In-Your-Face, Yet Unseen? Improving Head-Stabilized Warnings to Reduce Reaction Time

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ABSTRACT
One unique property of head-mounted displays (HMDs) is that content can easily be displayed at a fixed position within the user's field of view (head-stabilized). This ensures that critical information (e.g. warnings) is continuously visible and can, in principle, be perceived as quickly as possible. We examined this strategy with a physically and visually distracted driver. We ran two consecutive studies in a driving simulator, comparing different warning visualizations in a head-up display (HUD) and a HMD. In an initial study, we found no significant effects of warning type or display technology on the reaction times. In a second study, after modifying our visualization to include a visual reference marker, we found that with only this minor change, reaction times were significantly lower in the HMD when compared to the HUD. Our insights can help others design better head-stabilized notifications.

Author Keywords
Driver safety; head-mounted displays; head-up displays.

ACM Classification Keywords
H.5.2. Information interfaces and presentation (e.g., HCI): User Interfaces.

HEAD-STABILIZED WARNINGS
When using head-mounted Displays (HMDs), there are three different types of content stabilization: Depending on the reference system, content can be head-, body- or world-stabilized [2]. In prior work, head-stabilized content has mainly been used to display fixed menus for interaction with an augmented reality scene (e.g., [4]). However, there is another advantage of head-stabilized content: It is always within the user's field of view, independently of where the user is turning his/her head. Thus, it might be an appropriate presentation technique for information that is crucial for the user and has to be perceived very quickly. According to a 2012 NHTSA report [7], 17% of all traffic accidents involve at least one distracted driver, and 3% of those happen because the driver is manipulating a control device integrated in the cockpit. Especially in the onset of automated driving, there will be a variety of distracting situations for drivers, in which warnings on displays in their peripheral vision will not even be noticed. A prominently displayed warning perceivable in all situations could not only be of great value when manipulating an integrated control device, but also in moments when the driver's attention is turned to the side window, the glove box, the cup holder or a passenger.

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Figure 1: Displaying a rectangular marker, even when no warning is active (a), can provide visual reference and may improve perception. Two different warnings indicate a different reaction (b: *evade*, c: *brake*).

Initially, it seemed obvious that the driver's attention could be more easily captured if a warning was displayed within the HMD's field of view. Nevertheless, we wanted to examine whether the stabilization technique itself would influence the driver's reaction time. For this, we conducted two studies, comparing equally large HMD (head-stabilized) and HUD (cockpit-stabilized) warnings (fig. 1).

RELATED WORK
Our work builds on prior studies of critical situations in the car, respectively warning the driver of potentially dangerous situations. Tönnis et al. evaluated how to direct the driver's attention towards the source of danger by means of Mixed/Augmented Reality [11]. Their first study indicated that an exocentric top view visualization of the car's surrounding has benefits over a car-stabilized 3D arrow, pointing directly at the source of the danger. In a later study, they again compared different visualization techniques in combination with sound [10]. In this study, the visualization within the driver's frame of reference outperformed other concept variations. Bock et al. use an optical see-through HMD to augment a driving scene with

virtual traffic participants, in order to safely test driver assistance systems [3]. Their technique was successfully used for evaluating a system, which supports drivers in evasion maneuvers [5]. Using a HMD as a HUD replacement has also been considered in the field of aerospace cockpits [9]. It is argued that HMDs are more flexible to use than HUDs or even head down displays. The visualization of critical information, such as warnings in the HMD has also been proposed in this paper, but has not been thoroughly evaluated. Baber et al. compared the performance of an HMD to that of a desk-mounted display in a study [1]. They explained the increased total task time in the HMD condition with divided attention effects and an increased effort of refocusing between the task and the HMD visualization.

FIRST STUDY

Apparatus

The first study was conducted in a driving simulator (see figure 2). A high fidelity car mockup was placed in front of three 50“ plasma screens, displaying a realistic driving scene. Two 8” LCD panels on the sides of the car mockup simulated rear view mirrors. For displaying secondary tasks, a 10” LCD screen was built into the car mockup’s center stack. A semi-reflective glass panel (70% transparency) on top of the mockup’s hood simulated a HUD. This glass panel reflected the content of an accordingly positioned LCD screen (resolution set to 1280*720 px., 250 cd/m², contrast ratio 2500:1) to make it seem to hover in front of the driving scene. The resulting image (contrast was drastically reduced due to the varying background of the driving simulation) had a 10.1° diagonal field of view at a distance of 2.8 m. For the HMD test condition, we used a binocular optical see-through HMD (Lumus DK-32) with a resolution of 1280 x 720 px., a 40° diagonal field of view, the virtual image appearing at a distance of 3m. Brightness was adjusted to 255.4 cd/m² with a contrast ratio of 100:1.

Task and Procedure

We used a straight motorway route as the driving scenario. Subjects (N=25, age 21-59, M=34.4, SD=11, all experienced drivers) were instructed to follow a leading vehicle while maintaining a driving speed of 100 km/h. To ensure a fixed distance of 50 m, the leading vehicle adjusted its speed automatically depending on the current distance. After having reached the target position behind the leading vehicle, subjects followed the vehicle for 2 minutes until an acoustic signal indicated the start of the secondary task. We used the surrogate reference task (SuRT), a standardized task designed to provoke situations of visual-manual distraction [6]. We applied a version of the SuRT, in which an array of 18 colored circular and square symbols appears on the screen in the center stack, circles in blue and squares in red. The subject’s task was to find the only (additional) symbol, which did not match the others (a blue square or a red circle), to then select it with a vertically movable selection bar and to confirm. Interaction was realized through a rotary control device located next to the driver’s seat at the bottom right side in the mockup’s middle console. Scrolling the selection bar meant turning the device, pushing it meant selection. The periods of distraction were used to simulate situations, in which drivers interact with the onboard infotainment system and thus are not entirely focused on the driving scene. During the test run, the test coordinator observed the subject’s behavior via video surveillance in an external control room. After approximately 3 minutes, in a moment when the test coordinator could assure that the subject was fully occupied with the secondary task, he manually triggered the leading vehicle to abruptly halt. Simultaneously one of two possible warnings was displayed (figure 1), in order to trigger a respective reaction of the driver. Depending on the warning symbol, subjects were asked to either brake or perform an evasion maneuver. This sequence of just following the leading vehicle, following it while performing the secondary task and finally being confronted with the next critical situation, was repeated another two times.

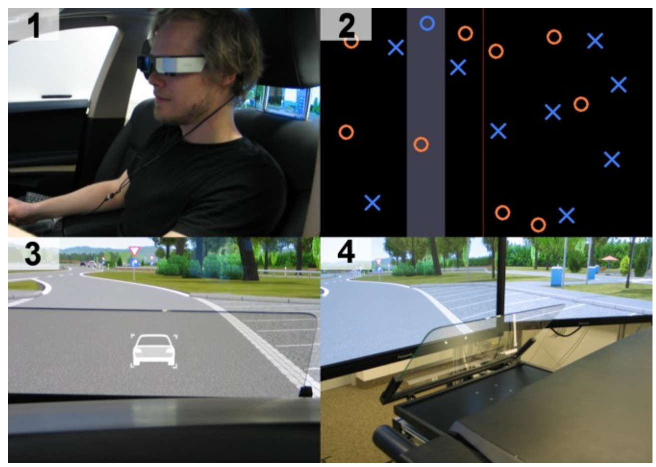

Figure 2: When subjects were fully occupied with the secondary task (2), warnings were displayed either in an HMD (1) or in an HUD mockup (3, 4).

Using a within-subjects design, each subject was asked to perform the scenario twice, once using the HUD, once using the HMD. Immediately before the actual test runs, the two warning types were introduced to the subjects, using the HUD or the HMD (depending on the subject’s first test condition). The warning type was permuted for each display condition. In order to avoid obvious sequences, we introduced a third warning situation as a distraction item, which was excluded from evaluation. In the beginning of each test, subjects were instructed in the driving scenario, the SuRT, the critical situations they would be confronted with, as well as about the different warning types and the appropriate reaction. After the first instruction, each subject performed an extensive training phase to get accustomed to the driving task itself and to performing the SuRT as a secondary task. After each test run, subjects had to fill out a short questionnaire. Besides demographic data, they were asked to estimate the quality of perception, recognition and reaction on a 5-point Likert scale. After having completed both test runs, subjects filled out a final questionnaire. In this questionnaire they were asked to state in which condition (HMD/ HUD) they felt their attention was directed faster to the danger (*attention*), in which condition they could decide faster, which type of reaction would be appropriate (*decision*) and in which condition they could cope faster with the situation (*accomplishment*). To compare different reaction times as well as the subject's behavior, we logged the driving data (gas and brake pedal, speed, heading, acceleration, angle of steering wheel, occurrence of a critical event) during the test runs with a frequency of 50 Hz. We calculated reaction times as the time difference between the first occurrence of the critical event and the time when the pressure of the braking pedal was larger than zero (brake) respectively when the steering wheel angle exceeded 10 degrees (evasion).In the first study, we did not provide any additional visual reference: The HUD/HMD either displayed nothing (in case the warning was inactive), or exclusively the appropriate warning. The warning symbol was displayed for 4 seconds, either in the HUD or in the HMD. In order to make warning sizes comparable, we scaled the graphics in order to match the portion of the field of view they covered. Thus, the displayed warnings covered 94 x 65 px. in the HMD condition and 201 x 139 px. in the HUD condition (both corresponding to 5.4° diagonal field of view).

Results

Table 1 shows the objectively measured reaction times for the different warning types and display technologies.

	HMD	HUD
Brake	M=1.48, SD=0.42	M=1.46, SD=0.55
Evasion	M=1.20, SD=0.37	M=1.53, SD=0.61
Warning independent	M=1.34, SD=0.41	M=1.50, SD=0.57

Table 1: Mean reaction times (M) with standard deviation (SD) in seconds.

In order to examine effects of the display type and warning type on the subject's reaction times, we analyzed the data with a two-way repeated measures ANOVA. We obtained 88 valid data sets. Contrary to our expectations, the differences in reaction times, depending on the display that was used ($F(1,84)=2.22$, $p>0.05$) or the type of warning that was shown ($F(1,84)=1.07$, $p>0.05$), were not significant. As shown in figure 3, the final questionnaire did not reveal any subjective preferences according to the three categories a*ttention, decision* and *accomplishment* for neither one of the display technologies (i.e. stabilization types). An analysis of the questionnaire, subjects were asked to complete immediately after each test condition, could neither identify any significant differences between the two conditions. According to the subjects, the main reason for favoring the HUD Technology was the better quality (sharpness) of the display (n=10) and the uncomfortable feeling of the subjects when wearing an HMD (n=2).

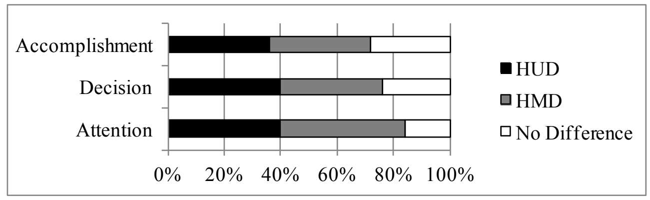

Figure 3: Subjective preference of display technology in 3 different categories (*attention, decision* and *accomplishment*).

Subjects also stated that they were surprised how few advantages head-stabilized warnings provided. They identified the spatial unawareness as one possible reason for this ("The warning appears somewhere in space and can in some situations also be perceived only peripherally."). De facto, warnings appeared well within the field of view, but not where the current focus of attention was, which may have provoked change blindness [8]. Based on the objective results of the study and on the assessments described above, we concluded that by enhancing this spatial awareness, we might also enhance the perception of warnings displayed in the HMD. We hoped to increase spatial awareness by displaying an additional visual cue. A constantly displayed visual marker was added to indicate the location in which a warning would potentially be shown.

SECOND STUDY

Study Design

Our second study used the same apparatus, design and methodology as in the first study. The only change we made was to introduce the marker to indicate the display position of the warning (as depicted in figure 1). This marker was shown in both conditions (HMD or HUD) even when the warning itself was not displayed. We thereby hoped to improve the subject's spatial awareness: even when there was no active warning symbol, subjects knew exactly where it would appear in case of a warning. Out of the 104 measurements (26 subjects, 2 conditions, 2 critical scenarios per subject), we obtained 88 valid data sets. Four data points were discarded as outliers (2 standard deviations above the mean), another 12 could not be included in the analysis due to technical problems with the HMD.

Results

Reaction times were analyzed using descriptive statistics and a two-way repeated measure ANOVA. With the revised visual design including the marker we could confirm our initial expectation: reaction times were now significantly shorter if the warning was displayed in the HMD than if displayed in the HUD (see table 2). A two-way repeated-measures ANOVA showed a significant main effect of the display, in which the warning was presented ($F(1,84)=3.96$, $p<.05$). We assured, that data was normally distributed using a Kolmogorov-Smirnov test ($p>.05$) and assessed the equality of variances using a Levene's test ($F(3, 84) = 2.52$, $p>.05$). In contrast to this, the type of the presented warning had no significant effect on the subject's reaction time.

	HMD	**HUD**
Brake	M=1.47, SD=0.52	M=1.71, SD=0.59
Evasion	M=1.43, SD=0.42	M=1.53, SD=0.53
Warning independent	M=1.45, SD=0.47	M=1.62, SD=0.56

Table 2: Mean reaction times (M) with standard deviation (SD) in seconds.

As shown in figure 4, an analysis of the final questionnaire revealed that the percentage of subjects who felt their attention was captured faster by warnings in the HMD increased from ~40% to over 60% (in comparison to the first study). Subjective assessments after each of the test conditions again resulted in no significant differences between either display conditions.

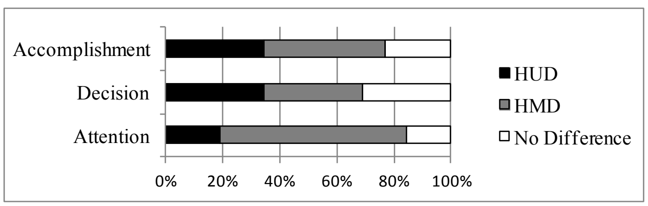

Figure 4: Subjective preference of display technology in 3 different categories (*attention, decision* and *accomplishment*).

CONCLUSION AND FUTURE WORK

In this paper we described two consecutive studies, comparing the visualization of warnings in HMDs and HUDs. Whenever a warning was displayed, the driver was fully distracted by a secondary task. Contrary to our expectations, the first study did not reveal any significant differences in reaction times between the HUD and the HMD visualizations. However, after having augmented the displayed warnings with permanently visible markers, a second study revealed significantly shorter reaction times in the HMD condition. Results show that in situations, when the driver's attention is turned away from the driving scene, HMDs can outperform traditional automotive displays (e.g., HUDs) and improve the situation for drivers. An interesting aspect is that the direct presentation in the HMD in this case outclasses the peripheral perception of content in the head-up display. This indicates that there is good reason to present critical information (such as warnings) in a head stabilized way, while other content such as navigational information or the current driving speed might rather be presented cockpit-stabilized. In comparison to our first study, the only change we made was adding visual markers. Subjects' statements indicate that this led to improved visual guidance, which might have caused the significant effect. To finally prove this phenomenon, a third study comparing HMD visualizations with and without visual markers will have to be conducted. If the positive influence of visual markers can be confirmed, an important guideline for HMD visualizations could be derived. Information should probably not just appear somewhere within the HMD's field of view. Similar to the markers we used in the second study, fixed content might also be arranged around empty spaces and provide a similar type of visual guidance. Warnings could then appear within these spaces.

REFERENCES

1. Baber, C., Knight, J., Haniff, D. and Cooper, L. Ergonomics of wearable computers. *Mobile Networks and Applications 4.1*, 1999. 15-21.
2. Billinghurst, M., Bowskill, M., Jessop, M. and Morphett, J. A wearable spatial conferencing space. *Proc. Wearable Computers*, IEEE (1998). 76-83.
3. Bock, T., Maurer, M. and Färber, G. Vehicle in the Loop (VIL) - A new simulator set-up for testing Advanced Driving Assistance Systems. *Driving Simulation Conference,* 2007.
4. Höllerer, T., Feiner, S. and Paylik, J. Situated documentaries: Embedding multimedia presentations in the real world. In *Wearable Computers 1999*. IEEE, 79-86.
5. Laschinsky, Y., von Neumann-Cosel, K., Gonter, M., Wegwerth, C., Dubitzky, R. and Knoll, A. Evaluation of an Active Safety Light using Virtual Test Drive within Vehicle in the Loop. In *ICIT 2010*, IEEE, 1119-1112.
6. Mattes, S. and Hallén, A. Surrogate Distraction Measurement Techniques: The lane change test. *Driver Distraction: theory, effects and mitigation.* CRC Press (2009). 107-121.
7. Notice on Visual-Manual NHTSA Driver Distraction Guidelines for In-Vehicle Electronic Devices, *Department of Transportation, Federal Register 77.37*, 2012.
8. Rensink, R.A., O'Regan, J.K. and Clark, J.J. To see or not to see: The need for attention to perceive changes in scenes. *Psychological Science 8.5,* 1997, 368-373.
9. Shaw, Robert L. Helmet-Mounted Display (HMD) Interface Design for Head-Up Display (HUD). *Replacement Exploratory Development-NTL, Inc. NTI* DAYTON, OH, 2002.
10. Tönnis, M. and Klinker, G. Effective control of a car driver's attention for visual and acoustic guidance towards the direction of imminent dangers. In *Proc. ISMAR 2006*, IEEE (2006). 13-22.
11. Tönnis, M., Sandor, C., Klinker, G., Lange, C. and Bubb, H. Experimental evaluation of an augmented reality visualization for directing a car driver's attention. *Proc. ISMAR 2005*. IEEE (2005). 56-5.