EYE GAZE STUDIES COMPARING HEAD-UP AND HEAD-DOWN DISPLAYS IN VEHICLES

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ABSTRACT

To minimize the mental workload for the driver and to keep the increasing amount of information easily accessible, sophisticated display and interaction techniques are essential. This contribution focuses on a user-centered analysis for an authoritative grading of head-up displays (HUDs) in cars. Two studies delivered the evaluation data. In a field test, the potential and the usability of the HUD were analyzed. For special driving situations the according display needs and requirements of the users have been identified and compared with in-car displays, so-called head-down displays (HDD). As major result, a high acceptance of the HUD by the driver and a good performance compared to other in-car displays had been reached.

1. INTRODUCTION

Over the last decades the amount of electronic (mobile) devises in cars, like infotainment and comfort applications has increased enormously [1]. For example, navigation systems, mobile phones, CD-player, mp3-player entered in the car environment. Also advanced driver assistance systems (e.g. adaptive cruise control or lane departure warning) entered in modern cars to help the driver in its driving process and increase the traffic safety. Through the rise of information and functions and the constantly growing traffic, the driver is faced with a significant higher complexity. That strongly implicates an improvement of in- and output modalities and efficient information presentation in cars. For this reason, this paper exemplarily focuses the potential of head-up displays (HUDs) for multimodal interaction concepts.

2. BACKGROUND

Whenever the driver is steering his car, he is faced a certain mental workload. This stress level is due to the execution of so-called primary, secondary and tertiary tasks [2, 3]. While the driver accomplishes several tasks, inattention, distraction, and irritation can occur as a consequence of the high workload resulting from superposition.

2.1. Taxonomy of Driving-Tasks

This taxonomy distinguishes between three different driving tasks.

Primary tasks include direction control operations. These are segmented into navigation, steering, and stabilization. Choosing the route from departure to destination corresponds to the navigation task. Steering includes, for example, lane changes due to the current traffic situation. Stabilization is accomplished by utilizing the steering wheel as well as accelerator and break pedals. This primary driving task is essential for safe control of the car.

Secondary tasks are operations, like reactions to and dependent on driving demands, however they are not essential to keep the vehicle on track. Examples are the turn signal, honking, and turning the headlights up and down.

Tasks not concerning the actual driving itself are categorized as *tertiary tasks*. Besides convenience tasks like adjusting the temperature of the air condition, communication and entertainment features count in here as well.

2.2. Categorization of Driving Task and Information

According to this taxonomy many classic display concepts are arranged and segmented. For this reason HUDs mainly contain important information of the primary driving task.

2.3. Head-Up Display

The HUD makes it possible to project information directly into the driver's visual field. This principle is based on optical rules. An image is projected onto a glass window and is partially reflected. The reflected fraction is perceived by the observer as a virtual image with the distance of the image source. [4]

HUDs were pioneered for fighter jets in the early 70s and later for low-flying military helicopter pilots, for whom information overload was a significant issue, and for whom changing their view to look at the aircraft's instruments could be a fatal distraction. [5]

Fig. 1. HUD from BMW 5 series.[6]

Nowadays, HUDs are becoming increasingly available in production cars (see fig. 1), and usually offer important data, like speedometer and navigation information. The information appears to hover above the engine hood, a few meters away from the driver's eyes.

2.3.1. Advantages and Disadvantages of HUDs

However, HUDs deliver several advantages and disadvantages which are already manifest in several studies. The advantages of HUDs are shorter accommodation times for the driver as the eyes don't have to focus to very close information like inside the cockpit. The driver can read quickly the information near his perspective resulting in an increased eyes-on-the-road time. Studies show a significant faster reaction on passengers and a very high user acceptance. However, also several disadvantages are assumed. Phenomena like cognitive capture are discussed what means a unknown shift of the driver's attention towards the HUD. Also perceptual tunneling what can result in a reduction of the peripheral visual field is discussed. Studies also mention distance overestimation. It is also difficult to reach a high optical contrast by the display what results in a high dependence on light conditions. [7, 8, 9]

2.4. Eye Gaze Studies

One aspect of drivers' visual behavior that keeps a widespread attention is the visual distraction caused by the use of in-car devices such as radios, phones and climate control systems [10]. The eye gaze technique measures visual behavior by recording the frequency and duration of eye gazes at particular objects in the driver's visual field. When drivers perform a secondary or tertiary task while driving, they usually complete this task through a series of brief gazes (1 to 2 seconds) at the object interspersed with gazes at the roadway. Eye gaze studies give a measure of the total eyes-off-road time, and hence the visual demand or interference associated with performing the task. This method is a widely accepted and valid measure of the visual demand associated with the performance of a secondary task. It is highly correlated with the number of lane excursions committed during secondary task performance. Eye gaze behavior has traditionally been measured by using a video recorder to record the driver's eye and hand movements. The time consuming process of analyzing the tapes frame-by-frame is then conducted to obtain the eye gaze data. Today, sophisticated head and eye tracking devices have simplified this process and allow real-time measurement of frequency and duration of eye glances, scan paths, eye-closures, and shoulder head turns.

Fig. 2. The JANUS eye tracking system [11]

The JANUS system (see fig. 2 is a head and eye gaze tracker and is capable of tracking head and eye movements under different lighting, vibration and head motion conditions [12]. It consists of a mobile component for data recording and a stationary component for post processing. The mobile component consists of a measuring helmet, a measuring rack with recording system and energy supply. Through the video transcription the task length, total gaze time, gaze frequency and gaze duration can be measured. The JANUS system is a valid measure of the visual distraction associated with the performance of several in-vehicle tasks and is an easy to use and efficient method for testing the safety of in-vehicle systems.

3. EVALUATION

To range the appropriateness of HUDs, two different studies delivered the evaluation data. [13]

3.1. Field study I: Comparing HUD and HDD

First, in a field test, the potential and the usability of the HUD were analyzed, using a test car. The test car was equipped with two head-down displays (HDD), the driver-centered combi-display (DCD) for displaying speed and status information and a central information display (CID) for entertainment and comfort functions. The car contained a commercial HUD that projects the virtual image in a distance of 2 meters to the driver. The test track was about 60 kilometers and the average driving time was one hour. For special driving situations (city road, highway), the according display needs and requirements of the users have been identified. Moreover, the HUD was compared with redundantly competing types of in-car displays (HDDs). The test persons had been equipped with the JANUS eye tracking system (see chapter 2.4). The subjects had to keep the car on the test track and have been instructed among other tasks to read out the road signs and control the speed limits on the displays.

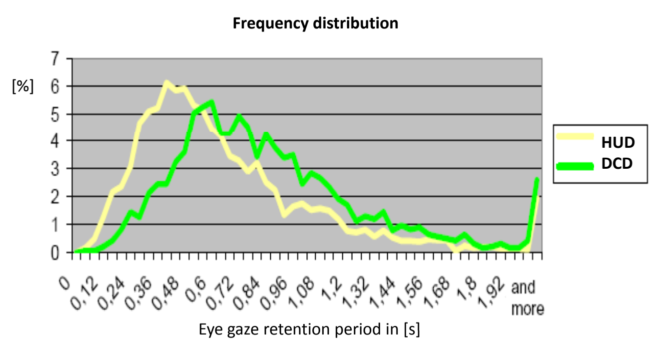

Fig. 3. Overview eye gaze frequency distribution

For information capture on a display the gaze retention period (GRP) is defined as eye fixation period plus eye movement period. 18 subjects (average age: 43.9a, 3 female) participated in the study.

3.2. Results of field study I

85% of the test persons pointed out that they accept and desire the HUD while driving. The HUD is an important completion of the information supply, and useful for different types of drivers, independently from age, system experience, and domain-specific knowledge.

According to the analysis of the GRP in all conditions the HUD showed the best performance (see fig. 3: The right tail of the distribution is distorted due a cumulation of several categories starting at 2 sec). In uncritical situations like driving on interstates, the GRP of all users was between 15 and 20% less on average compared to the GRPs regarding the DCD and the CID. In complex scenarios with much traffic like city roads, the averaged GRPs were even reduced up to 25%, which means that a HUD has a high potential for efficient information capturing in complex situations. Especially in the group of people aged between 51a and 60a, the process of information gathering from the HUD was about 200ms faster (see fig. 4).

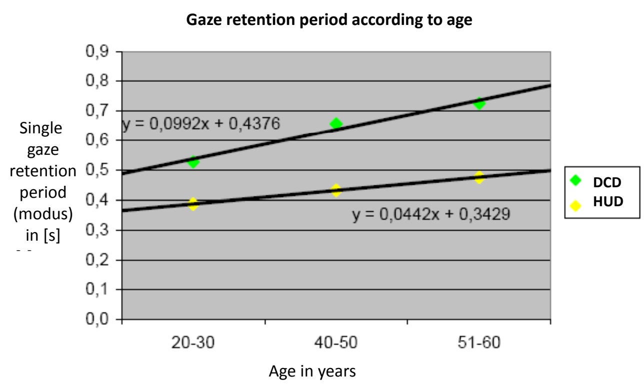

Fig. 4. Overview eye gaze retention period according to age

Between 86% and 90% stated that information regarding speed and active cruise control should, by all means, be displayed in the HUD. The subjects stated the following reasons for prefering the HUD: GRP reduction, comfort and safety. More than 70% of the test persons wished more information and functions. Beside individualization the test persons disered blind angle warning (86%), vehicle failure warning (85%), detour information (83%), speed limits (75%), fuel range (75%), saftey distance (55%), collision warning (50%). Beyond this the subjects desired status information like outside temperature, radio channel, time, gear information and fuel range. Yet, in the opinion of the test persons, the HUD cannot thoroughly replace the customary display types (CID and DCD). 50% would abandon the DCD, and 40% of all subjects would renounce the CID. Also, for some applications (e.g., like displaying the detailed navigation map or long lists), the HUD is not yet fully developed regarding visualization technology and user friendliness.

3.3. Field study II: Evaluating HUD content

In dependence of the situational context (e.g., curves vs. straight route), a field test was designed to evaluate special HUD layouts with regard to content and form. In this study the virtual image was projected using a laser HUD (monochrome) in a distance of about 1 meter. In this test 14 subjects participated. A follow car was driving in front of the test persons simulate real traffic. The drivers have been recorded by a video camera.

3.4. Results of field study II

As an important result, it was found out that, on average, the test subjects needed a total of 4,9s for mentally conceiving four new symbols, in curvaceous situations even up to 5,8s. Consequently, the maximum number of new information symbols or information units should not exceed approx. four new items at a time.

On the basis of the previous test results, a comprehensive multimodal display and operation concept will be developed in future times.

3.5. CONCLUSIONS AND OUTLOOK

The main aspect of these studies has been to primarily improve the traffic safety and to accelerate the intuitive capture of information in vehicles. The results of the usability study have shown that HUDs can deliver an improvement of efficient information presentation. Consequently, the HUD has a great potential for multimodal interaction concepts in cars. A appropriate layout concept will be designed. To meet the drivers' intention, further research will be focused on evaluation of HUD concepts. Furthermore, phenomena like attention capture and tunneling of HUDs have to be studied intensely. The drivers' attention to the traffic should not be influenced by an information overload, what could manipulate the main goal of more safety and user-friendliness in a negative way. In future, driving simulator studies to measure these effects are planned.

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