THE EFFECT OF REDUNDANT INFORMATION IN HUD AND HDD ON DRIVER PERFORMANCE IN SIMPLE AND COMPLEX SECONDARY TASKS

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ABSTRACT

The aim of this study was to investigate the effects of redundant driving information while conducting simple vs complex tasks via instructions presented simultaneously from the Head-Up Display (HUD) and Head Down Display (HDD) placements in normal driving conditions. Twenty respondents drove a fixed based high-fidelity driving simulator through 15km of light to moderate traffic in both rural and urban areas while responding to instructions. Ten respondents received ten warnings to respond to by pressing a button while the other ten respondents received ten instructions to conduct tasks in the center-stack area of the simulator. These tasks varied in difficulty from turn on CD player, to dial a given telephone number. Driving performance was measured via response time, gaze patterns, average speed, and maneuverability. Cognitive workload was assessed with the Driving Activity Load Index (DALI). The results showed that there were no significant differences between the baseline and experimental runs for the warnings due to the simple nature of the tasks while significant differences were found in the average speed and deviation from speed limit. The respondents rated the complex tasks as having a greater visual and temporal demand in relation to the simple tasks. The HUD was almost exclusively used by the respondents for driving information and stated that it was fitting for warnings and primary driver information.

KEYWORDS

Displays, traffic safety, reaction time, distraction, redundant information

INTRODUCTION

The awareness for traffic safety has increased internationally and automobile manufacturer’s, along with that, are seeking to build vehicles that enhance the users’ driving experiences. Unfortunately there are times these end up being conflicting goals. Since the driving process is highly visual [1, 2] and many functions are being added to vehicles today, which are highly visual, and can show too much, or improper, information at the wrong time. This can lead to distraction, in that, it taxes the drivers’ mental processing capabilities [3]. The driving process demands that a driver track changes in the traffic environment but, if the drivers’ attention is captured by a non-driving secondary task, or if the driver is cognitively loaded in another way [4], the driver will not be able to react quickly and appropriately to unexpected hazards. One of the main safety considerations when using visually demanding in-car equipment, like Intelligent Vehicle Technologies (IVT), is the driver’ s ability to accurately detect objects in front of the vehicle [5]. Accident research shows that distraction is a major factor to rear-end collisions [6] and drivers do choose to engage in distracting activities since they do not have a correct picture of how it effects their driving [7, 8].

Studies have shown that displays up front and within 15˚ of the line of sight, called Head-Up Displays (HUD), are optimal for reducing the risk for visual distraction since the driver does not need to look away from the traffic scene to read important driving information or conduct secondary tasks [5, 9]. When visual attention is focused on onboard displays, road control can still be maintained when the distance of the display to the traffic scene is not too great [9]. If all information were to be placed high up in the line of sight then a problem of cognitive overload could occur since too much information will be avaliable at one place in one time. Therefore the different placements used in today's high-end automobiles (e.g. BMW 7-series) for driving information should be tested to improve the knowledge of how tasks are read and responded to. Even though research has shown that HUD's are a viable safety alternative it's not certain that the level of acceptance by drivers' constitutes the implementation of HUD's in passenger vehicles. When young drivers and lesser experienced drivers were asked for perceptions of driver information and its placements they did not chose the HUD even though it was an option [10]. It can be that what driver's have experienced in the vehicles, that which they have been in direct contact with also has limited them to conceive the HUD as a viable option.

Methods measuring driving performance and physiological responses result in important information concerning driver performance. The Driving Activity Load Index (DALI) is designed specifically to be used for measuring the subjective cognitive load of the driving task, whereas other methods like the NASA-TLX were initially developed for other fields of research [11-13]. The purpose of this paper is to, from a user perspective, test and compare redundancy of information from the HUD and HDD display placements. The usability and likeability of driver information will also be tested. The respondents' cognitive workload, their perceptions of usability and acceptance concerning display placements, and their overall perception of in-vehicle display placements will also be investigated.

METHOD

Respondents

Twenty respondents with more than five years driving experience were assigned to two experimental groups with ten respondents in each group. The groups were balanced with respect to gender, age, experience, and mileage. The respondents consisted of two groups, Simple task and Complex task. The average age of the Simple task group was 39 years and 41 for the Complex task group. The average license age was 19 years for the Simple task group and 21 for the Complex task group. The average distance driven per week for Simple and Complex task groups was 138 km and 151 km, respectively.

Driving environment

The experiment was conducted in a high-fidelity fixed base simulator with four programmable digital displays (Figure 1) of which one Center-stack display (CS) was a touch-screen. The HUD placement consisted of a 8" LCD screen placed from 10˚ to 12˚

below the line of sight in front of the driver with a focal point of circa one meter from the drivers' eyes, the Head Down Display (HDD) consisted of a 12" LCD screen placed behind the steering wheel from 18˚ to 22˚ below the forward line of sight, and the CS consisted of a 12" touch-screen on edge placed 30˚ to the right of the driver and 30˚ below the line of sight.

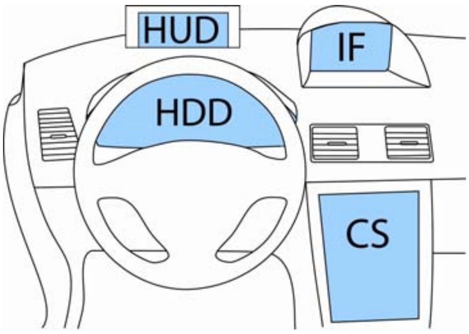

Figure 1. Display placements for information presentation.

Road environment

The road environment consisted of three driving blocks, namely, the practice session, the baseline, and the experimental session. The practice session consisted of a 10 km stretch similar to the experimental and baseline runs. The baseline drive consisted of a 15 km route, which took over 20 minutes to complete, beginning in a rural area with light traffic continuing through several small communities to an urban area, where the driver met moderate traffic and was required to stop at a traffic light. The route had two roundabouts and finished up with light traffic in a rural area. The experimental route was the same as the baseline but in the reverse direction.

Procedure

The respondents were split up into two groups; those who were given either simple tasks or complex tasks. The between subject design was chosen so that the task would appear in the exact same traffic environment for the two different types of layouts, this was done to reduce the possibly to predict the traffic environment which would have helped the respondents to predict when the message was to appear, thus, reducing the chance that the respondents predict when the information would appear. The Simple task group was presented generic warning messages of which they were to respond to by pressing a "reset" button, easily accessible on the end of the turn signal handle. This was done to confirm that they had noticed the message and to delete it from the screen. The warnings were shown 10 times during the drive from the HUD and HDD simultaneously and this occurred often when the outside environment demanded the respondents' attention (e.g. at a stop light, entering a roundabout, etc). The Complex task group was given 10 instructions in the the exact same traffic situations as the Simple task group. The driver had to read and carry out the instructions. For example, the adjustments were to be made in the vehicles CS, this included to adjust temperature, change volume, activate CD, activate MP3, change MP3 artist, call two different telephone numbers, or change the fan speed. The subjects were not asked to prioritize either the driving or the secondary task over the other. The purpose of testing and comparing simple and complex tasks was to determine whether cognitive workload had any effect in how the respondents perceive the placements.

After each of the blocks a questionnaire measuring the cognitive workload, Driving Activity Load Index (DALI) [13, 14], was conducted. The DALI, based upon the NASA-TLX, is designed to evaluate the workload during the driving task, it measures the perceptual load, mental workload, and drivers state. These items are measured by the respondent rating visual demand, auditory demand, tactile demand, temporal demand, interference, attention demand, and situational stress on a six point scale which is from Low (0) to High (5). The respondents are asked to relate the given driving task to what they consider to be normal driving conditions. The tactile demand factor was removed since tactile demand was not studied.

An interview was conducted to measure the respondents' subjective experience of the tasks in relation to the screen placements. The interview contained questions concerning socio-demographic, driving and simulator experience, and questions concerning likeability and usability. An example is the first question "on a scale from one to ten there one means very easy and ten means very difficult, how would you rate the experiment of reading and completing the given task", "Given very good, good, average, poor, and bad how would you rate your experience of information being presented in HUD", and "Given very good, good, average, poor, and bad how would you rate the ease of use for completing a task from the HUD". Questions were also asked concerning the placement of driver information. The respondents were asked which display placement they preferred overall, which placement they preferred to receive warnings for serious failures, warnings concerning vehicle operation, service items, and miscellaneous reminders.

RESULTS

Driving Task

A summary of the driving task results are shown in Table 1. There were significant differences for glance frequency ($F_{1,16}$= 29.95, p= .000), total glance time ($F_{1,16}$ = 132.23, p= .000), glance time from road ($F_{1,16}$ = 32.20, p = .000), time to reset ($F_{1,16}$ = 84.64, p= .000), lane position deviation ($F_{1,16}$ = 11.65, p= .004), and speed limit deviation within the 70 zone ($F_{1,16}$ = 5.43, p= .033). Thus, all measures, except for speed limit deviation, indicated worse performance in the complex tasks.

Table 1. Mean scores on the driving performance measures for simple and complex tasks.

Test	Simple	Complex
Time to notice (sec.)	2.33	1.85
Glance frequency	3.57	8.45**
Total glance time (sec.)	.750	3.44**
Glance time from road (sec.)	6.64	19.9**
Time to reset (sec.)	5.25	31.04**
Lane Position Deviation (std dev)	.329	0.46**
Speed Limit Deviation (km/h)	7.57	5.24*

*p<.05 **p<.01

DALI

Overall, was there no significant difference between the Simple and Complex groups' baseline blocks (Table 2). With the exception of the visual demand and temporal demand in the Complex group was there little difference in the baseline and experiment blocks for both groups. A paired sample t-test found significant differences in the Complex group for Visual Demand (t= -4.583, df= 9, two tailed p= .001) and Temporal Demand (t= -2.623, df= 9, two tailed p= .028).

Table 2. DALI results (0 low to 5 high).

	Simple		**Complex**	
DALI factors	Base	Exp	Base	Exp
GAD	3.8	4.1	3.6	4.0
Visual Demand	3.6	3.7	3.5	4.2**
Auditory Demand	2.1	2.9	1.3	1.6
Stress	3.5	3.7	3.5	4.0
Temporal Demand	3.3	3.3	2.8	4.1*
Interference	2.7	3.0	3.3	3.6
Total				

**p<.01 *p<.05

Display Position

When asked to what display position was most preferred for warnings did 80% of the respondents in each group prefer the HUD as primary display of information while 20% preferred the HDD. Overall, 75% preferred a separation of information, i.e. groups of information there the most important information is placed in an easily accessible location and lesser important information placed in a less accessible location. A small number of respondents, 20%, wanted secondary information placed in the HDD, these were not the same respondents as those preferring the HDD overall. Finally, the respondents preferred information that was appropriately fitting, both aesthetically and logically, in the layout it was to be found in. Two respondents from the Simple task group used the HDD almost exclusively, 9 times out of 10, for reading the warning while the Complex group exclusively used the HUD for reading the instructions, although, the same respondents that used the HDD primarily to read the warnings did chose the HUD as their preferred display for important information.

Likeability and usability

Overall, the HUD was rated as more likeable and usable than the HDD (Table 3). For the Simple group was the HUD rated as being significantly more likeable than the HDD (t= -5.000, df= 7, two tailed p= .002) and the HUD was rated as being significantly more usable than the HDD (t= -7.071, df= 6, two tailed p= .000). For the Complex group was the HUD rated as being significantly more likeable than the HDD (t= -7.000, df= 3, two tailed p= .006).

For the Complex group concerning the usability of the HDD, six of the respondents did not look at the information found there.

Table 3. Likeability and usability ratings of display placement (1 very good – 5 very poor).

		Likeability	Usability	Total
Simple	HUD	1.30**	1.00**	**1.15****
	HDD	2.50	2.50	**2.50**
Complex	HUD	1.0**	1.13	**1.07****
	HDD	2.75	2.75	**2.75**

**p<.01 *p<.05

DISCUSSION

The driving task measures showed that the Complex group performed poorer in the driving task and they showed higher visual demand and temporal demand. While both groups preferred the HUD over the HDD, finding it more likeable and usable, the respondent's stated that they preferred a separation of driving information so that important information is accessed more easily than peripheral information.

Due to the increased level of complexity in the Complex task, when compared to the Simple task, were significant differences found for glance frequency, total glance time, glance time from road, time to reset, lane position deviation, and speed limit deviation. With the exception of speed limit deviation were the results significantly higher for the measured variables. The Complex respondents deviated more from the center of road when completing the task, which is reasonably explained by and observed in the glance time data. As measured the Complex task demanded a greater attention and a greater cognitive workload, in that, the respondents spent a longer time on the task at hand and a longer time from road, thus, the fewer corrections were made to maintain the vehicle in the center of road resulting in greater variation from the center of road. The Complex task group respondents' deviated less from the speed limit, in the 70 zone, than the Simple task group respondents. This agrees with earlier research which shows that drivers who are under a greater cognitive load tend to decrease their speed and drive more careful and more focused on driving safer [15], but this does not mean that the driver's are better prepared for unexpected events. The drivers drove slower and more careful when partaking of the Complex tasks as opposed to the Simple task group.

Both the Simple and Complex task groups were given a message simultaneously on the HUD and HDD display locations. Both groups used the HUD almost exclusively when reading the displayed information. The DALI results showed that the visual and temporal demand was higher for the Complex task group. The complex task was the more demanding of the two since it required increased attention requiring the drivers to follow instructions and complete them correctly. The complex task did demand more time to read and when using the controls in the vehicle it required the respondents to look away from the road for a longer period of time thus the higher rating for visual demand as well. The respondents did also rate a greater temporal demand which was probably due to the greater time it took to complete the task which affected their driving performance.

The respondents showed that they preferred the HUD placement through their high ratings of likeability and usability. This placement was high-up close to the drivers' line of sight and the information, according to respondents from both groups, was not too demanding. These results are also supported by findings from Dingus [16] and Green [17] for display placement. This was especially evident in the Complex task group since they had to not only read a message there they were to complete a task in that area of the vehicle. Previous research of HUD in automobiles has shown advantages for the HUD placement [9, 18], though others have reported that respondents' unfamiliar with HUD's tend to prefer more common solutions for information placement [10]. After having tested and experienced these display placements which are typical of some high-end automobiles the respondents in the current study tended to support the implementation of HUD's in passenger vehicles. Even though the HUD was preferred, the more time spent on a task even though the task is read from the HUD and completed in the CS driving accuracy was affected negatively.

CONCLUSIONS

The driving data results were congruent with previous driving tests as was the support for both HUD applications for information presentation. This study showed that the respondents were positive to a HUD in their own private vehicles although they initially were negative to it's use. The respondents also were positive to new and innovative solutions that could help them in the driving task.

ACKNOWLEDGEMENTS

This study was performed within the OPTIVe project, financed by the Swedish IVSS research foundation and the Swedish Road Administration.

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