Urban Driving: Where to Present What Types of Information – Comparison of Head-Down and Head-Up Displays

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Abstract. In this paper, a comparison is made of different categorizations of the content of information given with a warning presented, either on a head-up or head-down display, in the context of urban driving. The study shows a significant advantage of the head-up display in terms of workload. No significant difference for three warning scenarios was found in a driving simulator experiment where the reaction times and the standard deviation of the distance to lane center were compared. The results will help build a generic and integrative HMI concept in the future.

Keywords: HMI · HCI · Urban · Driving · Cockpit · Hud · Hdd · Head-up · Display · Head-down · Instrument · Cluster · Warnings · Adas · Assistance systems · Driver

1 Introduction

1.1 Motivation

In the near future, additional use cases for advanced driving assistance systems (ADAS) in urban area driving scenarios will be needed. This need is brought on because of several reasons like higher complexity of the driving situation (Schröder, 2012), obstructions of road signs or other cars (Schartner, 2013). Urban driving is characterized by multiple road users like busses, motorcycles and trains, as well as weaker road users (ex. Pedestrians or cyclists). This may require the communication of additional information and warnings. New technologies such as the head-up display (HUD) and a programmable head-down display (HDD) will change how information and warnings are currently presented. Additionally, it is necessary to avoid overloading the driver caused by multiple displays and, as a consequence, more saccades, gaze shifts, and visual scanning (Recarte & Nunes, 2003). For this reason, the information presented in the HUD and HDD needs to be limited and presented carefully on the right display for the different types of information in order to avoid further increasing the already demanding scenarios of urban driving (Gevatter, 2006). While the HUD is suitable for warnings in particular (Reif, 2010), the HDD can present more detailed information without excessively distracting the driver (Petermann-Stock & Rhede, 2013).

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1.2 Project UR:BAN

This paper reports the first step in a new generic and integrative HMI concept, part of a collaborative research project: UR:BAN (Urbaner Raum: Benutzergerechte Assistenzsysteme und Netzmanagement – Urban Space: User-oriented assistance systems and network management). UR:BAN is a 4 year project that started in 2012 and will be completed in 2016 (UR:BAN, 2013). Several industry and academic partners have joined in this project with the goal of revising current ADAS and traffic management systems for urban areas. The current study was carried out as part of UR:BAN, focusing on the human element in all aspects of mobility and traffic.

2 Method

2.1 Head-Up Display

One of the first to research Head-Up Displays in an automotive context can be attributed to Bubb (1978). The most crucial characteristic of this Human-Machine-Interface (HMI) is a virtual image in the line of sight of the driver. This image is the result of a reflection in the windshield and appears approx. 2.20 m in front of the eye (Schneid, 2008) with a viewing angle of 4° below the viewing direction of the driver. Reading information from the HUD maintains 40-50 % of the visual acuity for the driving scene since it is still in the parafoveal field of view while the visual acuity for the HDD drops down to approx. 10 % (Schmidtke, 1993). Figure 1 shows a comparison of the different angles and distances for the HUD and HDD.

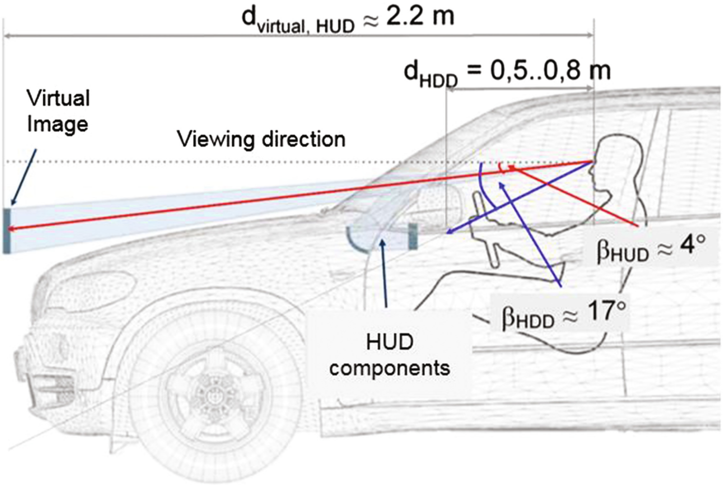


Fig. 1. Comparison of the different angles and display distances (HUD & HDD) (Miličić, 2010)

2.2 Head-Down Display

Head-Down Displays designate all in-vehicle displays where the driver has to move his head down to read the given information. The instrument cluster (IC) is one of those HDD and the display dealt with in this paper. The IC is one of the first components to transmit driving related information to the driver with an in-vehicle display. All types of information acquired by advanced driver assistance systems and in-vehicle information systems (IVIS) are presented on this primary human-machine-interface (Bengler et al., 2015). It usually consists of an analogue speedometer and a rev counter (Reif, 2010) with an additional small digital display; this allows for the possibility to display text and dynamic content (Winner et al., 2012). Many qualitative and quantitative requirements for the IC were published earlier (Götze, 2014).

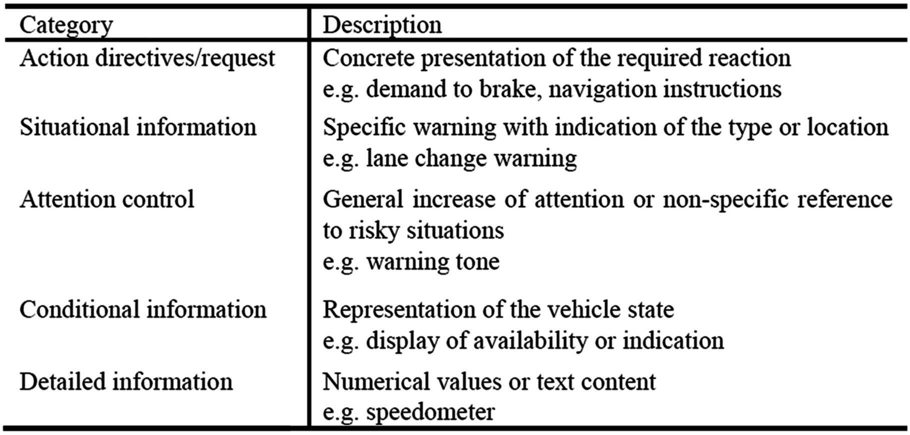
2.3 Information Categories

In a previous study (Götze, 2014), five different information categories were defined: Action directives/request, situational information, attention control, conditional information, and detailed information. Each of the categories is defined by a different range and complexity of the shown information. The aim of all types is to trigger a different driver reaction. The first three categories are used for warnings. While action directives/requests aim to concretely present the required driver action (e.g. demand to brake), the situational information indicates the specific type or location of the scenario (e.g. lane change warning), and attention control gives a general warning without specific information to increase the drivers attention to a risky situation (e.g. red warning sign). The last two categories are used to display non-critical information. The conditional information reports current HDD state and represents the vehicle state (e.g. availability or indication signals), while the detailed information displays numerical values or text content (e.g. speedometer). All of these five categories, shown in Table 1, were used in this study.

2.4 Framework Conditions of the Study

The participants performed an urban driving task in a 180° static driving simulator with side mirror projections, rear mirror projection, and a HUD projection. The simulation software used in this study was SILAB (SILAB, 2015). After the participants arrived, they filled out a demographic questionnaire and trained on the driving simulator and adapted to the different light level (because of the projections). All participants voluntarily performed the experiment. Each person had to drive two blocks (approximately 20 min. each) after a 10 min. training session. Each block was divided into 80 % urban driving and 20 % highway driving in order to prevent simulator sickness. Both blocks had different tracks and scenarios and were strictly permuted between all subjects. The participants operated either a HUD or HDD. Warnings, information, and navigation instructions were presented at the same position in both displays for all participants. Figure 2 shows the top middle position for the instrument cluster (HDD) and the middle position of the display over the current speed in the HUD. This procedure made

Table 1. Categorization of the content of information given with a warning/information (Götze et al., 2014).



Category	Description
Action directives/request	Concrete presentation of the required reaction e.g. demand to brake, navigation instructions
Situational information	Specific warning with indication of the type or location e.g. lane change warning
Attention control	General increase of attention or non-specific reference to risky situations e.g. warning tone
Conditional information	Representation of the vehicle state e.g. display of availability or indication
Detailed information	Numerical values or text content e.g. speedometer

Fig. 2. Position of the warnings and information shown in both displays

sure to expect all information at the same position over the trials to allow a low visual effort in finding the presented information.

The three warning categories (shown in Table 1) were used for three different risky scenarios: A parking vehicle, a pedestrian crossing the road and a fire truck taking the right of way. The two information categories were used to display either navigation information and the current speed, or status symbols. After each block, participants answered a questionnaire, rating the display type experiences in the last block. Additionally, the standardized NASA-TLX (Hart & Staveland, 1988) questionnaire was used to rate subjective workload. Furthermore, objective data was also recorded. After the experiment, all participants answered a final questionnaire comparing both display configurations.

2.5 Warning Scenarios

Warning Type: Action Request. This warning scenario of the type "action request" took place at a crossing with traffic lights. The participants saw the lights switching to the green signal quite early with no need to lower the speed or expect a traffic light change to red in the immediate future. After crossing the crossroad, an emergency vehicle took the right of way coming from the left side (see Fig. 3; scenario (a)). Without applying the brakes (or taking evasive action), an accident would have happened. The warning symbol with the additional text "BREMSEN" (brake) was shown in either display.

Warning Type: Situational Information. The "situational information" scenario (Fig. 3, scenario (b)) had a pedestrian crossing the road unexpectedly, hidden behind a van parking at the right side of the road. The speed allowed in this area was lowered to 30 km/h to give the participants a chance to avoid the accident. The warning symbol showed the parties involved in a potential accident (pedestrian) and the location of the threat (right side) as per definition in Götze et al. (2014).

Warning Type: Attention Control. The final warning scenario included the warning type for "attention control" where attention to a non-specific situation is communicated to the driver. The scenario involved a car pulling out of a parking spot (Fig. 3; scenario (c)). This car indicated leaving the parking spot quite late and simply pulled out just in front of the participant. The warning sign used in this scenario was a simple and generic warning triangle with no additional text.

2.6 Subjective and Objective Variables

In this study, different subjective and objective variables were examined. Different reaction times (RT) to the visual stimuli given on a display in the specific warning scenario and the SD of the distance to the lane center averaged over the whole track (Godthelp et al., 1984) were recorded. Stress and workload were also measured with the NASA-TLX to evaluate the different levels of visual load on different display positions. Lastly, participants graded the disturbance of status and indication symbols on a specific display.

NASA-TLX. For measuring the workload with the two different displays, the National Aeronautics and Space Administration Task Load Index (NASA-TLX) was used. The questionnaire measures on a 7-point scale. With increments of high, medium and low estimates for each point, it results in 21 gradations on the scales, where each complies for a score of 5 resulting in an overall score between 0-100. The topics addressed are the mental and physical demand, temporal demand, performance, effort, and frustration. A higher score on the scale corresponds to a higher workload.

Fig. 3. The three different scenarios with either warning symbols. Scenario (a) action request, scenario (b) situational information, and scenario (c) attention control.

3 Results

3.1 Participants

Thirty-two healthy volunteers participated in this simulator study with an average age of 26 years (SD = 3). Two participants had to be excluded because of simulator sickness. Twenty-five male and seven female participants were considered for the analysis. All of them had at least five years of driving experience and none of them suffered any visual impairments (visual acuity or color vision). For eleven volunteers, it was the first driving experience in a driving simulator, while the other twenty-one had driven at least once in a static driving simulator.

3.2 Objective Data

Statistical t-tests were performed to examine differences in the reaction time of the three warning categories and the standard deviation of the distance to the lane center.

Reaction Times. For the reaction time analysis, hits shorter than 200 ms and longer than 2000 ms were excluded as outliners. Additionally, for each participant, the mean reaction time was calculated and trials in a range M ± 2.5 SD were excluded.

The mean global reaction time for the two display types across all participants was calculated. With these results, a paired-sampled t-test was executed to examine any difference in global reaction time between the HUD and HDD. There was no significant difference found between the head-up (M = 1022.6 ms, SD = 296.9) and head-down (M = 1072.1 ms, SD = 408.4) display; t(29) = -1597, p = .121.

To examine the effect of the display position for the three different warning types ((a) action request, (b) situational information, (c) attention control) a paired-sampled t-test was executed for all three scenarios. There was no significant difference found for the RT in scenario (a) between the HUD (M_{HUD_a} = 1108.2 ms, SD_{HUD_a} = 232.5) and HDD (M_{HDD_a} = 1219.4 ms, SD_{HDD_a} = 479.4); $t_a(14)$ = -808, p_a = .432., neither in scenario (b) between the HUD (M_{HUD_b} = 1177.1 ms, SD_{HUD_b} = 231.5) and HDD (M_{HDD_b} = 1199.4 ms, SD_{HDD_b} = 323.1); $t_b(23)$ = -342, p_b = .735, nor in scenario (c) between the HUD (M_{HUD_c} = 830.5 ms, SD_{HUD_c} = 283.7) and HDD (M_{HDD_c} = 869.6 ms, SD_{HDD_c} = 361.9); $t_c(25)$ = 540, p_c = .594, see Fig. 4.

Distance to Lane Center. To examine the effect of the displays on lane keeping consistency, a paired-sampled t-test was executed for the standard deviation of the distance to lane center (DTL). For the DTL as well, no significant difference was found between head-up (M_{HUD} = .3388 m, SD_{HUD} = .0426) and head-down (M_{HDD} = .3462 m, SD_{HDD} = .0437) displays, see Fig. 5.

3.3 Subjective Data

NASA-TLX. The raw values without weighting were used to execute a paired-sampled t-test. For the global task load index, a significant difference was found between the head-up (M_{HUD} = 28.844, SD_{HUD} = 11.217) and the head-down (M_{HDD} = 34.188, SD_{HDD} = 14.579) display, $t(31)$ = 2.873, p = .007, see Fig. 6.

Additionally, the NASA-TLX score for each of the six categories was used to execute another t-test to compare both display types. No significant difference between the displays was found for the mental demand (M_{HUD_MD} = 40.47, SD_{HUD_MD} = 22.01; M_{HDD_MD} = 46.41, SD_{HDD_MD} = 20.57), the effort (M_{HUD_EF} = 37.34, SD_{HUD_EF} = 21.99; M_{HDD_EF} = 42.81, SD_{HDD_EF} = 20.28), and the temporal demand (M_{HUD_TD} = 22.81, SD_{HUD_TD} = 20.79; M_{HDD_TD} = 25.00, SD_{HDD_TD} = 18.92). A significant difference was found for the physical demand (M_{HUD_PD} = 17.97, SD_{HUD_PD} = 17.09; M_{HDD_PD} = 22.50, SD_{HDD_PD} = 14.02); $t(31)_{\_PD}$ = 2.159, $p_{\_PD}$ = .039, the frustration (M_{HUD_FR} = 23.13, SD_{HUD_FR} = 19.76; M_{HDD_FR} = 31.25, SD_{HDD_FR} = 17.26); $t(31)_{\_FR}$ = 2.707, $p_{\_FR}$ = .011, and the performance (M_{HUD_PE} = 30.63, SD_{HUD_PE} = 19.45; M_{HDD_PE} = 36.72, SD_{HDD_PE} = 14.35); $t(31)_{\_PE}$ = 2.365, $p_{\_PE}$ = .024, see Fig. 7.

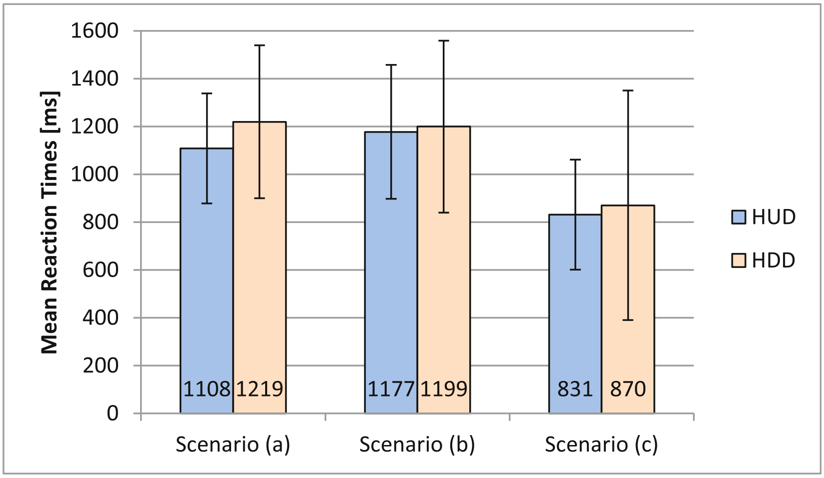


Fig. 4. Mean reaction times in [ms] for the three different scenarios with either HUD or HDD

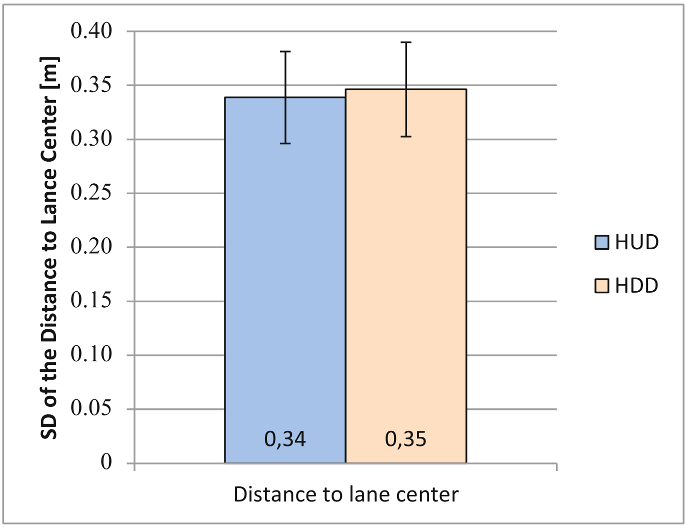


Fig. 5. The diagram shows the mean SD of the distance to lane center in [m] (with SD)

Additional Questionnaire. The last questionnaire after the participant finished both tracks grades both display on a 5-point likert scale and examined a significant difference for the HUD ($M_{\mathrm{HUD}} = 4.5$, $SD_{\mathrm{HUD}} = 0.6$) over the HDD ($M_{\mathrm{HDD}} = 2.3$, $SD_{\mathrm{HDD}} = 1.4$) regarding the subjective level of disturbance of status and indication symbols; $t(31) = 9.827$, $p < .001$.

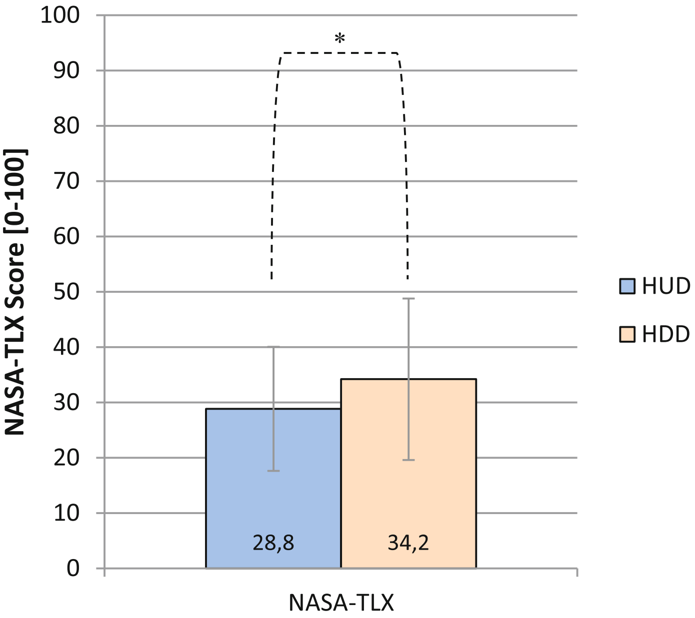


Fig. 6. The overall NASA-TLX score for the global task load index with the average of all six categories (with SD).

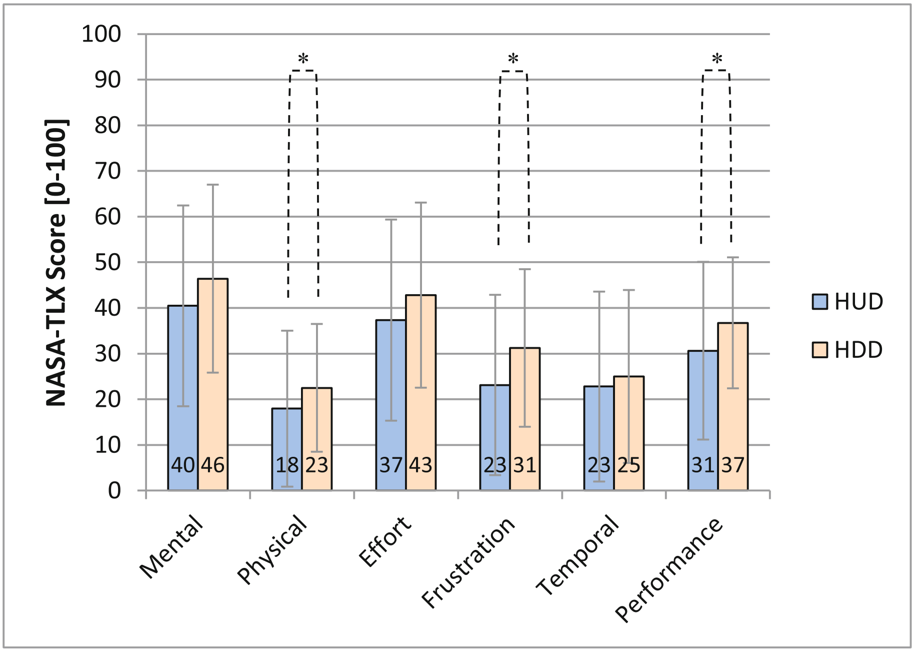


Fig. 7. The NASA-TLX score for the global task load index for each category (with SD)

4 Discussion

The aims of this study were to compare different types of information presented in a head-up or head-down display in an urban setting. The subjective analysis showed a significant preference for the head-up display presenting time critical warnings, dynamic information as the navigation or current speed, and driving related content (e.g. traffic sign recognition). Nevertheless, no objective difference was found for the reaction time in warning situations or lane keeping. One reason could be the scenario design of the warning scenarios, where some participants reacted to the potential risk earlier than the function could present the warning symbols. Status and indication symbols were significantly more disturbing in the HUD and should stay in the HDD since it brings no relevant advantage to have them in the driver's line of sight all the time. Only updates with those symbols (on/off/active) could possibly be presented in the HUD for a specific time interval.

The next steps will be to develop a first version of a generic and integrative HMI concept using the aforementioned components with an additional third component of a different modality (e.g. Acceleration Force Feedback Pedal for haptic stimuli or warning sounds for auditory stimuli), and evaluate it in a driving simulator. More ADAS could be integrated into this overall concept.

In conclusion, this paper shows the favored display (objective and subjective) for various types of presented information in the car while driving in an urban setting.

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