post-hoc test on DISPLAY revealed that subjects changed their visual focus fewer times when using the WSD ($mean$ = 20.844, $CI[17.643, 24.046]$) compared to the NOD ($mean$ = 31.5556, $CI[25.096, 38.015]$) but also compared to HUD condition ($mean$ = 31.228, $CI[25.371, 37.085]$). We did not find a significant difference between HUD and NOD.

We also found a significant main effect for DEMAND ($F_{1,17}$ = 23.302, p = 0.0002). Participants overall reduced the amount of visual focus shifts when the situation was more demanding. Tuckey post-hoc test on the interaction of DEMAND × DISPLAY ($F_{1.408,23.943}$ = 3.930, p = 0.046) showed that opposing the EASY and HARD driving situations, this effect was prominent for all DISPLAY conditions, but the smallest for WSD. This indicates that a higher driving demand affects the driver's gaze behavior the least when they use a WSD.

As already mentioned for glance duration, the main effect for the variable AREA ($F_{1.493,25.381}$ = 185.475, p < 0.0001) can be attributed to the fixed position of the primary task in the AREA CAR. Participants looked significantly more in the area CAR compared to each all other areas. Analyzing the interaction effect for DISPLAY × AREA ($F_{2.763,49.970}$ = 9.402, p = 0.00009), we found that participants using the WSD had the fewest glance counts for all AREAS and therefore the fewest attentional shifts. That glance count is overall reduced for WSD in all areas where hazards appeared indicates that subjects had the most controlled gaze behavior and the most effective search when using the WSD. This is in line with the higher mean glance duration on the vehicle ahead for the WSD use and is an overall very positive effect. Driving without any display leaded to very high glance counts and therefore shows that participants needed to shift their visual focus more often to detect hazards.

We did not particularly look at the interaction effect of AREA × DEMAND ($F_{1.538,26.141}$ = 12.024, p = 0.001) as it would not give any information relevant for our hypotheses. Instead, we directly analyzed the interaction effect of DISPLAY × AREA × DEMAND ($F_{3.366,57.219}$ = 3.976, p = 0.01). Fig. 8 shows very similar patterns for the areas CAR and RIGHT and also for the areas LEFT and OUTER_RIGHT. As glances in the areas where hazards appeared are significantly reduced when using the WSD compared to the HUD and also the NOD, it is very unlikely that participants reacted with a reflexive shift of the visual focus towards the hazards.

In the OUTER_RIGHT area no obstacles appeared but if they were no hazards, they moved into this area. Therefore, this area was not directly safety-relevant in our test.

User Experience

We gathered knowledge about the users' experience by a questionnaire. Subjects had to answer six questions by choosing one DISPLAY condition: NOD, HUD, or WSD. WSD was rated best for all questions except one (see Fig. 9): Driving with WSD was more distracting than driving without display; but less distracting than using a HUD. Participants felt safest and best supported in fast detection and also correct judgment by WSD. They liked the WSD the most and would prefer to use it over the HUD.

The last question evaluated the perceived virtual image distance. Subjects estimated the image distance in the HUD condition as 1 m. Though the position of the displays was not changed, the WSD image was perceived as more distant, (median = 2.5 m). This gap might partially be caused by the increasing distance between driver and virtual image to the right and also by the closeness of the warning sign to the horizon. But this effect is more likely to be related to the contact-analog information presentation, as the warning sign moved according to the football and therefore to the real world. This could indicate that the feeling of merging decreases the subjective distance between virtual image and real world.

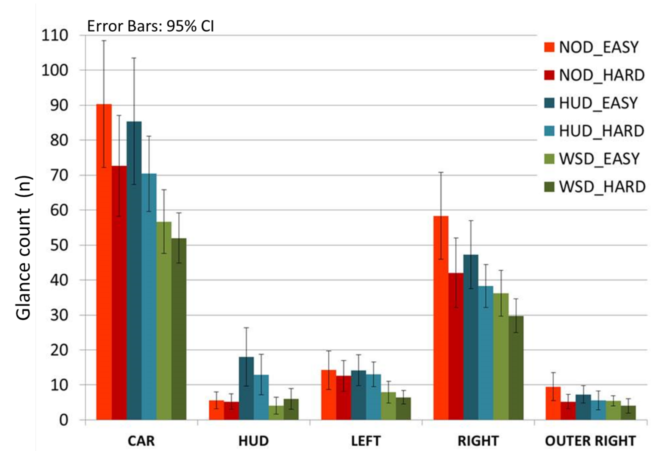

Figure 8. WSD leaded to an overall decrease of glance count

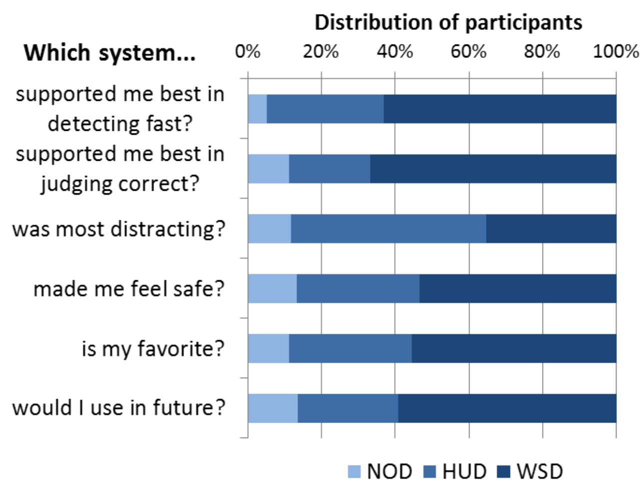

Figure 9. Participants prefer WSD over HUD

CONCLUSIONS AND FUTURE WORK

Enhancing the driving performance by blending in virtual information on HUD or WSD seems to have no influence on peoples ability to correctly judge a hazard situation. However, our hazards were simple: we had just one type of hazard. It remains unclear if HUD and WSD are still advantageous in more difficult hazard judging situations.

A stronger indication for an advantage of WSD over NOD and even HUD is the gaze behavior: the advantage of contact-analog marking on WSDs can be that driver need fewer shifts of visual focus and attention away from the road to detect an equivalent amount of hazards. This allows the driver to remain focused on the leading car for longer time (on average 1.5 s longer compared to HUD in our experiment). We did not find any indication that participants reacted by a reflexive shift of locus of attention towards a stimuli appearing in the periphery. Instead people show a more agitated behavior: they have to look around to find hazards themselves (NOD); but even when the HUD indicates a hazard, drivers still need to find its source and decide on an appropriate reaction. Our results indicate that WSDs lead to a more concentrated driving behavior as well as more effective search behavior, especially in more demanding driving situations. As driving performance is directly related to the time observing the road ahead [23], Windshield Displays can improve road safety.

When the central hazard (0°) was occluded due to bad lateral control, WSDs leaded to a lower judgment time compared to HUD and NOD. WSDs might support the detection of hazards especially in bad visibility conditions such as a crowded urban street or night view. Under bad weather conditions, traffic congestion and out-of-view sharp turn warnings on HUDs can lead to collision reduction of 32.5% [3].

The used driving simulator and also the driving task are simplistic. The simulator scene shows a highway with green fields to both sides. As the scene does not change over time, the peripheral workload induced by the environmental view is very low. Obviously, a normal real world scene is way more complex and the peripheral workload increased. Especially on an urban street, drivers have to constantly monitor environment to detect and track potentially dangerous objects and events. The results of our study indicate that drivers will react faster on highly peripheral events and he will feel a big relief in not having to visually search in the environment for hazards. We expect that these findings will foster at higher eccentricities.

Future research on WSDs and contact-analog information display should investigate more on demanding driving situations and the safety benefit of such displays under bad viewing conditions. Also, the display of warnings at larger eccentricities and simultaneously at an expected position (HUD) and in a contact-analog manner (WSD) could be matter of future research. Measuring stress level will give more insights into the humans' state when using such system.

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