Impact of In-Vehicle Displays Location Preferences on Drivers' Performance and Gaze

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***Abstract*—Advanced Driver Assistance (ADAS) and Driver Information Systems (DIS) do not always comply with the intended driver safety enhancement. Even if they aim to augment the driver's awareness of the surrounding environment, perceiving this information requires the occasional attention diversion from the road, which could lead to a loss of vehicle control if the total eyes-off-road time exceeds the NHTSA recommendation for glances away from the roadway. Additionally, technologies that can be found in other mobile environments, smart phones and tablets are increasingly being integrated into cars, providing a necessary facet of study and continued research in their effects. We addressed this question analyzing differential preferences for the layout of DIS and ADAS compared to existing ones through a card sorting experiment. To validate our data, we additionally studied the drivers performance and gaze with the preferred locations for in-vehicle information through gaze location and speed metrics measurements. Our validation process showed that the time the drivers needed to find the conveyed information in the preferred layout was within the recommended time of the NHTSA Guidelines. Drivers preferences regarding the functional layout of current DIS and ADAS compared to existing ones did not essentially differ from the layouts that are currently on the market. However, including mobile applications and social media in a vehicular context was not considered necessary.**

***Index Terms*—Vehicular User Interfaces, In-Vehicle Displays, Information Visualization**

I. Introduction

Road visual distraction involves taking one's eyes off the road. According to the National Highway Traffic Safety Administration (NHTSA) only in 2011, 10% of the fatal and 17% of the injury crashes in the US were reported as distraction-affected crashes [1], meaning that 390.331 people were killed or injured in crashes involving a distracted driver. Over 17% of these distractions were influenced by using a mobile phone or manipulating other systems in the car. From these statistics we can infer that innovative Advanced Driver Assistance Systems (ADAS) and Driver Information Systems (DIS) do not always comply with the driving safety enhancement intended. ADAS aim to augment the driver's awareness of the surrounding environment. However, perceiving this information requires sometimes diverting gaze from the road that could lead to a loss of vehicle control if the eyes-off-road time exceeds the NHTSA recommendation for glances away from the roadway of 2 seconds [2]. The development of ADAS is rapidly increasing [3], [4], [5]. Many of these systems rely on sensors that collect data to identify for instance, the distance to the preceding vehicle, or the information shown on traffic signs. Vehicle-to-Vehicle (V2V) communication open the possibility of designing cooperative Advanced Driver Assistance Systems (co-ADAS) that use data collected by sensors located in other vehicles [6], [7] augmenting thus the sources of information.

The automobile industry is quickly adopting technologies that can be found in other mobile environments, such as smart phones and tablets. More and more vehicle manufacturers are offering to their customers the possibility of connecting their smart phones to the in-vehicle systems through an app to stream the personalized content into the car. This additional information can affect the driver's processing capabilities [8], [9] since the distribution of it in multiple displays requires more visual scanning time that implies taking the eyes off the road [10]. Therefore it is important to study where the increasing conveyed information should be located in the vehicle to reduce the time that a driver needs to look for it. A possible location for them would be within the driver's visual field since it reduces drivers' eye time off the road. Therefore some manufacturers project the vehicle speed on the bottom of the front windshield on a Head Up Display (HUD).

Automotive technology development and human factors research have always been closely related. Societal needs or technology trends have affected new automotive developments and therefore contributed to the growth of vehicle safety research [11], [12]. The reason for this study is the rapid increase of applications which can be found in other mobile environments that are being included in systems developed to be operated in a vehicular environment. We believe that this continued growth of not always desired or useful information could overwhelm and upset the driver, thus affecting road safety. For example, if certain information that is not relevant to driving is located in a prominent place in the car, more important information will be pushed into the background. By contrast, proper in-vehicle information visibility could facilitate driver interaction, assuring a smoother operation and reduction of distraction potential. Visibility can be enhanced through the proper placement of the in-vehicle functions, ensuring a user-friendly design according to user preferences and expectations.

It is therefore important to determine if drivers desire a social media integration in the vehicle besides current in-vehicle

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safety information and warning systems and to find out where the drivers would find this information to be most beneficially located.

In this paper we investigate drivers preferences and analyze the following research questions:

1) Where do drivers prefer to have vehicle features located?
2) Do drivers have differential preferences for the layout of DIS and ADAS compared to existing ones?. The choice of preferences could be affected by the habit of seeing certain functions be located in certain location in current vehicles. Do gender and age affect the preferences?
3) How does the driving performance and the distraction in terms of eyes off road of the preferred layout compare with the current display layout in the vehicle?

The key contributions of this paper are as follows:

- We designed a card sorting experiment to determine preferences of display location and functional integration in the vehicle while driving from a sample of 45 persons, extending therefore the sample from the approach that we originally presented in [13].
- We performed a validation process in a high fidelity driving simulator to study the driving performance when interacting with the preferred layout and find out if it differed from the performance with current layouts.

The approach presented in this paper provides new insights into in-vehicle menu structures and displays layouts as well as results relevant for a personalization of the provided functionality in an automotive context. The remainder of this paper is organized as follows.

In the next section we review the state-of-the-art of visual demand and in-vehicle layout studies. In sections III and V we describe in detail the experimental design of both, the card data sorting and driving simulator experiments. Sections IV and VI present our results. Finally, section VII concludes the paper.

II. State of the Art of Related Technologies

In-vehicle information distribution has been examined in detail in several works [14], [15]. In particular, design parameters of display modality and location concerning information relevant for driving (i.e. warning and traffic signs) have been addressed investigating if this information should be located in a central display or distributed along different screens located in other areas [16].

A. Visual Attention

According to [17] visual attention is determined by the gaze location. In this context, several works have investigated the visual demand required to interact with systems in an automotive context through simulations and models [18], [19], [20] as well as through real-world driving data records [21]. Most of these assessed the visual workload, comparing different kinds of information presentation, such as route information [22], [23], or information displayed on a multifunction information system including navigation, email, communication modules and independent audio, climate and cell phone displays [24]. The most commonly used measurement techniques were occlusion [25], frequency of glances to function location, glance duration and total eyes-off-road time (EORT) [26]. All studies led to the same conclusion: visually demanding tasks carry the highest degree of risk compared to other tasks performed in a vehicle. Moreover, it has been shown that multiple glances between in-vehicle devices and the road can affect driver attention, reducing the ability to maintain vehicle control and delaying and/or interrupting the cognitive processing of traffic information [27], [28], [29], [30].

In the context of the optimization of in-vehicle display systems, one common approach is the identification of the duration and frequency of drivers' glance to the displays, being the NHTSA recommendation for glances away from the roadway of 2 seconds or less [2]. Taking this into account, several authors compared drivers' visual behavior using different information locations comparing the instrument cluster and the center console, as well as the glances to the instrument cluster, the center console, and the head-up display (HUD) [31], [32], [33]. The studies concluded that drivers' glance behavior was affected by the display location. It seems that information closely displayed to the windshield allows less attention to be deviated from the road. This would be the case for technologies, such as HUDs, where information is projected onto the front windshield. However, in order to enhance visibility of the information, it is important to know where the drivers would like to have both current and new information located. This is still a topic that has not been sufficiently investigated. In our study, we derive the displays information location from the drivers' preference data we had previously collected and perform a validation process to find out the visual attention that these layouts require.

B. Current In-Vehicle Displays Layouts

Proper in-vehicle warnings and function location that enhances visibility and reduces the distraction potential has been the focus of design by automotive manufacturers. As a result there is an extensive variety of designs. In this section we intend to cover as many variant designs as possible selecting vehicle manufactures representatives for the main continents where they are produced. Namely, BMW as a German brand for Europe [34], [35], Honda as a Japanese brand for Asia [36], Chevrolet for the American corporation General Motors [37] and Tesla, also as an American company manufacturing electric cars [38]. We compiled this information and then labeled the displays with our predefined layout names. The compiled information is not all inclusive and not all displays are available in all the listed brands. In some cases even a display button enables selected information to be shown on the main displays meaning that some of the functions can be found on several displays.

- Display 1: Information that is relevant to the driver is currently visible in this location. For example, cruise control with braking function, active cruise control with stop and go function, warnings such as collision warning with braking function, navigation instructions, check control messages, vehicle speed, speed limit information, distance information, lane guiding and pedestrian recognition.

- Display 2: In this display some manufacturers such as Honda and Chevrolet show condition indicators that require an action from the driver (i.e. low fuel:refill), malfunction indicators such as low brake fluid, brake system, on-off indicators (i.e. fuel economy on) and warnings such as forward collision warning (FCW), lane departure warning (LDW) etc. BMW locates the following functions in their mini convertibles in this panel as well: odometer or distance traveled indicator, clock, fuel and temperature gauge, tachometer, next technical inspection date. In some electrical vehicles (i.e. Tesla, ROADSTER) the speedometer and tachometer are also located in this screen together along with the power meter, LCD panel for charging levels indication as well as odometer and warning indicators. Chevrolet locates in this display the speedometer (that can be also displayed in a different selected location), odometer, tachometer, fuel and temperature gauge, safety belt, airbag readiness light, malfunctions, lane departure warning, forward collision alert and fuel economy light.
- Display 3 is available as an extra space in Honda to show warning indicators.
- Display 4: Honda provides on this display the navigation, multi-view rear camera, lane watch to check the right blind spot, phone screen, audio screen (radio, disc, etc.), info (trips, etc.) and help commands.
- Display 5: Chevrolet displays here information about the vehicle trips, fuel range, average fuel economy, navigation and warning messages such as low battery, change engine oil, low oil pressure and functions related to the infotainment system such as radio, audio players and phone. Honda locates on this display settings for the camera, vehicle, system, phone, info and audio systems; BMW uses this display for the phone functions that are allowed in the vehicle transferred from a mobile smart phone as well as navigation information, the audio functions radio, CD, MP3, vehicle functions such as parking distance control (PDC), BMW services and telephone and additional functions such as data services, on-board computer, journey computer, vehicle information, interactive owner's manual, heating, air condition and radio station choice; Chevrolet locates here the speedometer.
- Center Console: All the manufactures located in this space the climate control commands.

III. Card Sorting Experiment

To determine if drivers have a preference with regard to vehicle display layouts that are contrastive to existing layouts, particularly involving new functions that are to be integrated in the vehicle, we performed a card sorting experiment. The card-sorting method is especially well suited for exploratory studies, as it allows a clear graphical representation [39]. Through a data analysis we explored similarity distances between functions to identify homogeneous groups.

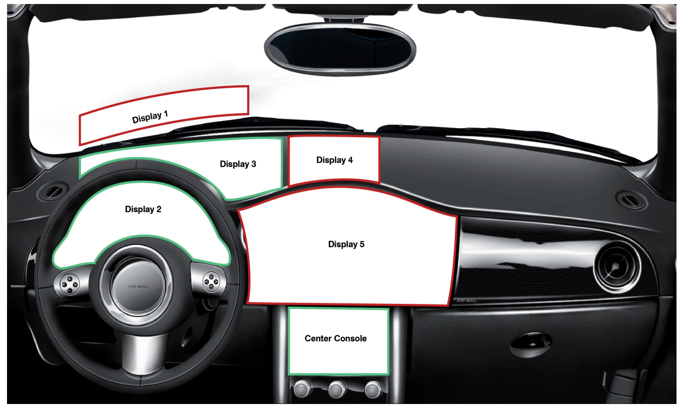

Fig. 1. Predefined display layout for the card sorting experiment (adapted from [40].)

A. Experimental Design

The card sorting experiment involved 62 cards, each representing a different function from different systems in the vehicle. We selected a closed card sorting approach, meaning that the test subjects had to group the cards they considered relevant for driving into predefined groups with the predefined labels Display 1 to Display 5 and Center Console that corresponded to different in-vehicle displays. It was not required to select all the cards. Figure 1 depicts the predefined groups distribution in the vehicle. 45 subjects (28 males, 17 females; mean age 36.5, *SD* = 13.4) were then asked to organize those cards into the given groups, depending on which location in the vehicle they would like to see the information contained in the card while they are driving. The test subjects were not required to own a car with a driver information system but needed to have used in-vehicle systems before. Therefore, we performed a screening and selected afterward only persons that were familiar with in-vehicle systems, had experience with smart phone applications and were in-vehicle technology aware. The sample was distributed in the following age classes: 21 between 20-34, 17 between 35-49 and 7 between 50-65.
From our previous analysis in [13], we learned that selected positions for functions that can be presented in both analog and digital form, did not differ. Thus, we merged in a common category functions that only differed in the specific name but had the same functionality (i.e. news and ntv). Additionally, we merged the "Warning lights" and "System status" functions into one category following the classification in the nomenclature system and warning systems [16].
To recruit a reasonable number of participants, we motivated participation through a raffle that was promoted through emails and posters, having thus each participant the chance of winning a prize. Volunteers contacted a given email address and received automatically an answer both in German and in English showing a short questionnaire and a link to select the most suitable date for the experiment appointment.

B. Data Analysis

To understand our collected data structure, we first performed an exploratory analysis, grouping the functions together that were sorted in a certain group and created a

matrix listing the cards in the rows and the display categories in the columns. We then determined how many subjects located a certain card into a certain display and calculated the percentages. This analysis allowed us to find out which vehicle components were considered important in a group category.
To identify relatively homogeneous groups of functions based on the selected display category, we conducted an agglomerative hierarchical cluster analysis using the single linkage method with Chi-squared frequencies as level of measurement to identify outliers. A cluster was then built for each function. After this, all the functions were sequentially combined into larger clusters. Since the two function clusters are merged based on the shortest distance, this method makes it easy to recognize outliers or functions that are numerically distant from the rest. Outliers were then excluded from further cluster analyses.
We then formed further clusters using a hierarchical cluster analysis relying on the Ward's minimum variance method and the distance between two clusters calculated as the Chi-square distance measures for count data [41]. Within this method the criterion to pair variables in one cluster is based on the minimum increase of the error sum of squares, i.e. the result is a minimization of the total within-cluster variance [42].
Using multidimensional scaling (MDS, PROXSCAL algorithm) we investigated similarity distances between functions to validate the cluster analysis. We created a set of 3844 unique pairs of the 62 functions and calculated the number of participants that located the functions in the same display. Additionally, to deduce if preferences were age or gender dependent, we conducted several Chi-squared tests comparing the data from female and male test subjects and for the age groups 20-34, 35-49 and 50-65.

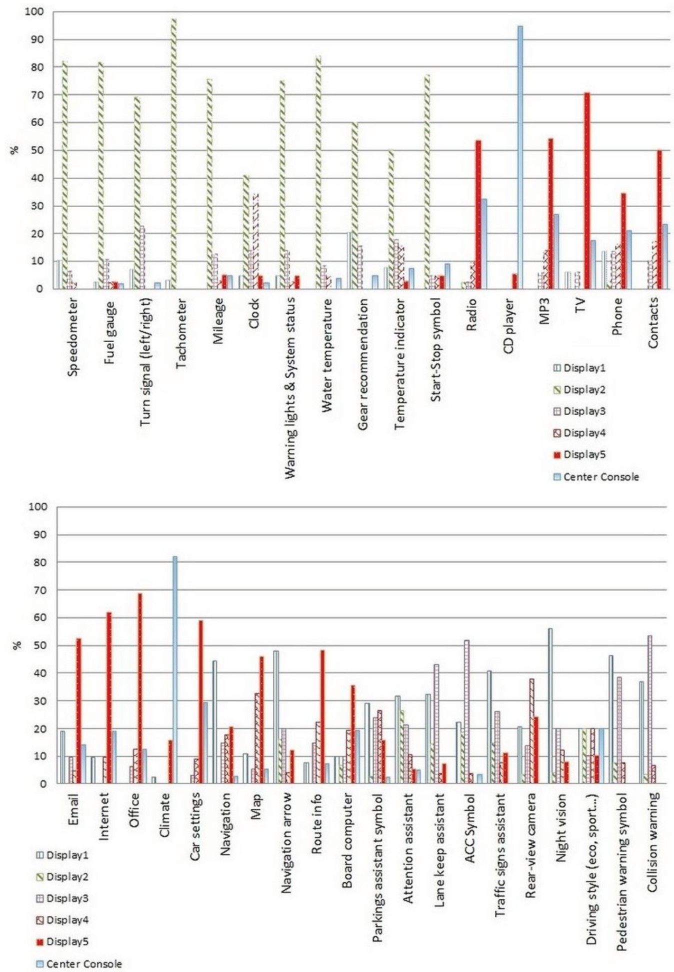

Fig. 2. Variation between individuals concerning the arrangement of the displays in the vehicle. A and B show the functions distribution in each predefined display and the percentage of subjects that selected them.

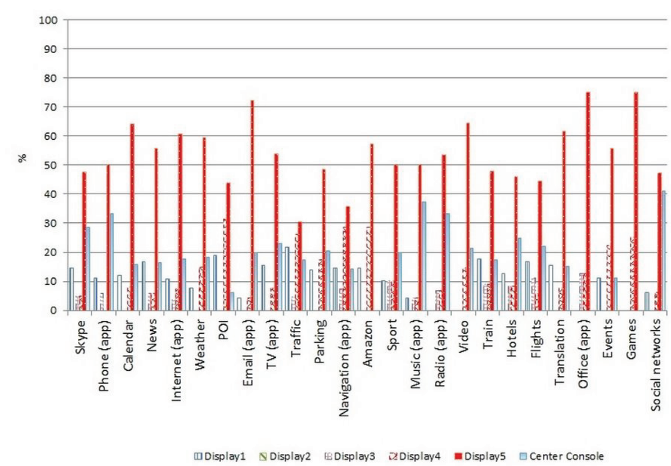

Fig. 3. Variation between individuals concerning the arrangement of the displays in the vehicle. The graphic shows the apps distribution in each predefined display and the percentage of subjects that selected them.

IV. Card Sorting Analysis Results

A. Driver Preferences

As mentioned in section III, we performed an exploratory analysis that consisted of grouping the functions together that were sorted in a certain group. Figure 2 and Figure 3 depict the variation between individuals concerning the arrangement of the functions and apps in the displays in the vehicle. The cards with the highest number of selections above a threshold of 50% built the display information for the driving simulator experiment to validate our data.

The agglomerative hierarchical cluster analysis to recognize outliers in our data, identified "CD player" and "Climate control" as similar functions with a greater distance to the other homogeneous groups of display categories. This result is consistent with the data that showed that both functions were clearly preferred in the Center Console. We therefore conclude that these two variables build a group.
Results concerning the hierarchical cluster analysis produced 3 fairly homogeneous clusters after several tests. Through the multidimensional scaling (MDS) approach we obtained the distances between the variables and validated the results from the cluster analysis. A visual representation of the distance at which clusters were combined is depicted in Figure 4. Additionally, Figure 5 shows the perceptual map with the relative positioning of all functions. Similar functions are placed close to each other on the map and functions that are perceived to be different from each other are placed far away.

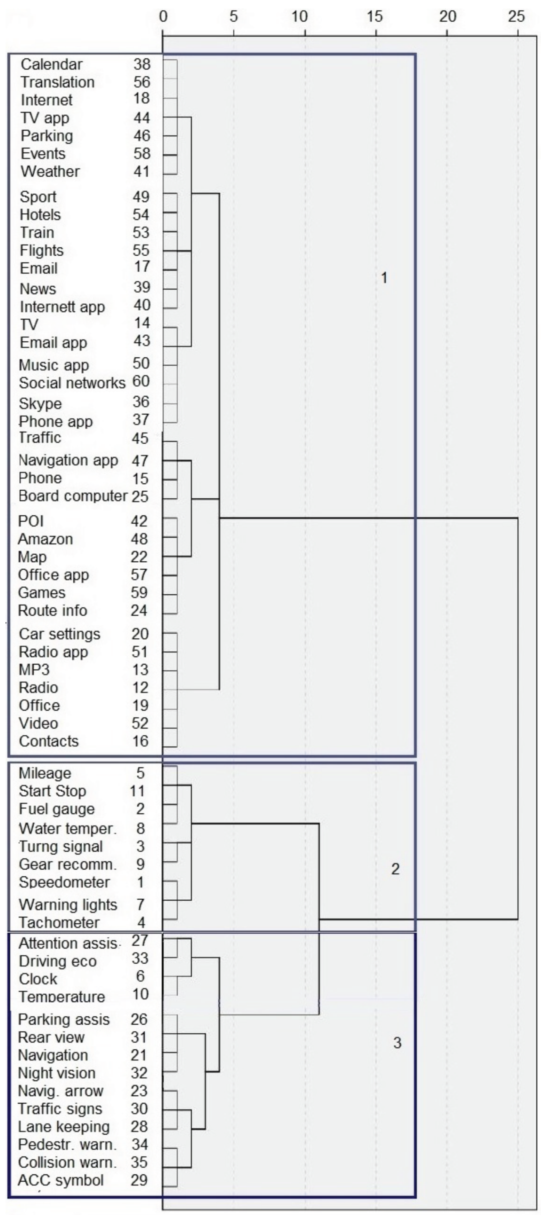

Fig. 4. Position distances between variables shown as rescaled distance cluster combination in the dendrogram using ward linkage.

We therefore obtained 4 groups with the following content:

- Cluster 1 contained entertainment, communication and office related functions not directly directed to the vehicle or road situation. As shown in Figure 2 and Figure 3, the cards depicting these functions were preferred to be visualized on Display 5 with a few exceptions also preferred on Display 1 or Display 4.
- Cluster 2 contained functions related to vehicle status and indicators (except for “Clock”). These functions were mainly preferred to be shown on Display 2 except for “Attention assistant” that was preferred on any display between Displays 1 to 4 and “Driving style”, that was preferred on Displays 1, 2, 4 or the Center Console.
- Cluster 3 contained Driving Assistance Systems that help in performing the driving task or systems that alert the driver about potentially unsafe situations. These functions were preferred to be presented on Displays 1 or 3 (except for the “Parking assistance symbol” that was additionally preferred on Displays 4 and 5 and the “Rear view camera” that was preferred either on Display 1, Display 4 or 5).
- The last group (outliers) consisted of the “Climate” and “CD player” that clearly indicated a preference for Center Console location.

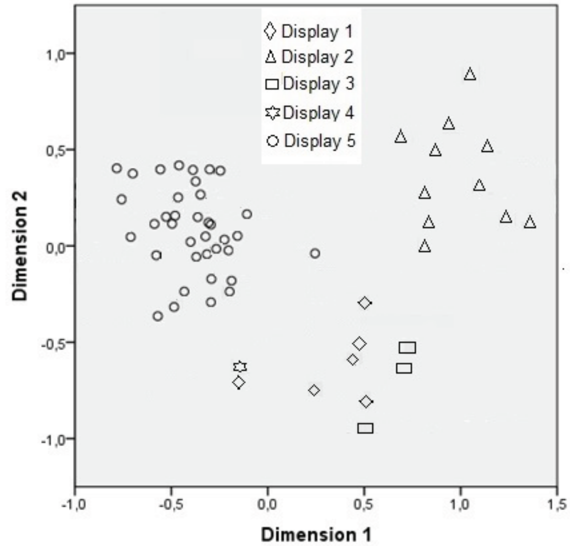

Fig. 5. Perceptual map with the relative positioning of all functions in the multidimensional scaling diagram

Regarding the relationship between the preferences of one display or another, as well as the gender and age of the subject, results from our exploratory analysis did not deliver any consistent or systematic patterns. Significant differences between genders and age classes in the functions distribution in the displays could only be found for the functions shown in Table I and Table II.

Concerning the functions to be visualized in the vehicle, not all the functions available were selected. In some cases a certain function was selected but only by a low number of participants, meaning that they considered the specific function not important to be shown while driving. Figure 6 depicts the percentage of subjects that selected the functions to be visualized in the vehicle, independently of the display selected. Results related to social media integration and mobile applications in an in-vehicle context showed that these functions were not relevant for driving. Only Internet was selected as an important app worthy to be displayed in the vehicle (62% of subjects). With a few exceptions, the remaining apps were not selected by a sufficient number of people to be visualized in the vehicle while driving.

B. Comparison with Existing Layouts

To determine the differences between found results and actual DIS layouts, we compared our data with the information

Function	Display	Males	Females	Sign.test (n=45)
Navigation	Display1	13 (87%)	2 (13%)	$\chi^2(1)=$ 5.72; p=0.0168*
Pedestrian warning	Display3	2 (20%)	8 (80%)	$\chi^2(1)=$ 9.751; p=0.0018*
Phone	CC	1 (12%)	7 (88%)	$\chi^2(1)=$ 10.233; p=0.0014*

TABLE I
DIFFERENCES BETWEEN GENDERS IN THE FUNCTIONS DISTRIBUTION IN THE DISPLAYS. SHOWN ARE ONLY SIGNIFICANT DIFFERENCES. CC = CENTER CONSOLE

Function	Display	20-34	35-49	50-65	Sign.test (n=45)
Weather	Display5	3 (19%)	8 (50%)	5 (31%)	$\chi^2(2)=$ 9.059; p=0.0108*
Radio	CC	11 (79%)	3 (21%)	0	$\chi^2(2)=$ 9.032; p=0.0109*
Phone	CC	7 (87%)	1 (13%)	0	$\chi^2(2)=$ 6.636; p=0.0362*
Climate	CC	20 (54%)	14 (38%)	3 (8%)	$\chi^2(2)=$ 9.855; p=0.0072*
Car settings	CC	8 (80%)	2 (20%)	0	$\chi^2(2)=$ 6.137; p=0.0465*
Skype	CC	6 (100%)	0	0	$\chi^2(2)=$ 7.912; p=0.0191*
Music app	CC	8 (89%)	1 (11%)	0	$\chi^2(2)=$ 8.165; p=0.0169*

TABLE II
DIFFERENCES BETWEEN AGE CLASSES IN THE FUNCTIONS DISTRIBUTION IN THE DISPLAYS. SHOWN ARE ONLY SIGNIFICANT DIFFERENCES. CC = CENTER CONSOLE.

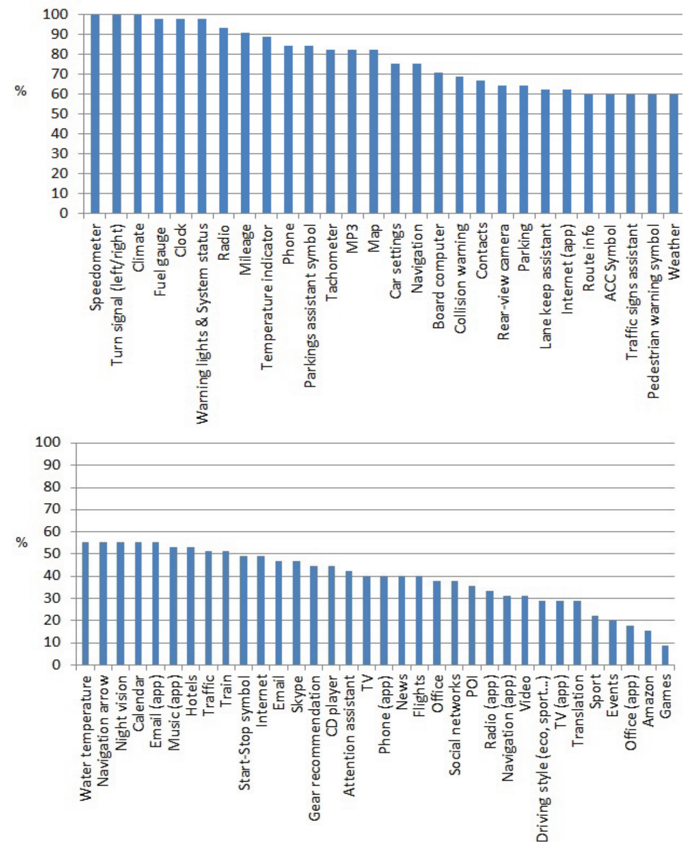

Fig. 6. Sorted percentage of test subjects who selected a specific function to be visualized in the vehicle while driving.

from section II. Generally speaking, preferences reported in our study are congruent with current layouts. Depending on the car manufacturer in-vehicle information is shown in different displays, although some brands even allow the driver to create a personal preference in display location.

The layout variability of modalities made it difficult to find a clear pattern to compare with our built clusters. However, we could infer that functions the test subjects located in the experiment on Display 2 are currently being visualized in this display as well. Functions preferred on Display 5, are also located in current layouts but some manufacturers position them on Display 4 as well. The current layout of Display 3 consists of warnings indicators. This information does not differ from our results either.

There were also some functions that were preferred by test subjects in a vastly different locations than layouts that are currently on the market. This applied to the “Collision warning”, preferred on Display 3 and currently located on Display 1 or Display 2 and to the “Lane keeping” preferred on Display 3 and currently located on Display 1.

V. DRIVING SIMULATOR EXPERIMENT

To validate the mapping of the selected functions and displays and determine the driving performance and glance duration related to the preferred in-vehicle displays layout while driving, we performed an experiment in a static driving simulator to collect relevant data. We built the displays layout considering the displays from the exploratory analysis where the cards had been selected to be located and the cards that were most frequently chosen. This was the case for the following set up that we labeled task set 1:

- Display1: Night vision, Navigation arrow, Navigation.
- Display2: Tachometer, Speedometer, Fuel gauge, Mileage, Warning lights, Turn signal.
- Display3: Collision warning, ACC Symbol, Lane keeping.
- Display4: Rear view camera.
- Display5: Skype, Hotels, Amazon, TV app, Email app.

Additionally, we compared the driver’s glance duration for selected functions with current displays layouts (task set 2). The independent variables in our experiment were the current display layout and the layout resulting from the data we collected in our card sorting approach.

A. Experimental Design

We established the experiment baseline in which no secondary tasks were performed as the base where the test subjects were looking at the road to compare the outcome with the results from looking at the displays layout that resulted

from our collected data (task set 1) and the layout for selected functions that can be currently found in the market (task set 2).
The total sample consisted of 13 persons (10 males, 3 females; mean age = 32.2, *SD* = 10.5). They were instructed to drive as usual at 50-60 km/h respecting the speed limit of 60 km/h while performing several secondary tasks consisting of identifying selected information that was projected into the displays requested by the evaluator through a specific question (i.e. please, report to which direction shows the navigation arrow on the HUD).

As the functions “Collision warning” and “Lane keeping” are located on layouts from some car manufacturers on Display 1, we asked for this position and as well for position 3 since this was the location that was selected by the highest percentage of test subjects to visualize functions. Through an eye tracking device we logged their glances to the Displays 1 to 5 and to the road to investigate the gaze behavior. We also recorded the speed as driving performance metric.

B. Equipment

For our experiment we used the static driving simulator for driver assistance systems and driving behavior research (BMW 6-Series) of the Institute of Ergonomics at TUM. A high-quality 6-channel projection system consisting of three projectors for the front view and three projectors for the rear view provided a realistic driving environment with a field of view of approximately 180 °. A 6-channel sound simulation completed the system.
We used the faceLAB software package using a set of cameras to get images for characteristic analysis of a subject’s face to measure gaze behavior. The advantage of this system is its nonintrusive nature and ease of use that removes the use of uncomfortable and restrictive goggles, wires or other sensing devices [43].
The SILAB driving simulator software [44] with road scenery, car dynamics, lane information and Human Car Interface elements was used to perform the experiment.

C. Simulation Framework

We developed a framework coupling the SILAB platform with an appropriate scenario and user interfaces interconnecting different displays in the vehicle. Additionally, we created an interface for the connection of the eye tracking external systems with the driving simulator software to track road gaze and the amount of time driver is focusing on a certain display.
The framework was deployed on eight machines, three of them for the visualization of the road scenery, three to provide rear view, one machine to show displays in the car including the Head Up Display (HUD) and an additional operator machine that controlled the whole system.
We defined a map for an urban road scenery to be used in the experiment connecting a set of routes predefined in SILAB. We also defined the traffic conditions by adding different cars into the road.
We then projected different information into the different

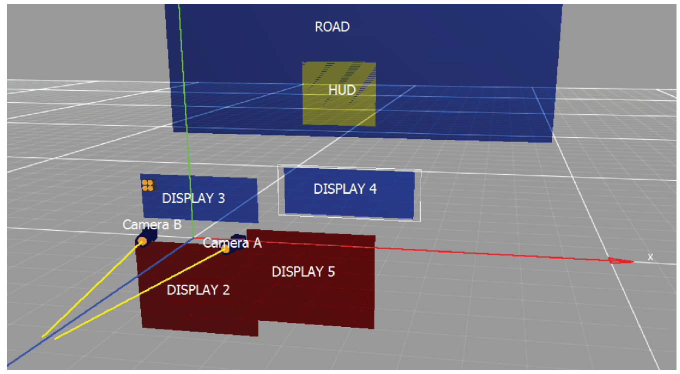

Fig. 7. Definition of the Displays distribution on the FaceLAB coordinates system

displays’ areas available in the car mock up (Display 1, Display 2 and Display 5) and added two extra screens to represent the information on Display 3 and Display 4.
To ensure an accurate calibration of the displays, we calibrated only the portion of the screen where faceLAB tracked both eyes. Our experiment did not require high accuracy or robust tracking, so gaze tracking was performed using the iris. The data provided the eye gaze in an angle format that was transformed into a direction vector. We created a representation of the displays in form of planar regions to reproduce which image the subject was observing in the subject field of view.
To show the relevant information on the corresponding display, we built a Data Processing Unit (DPU), selecting the coordinates of the item to be shown and mapping it in the desired position in the car mock up (Figure 7). Most of the items set up for the experiment were defined as ”Image” as no physical interaction was required from the test subject. Additionally, the type of object ”Needle” was used to show the speedometer and RPM information as well as to display the fuel level in the car. Figure 8 shows the set up with the eye tracking external systems and mounted display and the different type of objects used in the set up for the different Displays 1-5.

D. Data Analysis

To investigate the drivers performance and gaze related to the displays and to the road, we relied on the driving control performance metrics definitions in [45]. We measured the following dependent variables for both, the preferred layout obtained from the card sorting experiment and the current layout on the market and then compared the values testing the differences.

- The Eyes-off-Road Time or time drivers spent not looking at the road [46].
- Mean speed as an indicator of road visual distraction that involves taking one’s eyes off the road as a visual distraction results in a reduced speed [47].

Since our experiment was performed in an urban scenario with sections with curvature we did not measure other metrics

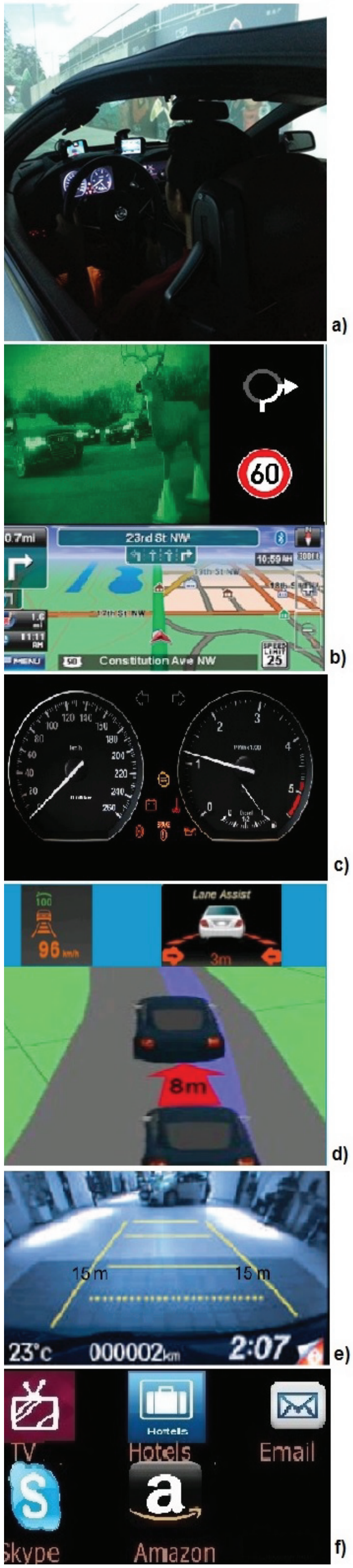

Fig. 8. In-vehicle information on the displays. Figure a) depicts the set up with the eye tracking external system and mounted displays in the driving simulator. Figures b) to g) illustrate the information shown in each of the displays 1 to 5.

such as standard deviation of steering wheel angle (SDSTW) or lateral position variation.

To test differences, we compared how the experimental group performed in the six experimental conditions with the Display 1 to Display 5 and the “road” and used a one-way repeated-measures ANOVA.

VI. Driving Simulator Results

We present in this section the results obtained from the driving performance and gaze through the driving simulator experiment.

A. Displays Comparison

Regarding the performance of the experimental group in the six experimental conditions Display 1, 2, 3, 4, 5 and “road”, the one-way repeated-measures ANOVA delivered the following results: The maximum glance duration during the tasks was affected by the type of visual target being the differences between the glance duration to the displays and to the road significant (F (1.17, 14.01) = 14.55, p $<$ .001, w^2 = .51, 1- $\beta >$ .8). The median glance duration to find the relevant information within a display that was tailored to preferences ranged between 1 and 1.5 seconds, being therefore below the total time of 2 seconds or less recommended by the NHTSA Guidelines [2]. Only Display 1 showed a higher value of 4.1 seconds. This was due to the proximity of both the Display 1 (HUD) and the “road” on the FaceLab coordinates system that did not always allow a clear distinction between the visual targets (see Figure 7).

Comparisons between the displays and the “road” regarding the mean speed did not result in any significant differences (F (1.8, 22.1) = .53, p = .58, $w^2 \approx$ 0, 1- $\beta >$ .8). As Figure 9 shows, the mean speed varied slightly depending on if the comparison group was looking at the displays or at the road, being the median values between 48 and 57 km/h, confirming therefore that the speed limit of 60 km/h had been respected while performing the displays’ tasks.

Results concerning the preferred layout showed that the time drivers needed to find the conveyed information was within the recommended time in the NHTSA Guidelines.

B. Comparison with Existing Layouts

Regarding the test subjects performance with the tailored layout from our card sorting experiment and the current layout on the market regarding the Displays 1 and 3, the box plots in Figure 10 show the results. The duration of driver’s glance to find the relevant information within the layout that was tailored to the preferences from the card sorting experiment (Task set 2), was with 2.3 seconds slightly lower than the driver’s glance duration to current display layouts on the market with 3.7 seconds (Task set 1). This difference was not significant (F (1, 12) = 4.67, p = .052, $w^2 \approx$ .09, 1- $\beta >$ .8).
Results concerning the mean speed with both layouts showed a slight decrease in the speed with the card sorting experiment layout with 48 km/h. compared to the 54 km/h with current layouts. This difference was not significant (F (1, 12) = 1.78,

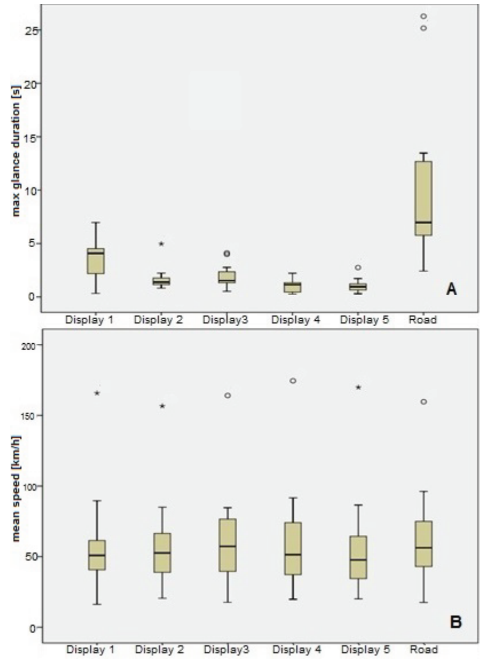

Fig. 9. Driving performance effect on the dependent variables. Graphic A depicts the maximal glance duration, graphic B the mean speed. Depending on the interquartile range (IQR) outliers are indicated by circles (1.5-3) or stars (>3).

p = .21, $w^2 \approx 0$, 1- $\beta > .8$).
Driving performance with the preferred layout did not differ from current layouts.

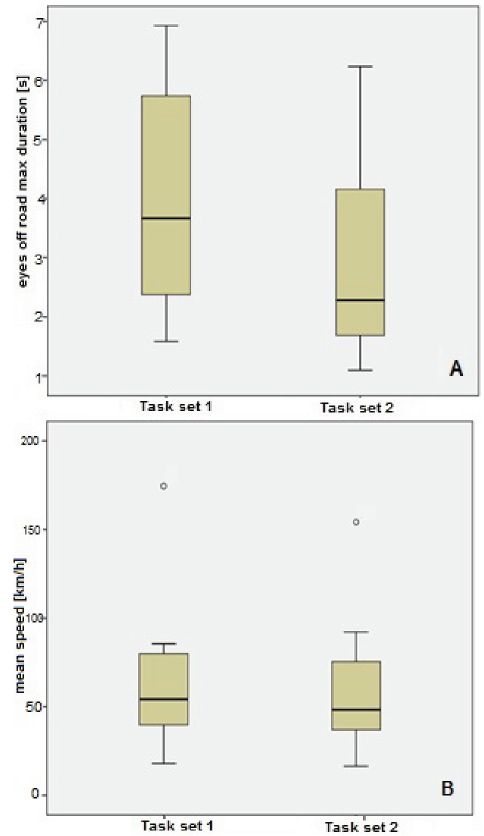

Fig. 10. Subjects performance with the tailored layout from our card sorting experiment (Task set 2) and the current layout on the market (Task set 1). A represents the eyes-off road time. B represents the mean speed variation. Outliers are indicated by circles.

VII. Conclusion

In this paper we presented an approach to analyzing differing preferences for the layout of DIS and ADAS compared to existing ones. We investigated where drivers would like to have in-vehicle and additional information located that can be also found in other mobile environments. We then studied the driving performance with the preferred locations for in-vehicle information and measured the gaze locations.

Regarding the first research question, focusing on where drivers preferred to have vehicle features located, we could build 4 fairly homogeneous groups of functions to be distributed in 4 different display locations. As to collect the pertinent data through our card sorting experiment we proposed 5 different locations (and the center console), a lower number of displays to convey the same information could be considered in future designs. Our results showed that the preferences that drivers have regarding the functional layout of current DIS and ADAS compared to existing ones do not essentially differ from the layouts that are currently on the market. These preferences were not affected by the gender of the subjects. The layout variability on the market, in terms of functions located on one or another display made it difficult to find a clear pattern to compare with our built clusters. However, our study indicated clear preferences regarding the wish to locate new functions in the vehicle that are still to come and can presently be extensively found in smart phones or similar devices: according to our results, social media and apps integration in a vehicular context was not considered an essential topic for driving. Due to the ever-expanding inclusion of the connection of smart phones with in-vehicle systems and the introduction of new technologies to make it easier for smart phone users to interact with mobile applications in their cars these results form the basis for future research in the field and should be considered in future systems.

With reference to the driving performance and distraction in terms of eyes-off-road time with the preferred layout compared with the current display layout in the vehicle, the time drivers needed to find the conveyed information in the five display categories asked in the card sorting approach was within the recommended time in the NHTSA Guidelines. Only the head-up display showed a higher value. According to [32], [33] this is due to the fact that the projected information in a HUD overlaps with the outside road and can interfere in the identification of the stimuli. The driving performance did not significantly differ from the driving performance with current layouts. Since more time is required to find a function that is not located where one expects, we can derive from our results that the functions information was located where the drivers expected to find it. With it the functions selection of the card sorting test subjects was validated by the second group of probands in the simulator. We can conclude that the card sorting experiment delivered a function distribution that correlated with current displays layouts. The habit of seeing certain in-vehicle functions in certain locations could have affected the card choices.

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