Investigation of Users' Age and Driving Performance With the Use of Prototype Automotive HUD System

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ABSTRACT

A plethora of rear collision avoidance or warning systems have recently been developed in order to assist drivers in demanding driving situations and weather conditions. However vehicle's controllability through human decision-making is often sacrificed due to unambiguous interface designs. Our effort focuses on the development of a system that could complement human senses instead of replacing them, and improve user's response times under adverse weather and traffic conditions. To this end we developed a prototype Head-Up Display (HUD) interface that could effectively convey the crucial information in a timely manner. The system was evaluated through trials with 40 users in a driving simulation environment. In this paper we will present a succinct brief overview of the HUD system and we will elaborate on the relation of the users' age with collision occurrence results derived from the comparative study of the HUD against the contemporary instrumentation panel.

INTRODUCTION

Contemporary profusion of automotive infotainment devices alongside with associated navigation technologies has burdened the typical vehicle's interior with a plethora of instrumentation devices (1). As a result of this trend, the vehicle's interior is increasingly being changed into an overloaded space of devices that announce, project and otherwise call attention to various pieces of information. An imminent result of these attention-seeking devices is visual clutter as dials vie intensely for the driver's attention (2, 3). Evidently driver's concentration could easily be divided amongst different tasks instead of focusing on the main task of driving. Instead of considering a more spartan driving environment, the current research trend is to examine ways of fulfilling the prominent infotainment needs of modern drivers without jeopardising the safety of the driving process.

Proliferation in vehicular technology has produced Head-Up Display (HUD) interfaces as an alternative to complicated in-vehicle devices, typically known as Head-Down Displays (HDDs). Apparently HUDs emerge as a substitute method for the depiction of information using symbolic or alphanumeric representation and attribute a larger viewing area, i.e. a part of the windscreen, than traditional dashboard instrumentation. As such, HUDs present an increasingly viable medium, suitable to present navigation/guidance features aligned to the driver's field of view (FOV).

Although the preliminary collision occurrences results were indicative of HUD interface's ability to convey the appropriate information in a timely manner, it has remained an open research question whether the effectiveness of these new types of interfaces may be affected by driver's age. Particular interest was placed upon the elder drivers with reduced reflexes. This category of drivers offered an intriguing opportunity to identify the impact of the presentation of infotainment data in a useful manner, without endangering or inconveniencing the driver.

Hence, our hypothesis was based on the fact that HUD instrumentation (i.e. symbology in the particular case) may situate visual cues in close proximity to the driver's road-seeking gaze; as long as the cues are subtle and non-distracting there is little need for the driver to divert attention away from the driving task (1). Theoretically this could substantially benefit the older drivers as it could minimise their head movements, eye-accommodation in different devices and improve their attention on one task only. Analysing the performance of 40 drivers during a simulated accident scenario for the development of the HUD has provided interesting results, which will be presented further on.

The paper is organised as follows: The next section offers a brief overview of the HUD interface design components. The following section will elaborate on the accident simulation. The simulation requirements will be presented in section 4 and the subsequent section 5 will contain a detailed illustration of the simulation results regarding the headway time differences between HUD and HDD, with emphasis to the older drivers' performance. A discussion will follow which elaborates the impact of the HUD system and the potential issues that might arise in a physical prototype implementation. Finally we will outline the proposed system issues and potential outcomes and present a tentative plan for future work.

HUD DESCRIPTION

Due to position and size with respect to driver's field of view, HUDs can offer a large screen estate that could be populated with different types of information. Evidently, the flexibility provided by these interfaces with respect to the type of information projected is well beyond the bounds set by HDDs, partly due to the larger screen estate of HUDs and the nature of presentation (superimposed to the actual objects). Looking for an ideal use of the display, Strathclyde Police Department in Glasgow, Scotland, suggested that the most prominent and fatal accident situations occur under very low visibility in a motorway environment (4). Hence a guidance human-machine interface (HMI) would ideally be tested in such conditions. Following their suggestion, we designed the proposed HUD interface for use under low visibility conditions, such as fog and heavy rain (5). Interestingly, HUDs can either enhance human vision, or provide visual warnings regarding potential collision situations, if they provide only the crucial information to the driver with the right timing. Thus, achieving information portrayal parity between an HDD and an HUD would result in an overloaded and possibly illegible dashboard.

Typically a major issue in the readability and accumulation of information through dashboard devices is heavily related to the alphanumeric method of presentation. Conformal or symbolic representations could offer considerably faster response times instead (6). Comparative studies of symbols and alphanumeric data in HUDs have conclusively demonstrated that symbols are interpreted much faster by humans (7).

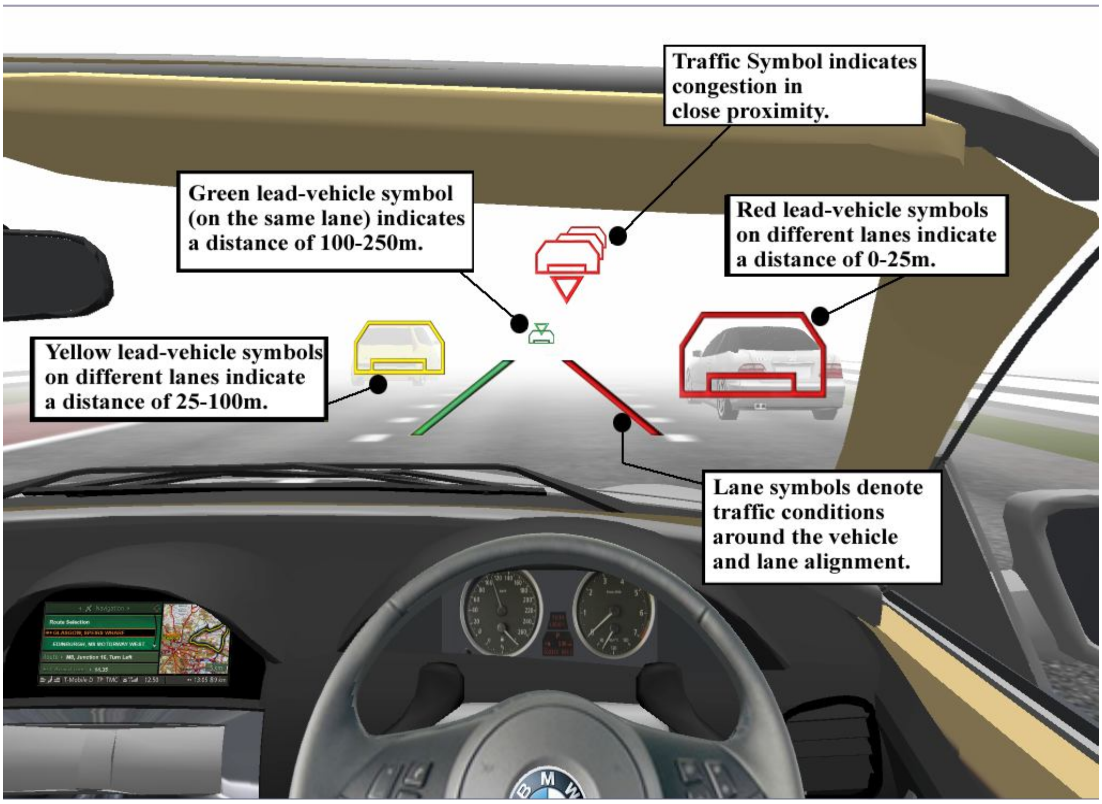

Figure 1: The HUD elements as presented during simulation

The proposed HUD interface design offers a range of symbolic representations with a two-fold functionality: visual warnings and visual enhancement. Considering human attention limitations and performance anxiety levels in a driving situation under low visibility on a motorway, it was evident that the system should convey crucial information only. The HUD peripheral sensors could “feed” the interface with time and distance measurements relevant to the potential hazard objects.

The projected graphical symbols have been extensively tested and developed in order to provide the driver with only the vital information for collision avoidance manoeuvring or braking in an imminent collision situation (8). Thus, considering the nature and the format of the information (real size vehicles, buildings and other obstacles) it deemed more suitable to use a full-scale (full windshield projection) design for increasing driver's spatial awareness. Furthermore, for enhancing human senses - vision in particular - the symbols appear in colourful visual cues adhering to the SAE colour coding standards. Additionally, they are enabled to alter their dimensions following perceptively and proportionally the object that they represent.

The development process of the HUD display highlighted four types of information that were identified as the most crucial for collision avoidance in motorways. This information was visualised through symbolic representation of actual objects, producing four symbols, including lane/pathway recognition, lead vehicle detection, traffic warning and sharp turn notification. The HMI symbols are described briefly in Figure 1.

The custom driving simulator developed for the HUD evaluation, falls into the category of static, virtual reality simulators. The simulated environment and the vehicle interior are displayed on a 1.8m wide by 1.2m tall back-projected screen (positioned 1.3m away from the driver), using an active stereo CRT projector. The user wears wireless stereo-glasses that separate the images for the left/right eye respectively. All software runs on a single PC with two Intel Xeon 3.6GHz processors and a high-end graphics card. The system maintains a steady frame rate between 40 and 60Hz, providing a smooth experience. The driving seat and vehicle controls are off-the-shelf components customised according to the projection area and the functionalities of the HUD interface.

SIMULATION SCENARIO

As the HUD interface was developed to counteract visual impairment under low visibility, it was considered necessary to evaluate its effectiveness in a simulated environment. For accurate re-enacting of the potentially hazardous driving situations, Strathclyde Police Department in Glasgow has provided the study with raw data from actual traffic police reports; annual accident statistics and planning diagrams aided to predict drivers' possible reactions (2).

Careful inspection of these data showed that two particular car-following scenarios occur fairly frequently and exhibit a high fatality rate. In this paper we will discuss the results of the first scenario, which has the higher fatality rate. The particular accident scenario is a variation of a generic car-following model that occurs due to sudden braking of the lead vehicle (9).

The particular sequence of events is as follows: the user drives in low visibility along the motorway for approximately 2km, when the lead vehicles are scheduled to brake abruptly, causing a braking chain reaction to the approaching vehicles. As anticipated, this event increases significantly the chances of vehicle collision.

A prior study in the mapping of driver's possible reactions in similar car following accident scenarios by (12) suggested that a driver's performance map is comprised of four driving states: low risk, conflict, near crash, and crash imminent, which correspond to four different warnings respectively. The first simulation scenario was developed along these guidelines in order to evaluate HUD's interface ability to convey effectively these four collision states to the driver. Segmenting the driver's performance-map into these four pre-collision periods provided the study with the advantage to identify the impact of the HUD information in every stage in comparison to the typical HDD.

For validation purposes, the movement, speed and distances of the vehicles had to adhere to the British traffic code. The results presented in this paper are based on 40 individual user tests. All subjects held a valid driving licence and they were aged between 20 and 82. In order to keep cost within affordable range, the research team opted for off-the-self hardware components and, initially, an open-source racing simulator, which would serve as the test-bed of the simulator development. A detailed description of the open source-driving simulator used for these experiments is presented in (11).

COLLISION VS AGE - WITH HUD AND HDD

The data analysis has presented an informative appraisal of the effectiveness of the HUD system through the estimation of collisions per trial, with and without the HUD interface (13). However this paper seeks to identify the correlation between the age of the driver and his/her collision avoidance dexterity.

From the original data set, Notably one of the users was removed due to exceptionally slow driving that was considerably outside the experiment design objectives. We employed a binary logistic regression with collisions as dependent variable and age as independent. This statistical analysis was applied in the results of both cases (i.e. with HUD and with HDD), which are presented below.

Collision vs. Age with HUD

The tables below offer a trail of the analysis methods that were utilised in order to identify the correlation of the HUD interface and the drivers' age into their collision avoidance performance.

Table 1: Model Summary for HUD

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	41.533(a)	.117	.169

The model summary (Table 2) above indicates that the relationship between age and collision is *not negligible* due to the high rates of both the R-squares, bearing in mind that the age factor is one of many that affect driving performance. Hence 16.9% for one factor is not negligible.

Table 2: Variables in the Equation for HUD

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1(a)	age	.049	.024	4.340	1	.037	1.051
	Constant	-2.928	1.066	7.542	1	.006	.054

An analysis of variance presented in Table 2 confirms the aforementioned results, as the B-coefficient for Age is 0.049, indicating that the age affects driving performance.

Hence older drivers have significantly more chances to collide with statistical significance at the 3.7% level as shown in the table above.

<u>Collision vs. Age with HDD</u>

The following group of tables present the statistical analysis of the collision results with the use of the traditional instrumentation panel, (HDD).

Table 3: Model Summary for HDD

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	21.070(a)	.002	.005

The HDD model summary (Table 3) above illustrates that the relationship between age and collision is minuscule and effectively *negligible* due to the very low rates of both the R-squares.

Table 4: Variables in the Equation for HDD

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1(a)	age	.011	.040	.079	1	.779	1.011
	Constant	2.067	1.563	1.749	1	.186	7.901

As expected, the ANOVA of the HDD results presented in Table 4 above shows that B-coefficient for Age = .011 suggests that someone older has a higher chance of colliding. However, it is not statistically significant (sig=77.9%). This occurs due to the small sample of users that might be sufficient for the HUD evaluation, but due to the extensive collision rates of the vast majority of the drivers is not ideal to identify a relationship between age and collision occurrences. This is clearly presented in the following Table 5. Evidently, there is not much variability in the age variable though, 53% are aged from 20 to 35; in addition to the fact that almost 90% of the drivers crashed in the simulated scenario without the use of HUD (13).

Age Groups

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	20-35 years	21	53.8	56.8	56.8
	36-50	9	23.1	24.3	81.1
	51-80	7	17.9	18.9	100.0
	Total	37	94.9	100.0	
Missing	System	2	5.1		
Total		39	100.0		

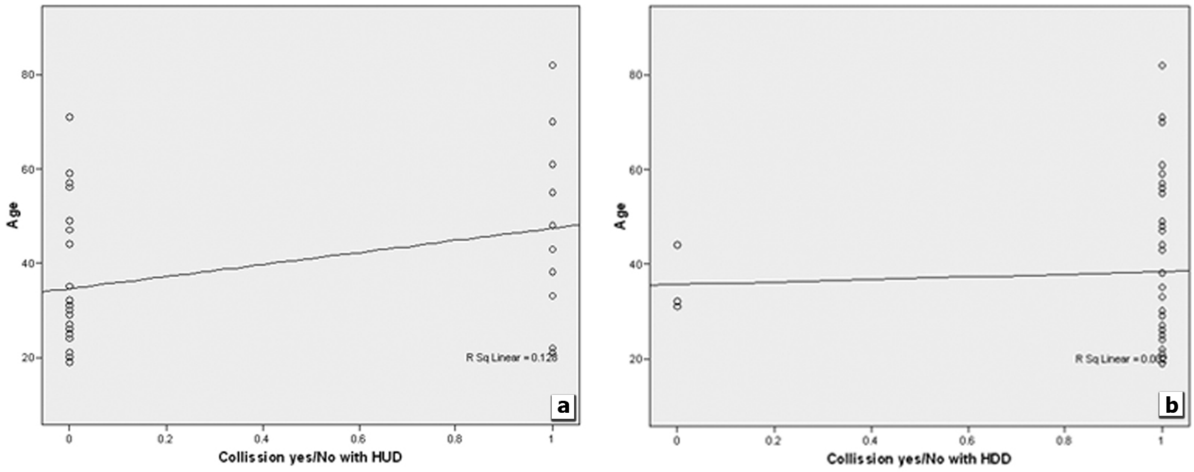

Figure 3: Comparison of age vs collision graphs (a) with HUD and (b) with HDD

The analysis of the collision occurrences has demonstrated that the age could affect driver's performance with HUD. Although this does not imply that older drivers' performance had deteriorated. In contrary a succinct investigation of the collision occurrences and the collision speeds demonstrates a significant improvement in collision avoidance as 43% avoided the collision in comparison to the results derived from the HDD as Figure 4 below illustrates. In particular the figure illustrates a significant benefit from the use of the proposed HUD interface, with the regard of the collision speeds. Evidently the collisions occurred with the HUD had considerably reduced speeds in comparison to the typical HDD, minimising in turn, the impact of the collided vehicles and increasing the survivability of the drivers. The older users have been highlighted with a grey tint.

USERS	GENDER	AGE	Collision Speed HUD	Collisions with HUD	Collision Speed HDD	Collisions with HDD
User_22	Male	56	0	0	23.358	1
User_23	Male	55	0	0	0	0
User_24	Male	70	5.84	1	17.84	1
User_25	Female	27	0	0	15.2	1
User_26	Male	38	13.1	1	21	1
User_27	Male	71	0	0	23.4	1
User_28	Male	48	20.45	1	15.4	1
User_29	Female	48	22.4	1	29.38	1
User_30	Male	61	15.008	1	29	1
User_31	Female	22	12.85	1	23.13	1
User_32	Male	57	0	0	19.5	1
User_33	Male	19	0	0	24.27	1
User_34	Male	49	0	0	21	1
User_35	Male	47	0	0	16.5	1
User_36	Male	55	16.35	1	22	1
User_37	Female	25	0	0	16.295	1
User_38	Male	27	0	0	6.77	1
User_39	Male	82	14.39	1	21.2	1
User_40	Female	59	0	0	9.7	1

Figure 4: Comparison of age vs. collision occurrences and the collision speeds.

CONCLUSIONS

This paper presented an evaluation of a proposed HUD design that supports driver awareness while driving under low visibility in a motorway environment. To facilitate an appraisal of the system, 40 users were tested in order to compare the driver's performance with and without the use of the proposed HUD interface. This study focused particularly on the driving performance related to age and the potential benefits or issues that might arise from the use of the aforementioned HUD system.

The experiments have shown that the system delivers on its promise for an efficient, non-distracting information display conduit, and assists effectively older drivers to avoid potential life threatening collisions. This was mainly achieved by the intuitive HMI design, which enabled a fast and accurate transfer of visual information to the user. We aim to repeat the experiment with a considerably larger group of users, which will provide us with a clearer view of the system attributes and pitfalls. In our future research, we aim to examine the behaviour of drivers in scenarios where faulty, or otherwise incomplete, information is available. Notably, we are keen to identify and investigate solutions in order to minimise the potential development costs that might occur for a real-life, full-windshield HUD. Finally it is our intention to extrapolate the functions of the HUD interface in general by amplifying its artificial intelligence capabilities in order to provide potentially the older drivers with more distinctive symbolic representations and well in advance.

Concluding, it is our belief that improved versions of the proposed HUD interface could incorporate digital 3D maps which will extend the system's ability to guide the user safely even in an urban environment and effectively exploit the large and currently unused windshield space.

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