An On-Road Study of Head-Up Display : Preferred Location and Acceptance Levels

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An On-Road Study of Head-Up Display: Preferred Location and Acceptance Levels

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The purpose of this study was to gain a better understanding of driver's perceptions of Head-Up Displays (HUD). Many HUD studies have been conducted but few have allowed drivers to test a HUD in their own vehicle, allowing them to choose the best HUD location for themselves. Forty participants drove their own vehicles using a portable HUD device, testing different HUD locations, and then rated the HUD using the Technology Acceptance Model. The results showed that the HUD was rated as easy to use and the drivers intended to use it in continuation. The drivers wanted the HUD to be located outside of the traffic scene, below their line of sight. These results give support for new HUD locations and for increased HUD implementation.

INTRODUCTION

A looming concern in the automobile industry is how to implement new vehicle systems, which are used to visually communicate to drivers without distracting them from the driving task. Since the numbers of systems being implemented in automobiles are increasing every year (Bishop, 2005; Walker, Stanton, and Young, 2001) and too much information can lead to increased driver distraction, which is a safety risk. This occurs when drivers focus their attention on a display for too long (Yantis & Jonides, 1996), are selective in their attention and miss important traffic changes (Wickens & Hollands, 2000), or are divided in their attention and cannot shut out unwanted distractions (Wickens & Hollands, 2000). The Head-Up Display (HUD) can be part of the solution since it is recognized to reduce the time and frequency drivers look away from the traffic scene (Tufano, 1997).

Today a HUD is commonly used to present speed information, warnings, and a few other indicators. In the near future additional warnings and indicators will most likely be added to the HUD so to provide necessary information to the driver in an easily accessible location. The HUD is recognized as being visual display that is either located in front of the driver within 15° of their line of sight (Green, 2007) or a virtual-image display within the driver's line of sight where the image appears to be located at some distance beyond the windshield (Weintraub & Ensing, 1992). The Society of Automotive Engineers also recommends that important warnings should be located within a 10° cone of the driver's line of sight (SAE J2400, 2003).

Since the onset of the automobile HUD a large number of studies concerning the pros and cons have been conducted to find out how it could be safely used in automobiles. Tufano (1997) and Fadden, Ververs, & Wickens (1998) present a comprehensive summary of HUD safety research. The positive benefits show that HUDs allow for more time to scan the traffic scene, quicker reaction times, and earlier detection of road hinders (Liu, 2003). While the negative aspects are that a HUD may distract the drivers because it can clutter the traffic scene, leading to focused attention, selective attention, or divided attention (Wickens & Hollands, 2000). More recent work has shown that even locations high-up on the dashboard may also result in quicker responses to abrupt indicators (Perez, Kiefer, Haskins, & Hankey, 2009) although abrupt changes in the peripheral vision are noticed often very quickly anyways (Wittmann, Kiss, Gugg, Steffen, Fink, Pöppel, et al., 2006, Yantis & Jonides, 1996).

In many ways the implementation of technologies, like HUD, are driven by the engineering and marketing departments, and not by those who will be using the automobile (Gartman, 1994; 2004). Even though the HUD has been around since the 80's it is still rather uncommon and eleven years after its inception, it was stated that the HUD did not have a high acceptance level amongst drivers (Gish, Staplin, Stewart, & Perel, 1999). Today only one model, the 2011 Toyota Prius, offers the HUD as a standard option in only a few markets. As seen in some sales data relatively few new vehicles with a HUD are sold each year and this may support the idea that HUDs are an item of low interest to drivers. The number of manufacturers making HUDs available in their product lines has increased the last five years but this may be due to price drops in the technology (Siemens develops, 2006) and marketing strategies from the manufacturers point of view instead of increased customer interest. There is great uncertainty in knowing the level of acceptance to HUDs.

One possible reason to why HUDs have not become more popular is that the design focus of the HUD has been upon implementing a technology more than accommodating the users. When considering the usefulness of a system, like the HUD, people tend to use or not use an application to the extent they believe it will help them perform their job better (Davis, 1989) and performance gains are often dependent upon the users' level of willingness to accept and use the system (Young, 1984). Thus, "understanding and creating the conditions under which information systems will be embraced by the human organization remains a high-priority research issue" (Venkatesh & Davis, 2000, p. 186). Therefore, a study conducted through several days would also help reduce the "novelty effect" (Kiefer, 1991) and allow for decreased levels of tension created by the test situation.

Thus far, HUD placement has been based upon either simulator studies or the analysis of driver's eye-movements

without using an actual HUD. Harrison (1994) stated that these results should be verified in traffic since the driver was not studied within the actual driving environment. There is a gap in the HUD literature there longitudinal studies are used and where users are studied for their preferences (Harrison, 1994). According to the author's knowledge, no study using a HUD, over a longer period of time has been conducted in a participant's own vehicle. It is one thing to test people in a test vehicle, or in a simulated driving environment, and another to allow them to use their own vehicle, of which they are comfortable using.

The aim of this study was to gain a better understanding of driver's level of acceptance to using HUDs and to gain insight on where drivers prefer the HUD image to be located through a longitudinal study in the participants own vehicles. The optimal situation would have been to install an actual HUD in the participant's own vehicles, allowing them to test the HUD for a longer period of time, e.g. months, but that was not possible. A feasible solution was to use a portable HUD device, which allowed for the test of HUD image positions on both the vertical and horizontal axis. Wherewith, important knowledge concerning HUD placement location and the participant's perceptions of HUDs was gained.

METHOD

Participants

A request, via e-mail, was send to 2,000 individuals who were registered in the database Testplats Botnia. The website closed after three days and out of the 58 willing participants 42 drivers were chosen to participate. The drivers were chosen based on: availability to use their vehicle for the test, sex, age, driving experience, and average distance travelled per week. Data from two participants were removed since they did not follow the instructions correctly. The participant's ages were 20 to 77 years (M = 40.48, SD = 13.98), their driving experience varied from 2 to 59 years (M= 21.50, SD = 14.19) and they drove an average of 10 to 2000 km/week (M =437.18, SD = 409.25). Fifteen females and 25 males participated and all had either normal or corrected to normal vision. Only one of the participants had previous experience with an automobile HUD and the majority did not know what an automobile HUD was nor did they know how it worked. The participants used the HUD in the experiment from 60 to 400 minutes (M = 152.66, SD = 91.70).

Equipment

The device used to project the HUD image on the windscreen was an off-the-shelf smart-phone. It was programmed to show speed information in real-time via the built-in GPS receiver. A clear and understandable mirrored image of the actual speed was produced and reflected on the windscreen. The participants were instructed to conduct the studies when they could see the HUD image clearly, which meant that conditions of low light were most appropriate for most of the drivers. Only the participants that drove long periods used the HUD in the daytime and evening. The projected image was white, the font was 1.3 cm x 2.8 cm in size, and the device's luminance could be both manually and automatically be adjusted. The participants were instructed to adjust the luminance to the level they felt most comfortable using while driving so that they could clearly see and use the HUD without being hindered while navigating in traffic. All were asked if they had difficulty reading the information and no one stated that they felt restricted by the equipment either before or after the experiment.

Before the start of the experiment was the HUD device placed on the dashboard, in front of the driver, where the HUD image would be reflected on the windscreen at about 15º below the line of sight. The virtual image distance of the HUD was 100 cm (±10 cm) from the drivers' eyes (Figure 1). A tray with a "sticky" rubber material, prevented the device from sliding on the dashboard, and it also allowed the device to be placed at different angles within the tray so that the HUD reflection would be as close to 90º to the driver's eyes. The final and most preferred HUD location was measured based upon the participant's eye position in relation to the projected image on the windscreen.

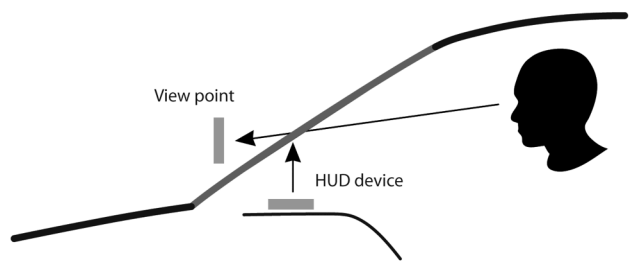

Figure 1. Description of HUD layout in participant's vehicles.

Procedure and experimental design

Permission to conduct the experiment was granted by the Swedish Ethical Review Board. Each participant was greeted then given information about the HUD, how it functioned, and how the experiment was to be conducted. If the conditions were agreed upon they were then informed about confidentiality and asked to sign a consent form before completing a questionnaire, which included an adapted version of the TAM. The HUD is particularly new and unfamiliar for most drivers, thus, the Technology Acceptance Model (TAM) was a fitting method to measure levels of acceptance to new or unfamiliar technology (Davis, 1989). The TAM is a "robust, powerful, and parsimonious model for predicting user acceptance" (Venkatesh & Davis, 2000, p. 187) and is frequently used to help determine and help predict people's likeliness to use the technology in the future (Venkatesh & Davis, 2000).

After this the participants were instructed on how to use the portable HUD device in their own private vehicles, instructed to drive as normally as possible, and adhere to the Swedish traffic regulations. They were also asked to test different HUD locations and, finally, upon returning show where would they prefer the HUD to be placed. The task was to drive

at least one occasion in each of the three days/evenings for at least 20 minutes and they were instructed to use the HUD in urban, rural, and highway traffic conditions while testing different HUD locations. After they were finished driving the TAM questionnaire was administered once again, followed by a semi-structured interview that contained ten open-ended questions, which concerned their use of the HUD and how they would prefer to use it in the future.

Data Analysis

The participants placement of the HUD was measured in relation to the forward line of sight, with the participant sitting in the parked vehicle facing a parking lot with parked vehicles in front of them at a distance of circa 20 m. The participant was asked to look forward as they would while driving, a mark on the windscreen was made where they stated the center of their sight path was. This distance was measured, then the angle and distance to the HUD image was measured. The level of measurement error was judged to be ±1° The data was analyzed using pair-wise t-tests, Repeated Measures ANOVA, and the factors were tested for reliability using Chronbach alpha in SPSS version 18.

RESULTS

HDD vs HUD

The participants rated the speedometers, Head-Down Display (HDD) and the HUD, on a seven-degree scale from very easy to use while driving to very difficult to use while driving. Both the HDD and HUD were rated before and after the experiment. The ratings were as follows: HDD before (M = 5.44; SD = 1.165), HDD after (M = 4.41; SD= 1.12), HUD before (M = 6.23; SD = .902), and HUD after (M = 6.59; SD= .549). A Repeated Measures ANOVA on ratings for *ease of use* showed significant effect of interface (HUD, HDD), $F(1,38) = 91.702$, $p = .000$, a significant effect of time (Before, After), $F(1,38) = 6.416$, $p = .016$, and a significant interaction between interface and time, $F(1,38) = 91.702$, $p = .000$. The interaction confirms that the increase in difference between mean ratings of HUD and HDD from before to after the experiment is valid (Figure 2). PostHoc testings at a level of significance of $p = .05$ with Bonferroni's correction showed that the ratings of *ease of use* of the HDD were lower after the experiment, ratings of HUD before and after were higher than the ratings of HDD, but the ratings of HUD had not changed significantly between before and after the experiment. All participants stated that they stopped using the HDD to read the vehicle speed during the experiment because the HUD was easier to use.

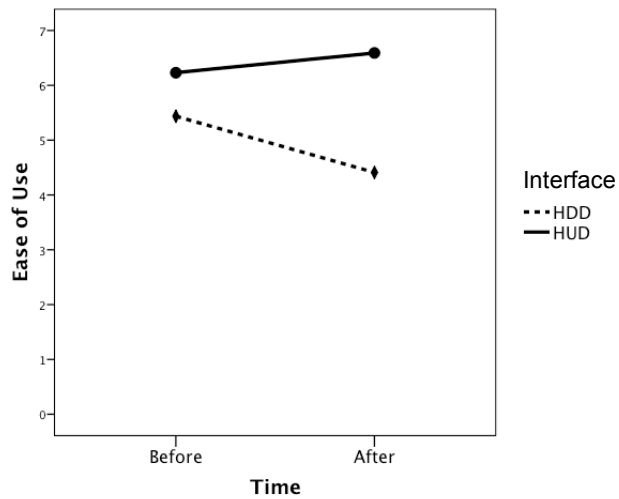

Figure 2. Ratings of *ease of use* for interface before and after the HUD experiment.

Preferred location for HUD image

The majority of the participants, 57%, preferred to have the HUD image directly in front of them just below their line of sight and more specifically 30% of them preferred the location 5-6° below their line of sight best. Thirteen participants wanted the HUD located to the left of the center, while nine wanted it to be found more than 5° to the left and five wanted it to be placed more than 13° to the right of center. In total 35% preferred the HUD to be located more than 10° to the right or left of center. Overall, the participants did not want the HUD image to be located within the line of sight, but just outside their focal vision when driving so they could quickly scan the information while driving. Figure 3 shows the preferred HUD placements of the participants.

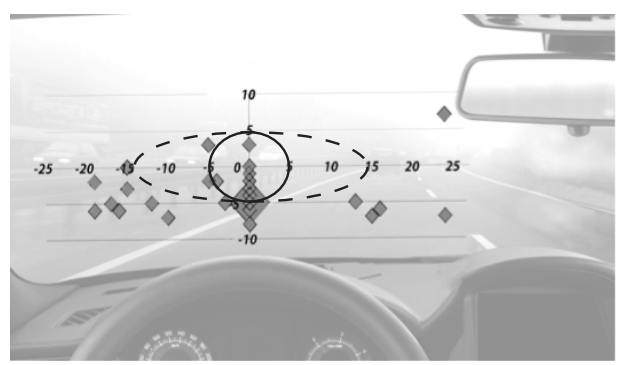

Figure 3. Preferred locations for HUD in relation to focal area and general field of view in relation to the traffic scene. The scale shows degrees from the participant's center line of sight.

Technology Acceptance Model

The participant's ratings in the TAM showed a high level of acceptance to the HUD, both before and after the experiment (Table 1). The participant's *behavioral intentions* to use

the HUD were high and significantly increased after using the HUD. The participants did rate the HUD as having significantly higher *perceived ease of use* after using the HUD and all the components had a relatively high internal reliability.

Table 1. Pair-wise comparisons of the TAM and attitude factors before and after the experiment, with their means (M) and Chronbach α.

Factor	Before (M)	After (M)	df	*t*	Sig
Behavioral Intentions	6.03	6.44	39	-4.229	.000
α	.603	.721			
Perceived Usefulness	5.13	5.30	39	-1.153	.256
α	.663	.692			
Perceived Ease of Use	6.08	6.43	39	-2.725	.010
α	.757	.607			

DISCUSSION

Many of the participants were not familiar with the HUD and this reflects how the overall driving community may be quite unfamiliar with HUDs. The participants, after learning about the HUD and shown how it worked, perceived the HUD to be *easy to use* and rated it as such. Since all of the participants stated that they stopped using the HDD during the experiment almost half of them expressed the need for important warnings to be shown in the HUD so that they would not miss any important information while driving. Almost all of the participants would have liked to continue using the HUD even after the test period. The most preferred HUD location was about 5° below the drivers line of sight and this agrees with earlier work (Inzuka, Osumi, & Shinkai 1991; Wittmann, et al., 2006; Yoo, Tsimhoni, Watanabe, Green, & Shah, 1999).

It would be reasonable to assume that the participants had a good understanding of how easy their own HDD was to use, however, after they had tested the HUD they lowered the HDD's rating from a 5.44 to a 4.41. Without anything to initially compare the HDD to it was rated very *easy to use* but after using the HUD was the HDD rated significantly more difficult to use than the HUD was. A likely explanation for this might be that when drivers are allowed to test the HUD in a comfortable environment, driving in normal driving conditions, they were able to respond with a more reliable judgment of the HUD. This type of study has not been done previously.

Even though the HUD image was not as clear as production HUDs are, nor the illumination strong enough for daylight driving in all vehicles, and neither was the GPS connection always 100%, the participants did rate it as being very *easy to use* and likeable. Good design shows that things that are perceived as easy to use are often preferred over other items that are perceived as less usable (Norman, 1990). In this study all the participants chose to use the HUD over the HDD because it was perceived as being easier to use and this was particularly because it gave them a better view of the traffic scene and driving situation.

Since all vehicles with a HUD today show redundant information a question can be asked, will it be necessary to show redundant information in the future? Redundancy is when similar information is presented in two display locations simultaneously; in this case speed information was shown in both the HUD and HDD and in this experiment the drivers chose the HUD over the HDD. Previous research has also shown that redundant information was not been advantageous for dual-task situations (Wickens & Gosney, 2003; Normark, Gärling, & Tretten, 2009).

The argument that clutter would be a problem if too much information were to be added to the HUD is a relevant one, but this should not stop the development and implementation of HUD. It is necessary to develop more advanced HUD images and test them in longitudinal studies. Just as with airplane HUDs (Kaiser, 1993) motor vehicle operators can also get used to a more complex layout as pilots have, thereby, enhancing their ability to sort and categorize information in relation to the traffic scene, which, in turn, might increase the overall safety.

The TAM results showed that the HUD received very positive ratings and after the experiment; *ease of use* and *behavioral intention*, were rated more positively. Motor vehicle owners may more positively accept the HUD if important safety improvements were made known. Not that the HUD in itself is an important safety feature but that it allows for the display of safety systems information in an easily noticeable location. According to the automobile industry "safety sells" (Hoffman, 2002) and it may be possible to use safety as an argument to sell the HUD, that is, if more on-road studies could be conclusive of the HUD safety advantages. One problem today is that the HUD has not been available to the average buyer (Siemens, 2006). The participants rated their optimal HUD location, thus, if all were to rate the exact same location it is possible the overall ratings for TAM would have been lower. Although one significant result of this work was that the majority of the drivers (77%) did not want the HUD image within their focal area while driving, instead they chose to locate the HUD either to the right, below, or to the left of the immediate area looked upon. Another question is that why do 35% choose to place the HUD more than 10° to either right or left of center. These locations could affect their ability to notice pedestrians but there are untested advantages of these locations since many drivers already choose to place their navigators in either to the right or left horizontal fields. One advantage of this location is that driver's normal scanning behavior falls upon the navigator location. This is much different from the OEM instrument panel locations today.

There is a mounting need for improved display techniques and improved display areas because things are getting too crowed in the dashboard. The results of this study show that HUDs are well liked when tested by users and the HUD should be located outside the drivers focal area, outside the recommended 10° given for warnings by SAE J2400 (2003). With modern advances in HUD technology are there even newer and more exciting locations and placements possible (GM reimages, 2011; Microvision, 2009), but it is necessary

to understand that new technologies often bring with them new, unforeseen, problems. With that in mind it is recommended that the implementation of HUD on a wider scale and the possibly to remove redundant of information is a viable solution.

CONCLUSIONS

The conclusions of this paper are that the HUD was well liked, easy to use, and after using the HUD were the participant's more interested to use the HUD in the future. The single most preferred HUD location was directly in front of the driver just below the line of sight at 5°. Generally speaking the HUD image was to be located outside the driver's line of sight either vertically or horizontally, and, finally, the participants did not consider redundant information to be necessary.

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