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ORIGINAL ARTICLE

Human–machine collaboration through vehicle head up display interface

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Abstract This work introduces a novel design for an automotive full-windshield head-up display (HUD) interface which aims to improve the driver's spatial awareness and response times under low visibility conditions. To fulfil these requirements, we have designed and implemented a working prototype of a human–machine interface (HMI). Particular emphasis was placed on the prioritisation and effective presentation of information available through vehicular sensors, which would assist, without distracting, the driver in successfully navigating the vehicle under low visibility conditions. The proposed interface is based on minimalist visual representations of real objects to offer a new form of interactive guidance for motorway environments. Overall, this work discusses the design challenges of such a human–machine system, elaborates on the interface design philosophy and presents the outcome of user trials that contrasted the effectiveness of our proposed HUD against a typical head-down display (HDD).

Keywords HMI · HUD · Navigation · Low visibility · Symbology

1 Introduction

The advent of affordable in-car infotainment equipment and its wide use in several consumer market segments has resulted in growing research interest in in-vehicle human–machine interfaces (HMIs) (Ross and Burnett 2001). The stimulus overload stemming from the deployment of such devices may, however, distract the driver from the main driving task, which can potentially lead to an accident (Recarte and Nunes 2003). In recent times and along with traditional instrumentation the dashboard has been burdened with the task of providing space and mind share for infotainment devices such as Global Positioning System (GPS) navigation and other information facilitators (Kenny et al. 2004). As a result of the proliferation of use of this space, head-down display (HDD) interfaces may not effectively provide critical information as the driver's attention could be distributed along several irrelevant information outlets.

A head-up display (HUD) interface inherently increases screen estate for supplementary driving-related information, thus complementing the traditional dashboard, while commanding attention as it lies within the driver's immediate field of view. As a consequence, a simple design may provide further useful information without adding content to the already congested dashboard. By interpreting a wealth of information available through vehicular sensors, a HUD interface could enhance understanding of the vehicle's surrounding space and improve the driver's response times, particularly under low visibility conditions as depicted in Fig. 1.

This report elaborates on the design decisions and prototype implementation issues involved in the development of a novel HUD interface and presents findings of initial user trials. Furthermore, this work contrasts the use of the

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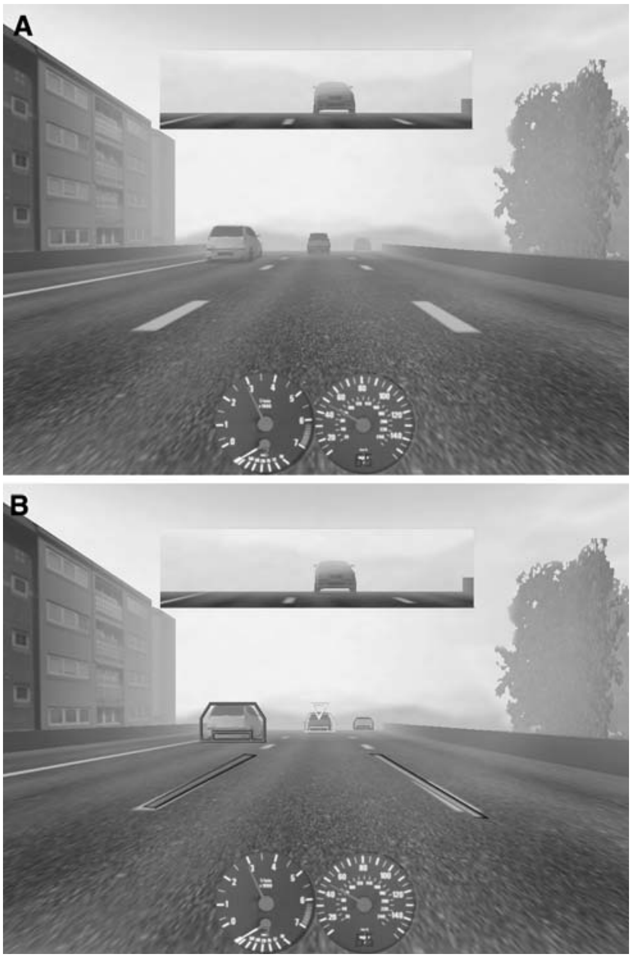


Fig. 1 Driving under low visibility conditions. **a** With contemporary HDD. **b** With proposed HUD visual aid

proposed HUD design against a contemporary HDD interface in simulated low visibility conditions. We have engaged observation notes, video-recordings, questionnaires and interviews to gauge drivers' reactions and preferences.

2 Role of HUD under low visibility conditions

The proposed HUD system becomes a critical regulator of information flow in an imminent crash situation under adverse weather conditions, by facilitating efficient collaboration and interaction between the system and the driver (machine and human elements). As the response times involved in avoiding a collision in such a scenario are in the order of a few seconds, we assert that an immediate conduit of communication among the vehicle and the driver should precede this event. Specifically, that link is to be provided by the HUD interface. Note, however, that the reaction responsibility cannot be exclusively delegated either way; recent research has revealed that the decision making process on driving responses should be distributed in a balanced manner among the machine and human elements for all types of vehicle interface design (McCann and McCandeless 2003).

Nevertheless, the human agent can easily experience stimulus and information overload, which may lead to failure to follow proper procedures or otherwise cause the agent to perform poorly. Yet, if a machine has been predefined to perform a specific action or calculation, it will consistently execute a set of procedures, in the correct order, substantially minimising the error possibilities (McCann and McCandeless 2003).

In this study, the machine, with the aid of sensor and radar equipment, is capable of identifying obstacles and inform the driver visually, through the HUD, of the position and speed of leading vehicles; by following a predetermined algorithm the decelerating vehicles can be traced and that information may be passed on to the driver through graphical symbols. Consequently, the system enhances human vision without interfering with the driving process.

3 Interface design

A major pitfall of HMIs, as applied in vehicles, is the creation of non-intuitive displays. In hazardous situations, such as low visibility navigation in a highway environment, interface delays or provision of irrelevant information due to an ineffective design can be fatal. In general, interface design and functionality should follow a human-centred approach. Consequently, a successful human-centred interface should enhance human actions (manoeuvrability with the use of traffic symbol), senses (vision enhancement through the front vehicle collision symbol) and judgement (lane selection and overtaking decision with the help of lane symbols). Furthermore it should guide the user and support rather than constrain his/her driving abilities. Therefore, during the design process of the HUD interface we were particularly interested to amplify and extend the driver's perception and cognitive abilities through visual cues. Subsequently, all essential information has been presented in a graphical form (symbols) which can be rapidly processed by the driver.

3.1 Visual data representation

Alphanumeric interfaces have been heavily used in the last decades as symbology for real-time navigation. This reflects the original military origins of the HUD design as a means of increasing targeting accuracy of military aircraft. Despite the fact that these interfaces serve a particular and well-defined purpose in that environment, their non-adjusted deployment can be inappropriate in the automotive field. A number of tests showed that HUDs overloaded with information, especially those using textual output, can create the effect known as cognitive capture (Ward and Parkes 1995).

In particular, cognitive capture occurs whenever the driver is distracted due to the presence of multiple visual stimuli. These visual cues take up a significant amount of the driver's attention resources and can dilute the essential focus on the driving task. Overall, cognitive capture is a perturbing cognitive issue with instantaneous, adverse impact on a driver's performance and safety (Ward and Parkes 1994).

It could be argued that alphanumeric representation can be much more suitable in certain situations than the alternatives; consider for instance, the case of expressing the exact vehicle position in a navigation system. On the other hand, the amount of information that drivers need to process in this manner can substantially delay their reaction to a possible collision incident. Comparative studies of symbols and alphanumeric data in HUDs have conclusively demonstrated that symbols are interpreted much faster by humans (Shekhar et al. 1991).

For reducing or even eliminating visual clutter, the conformal type of symbology for navigation information has been proposed (Fukano et al. 1994). In short, conformal symbology simulates the visual transformations of external objects to give observers the perception that the symbology is part of the external scene (Gish and Staplin 1995). In this way, it is also feasible to achieve minimal interference between the projected information and the critical details in the actual road scene. Our final design utilises simple geometric shapes as symbols in order to minimise the effect of cognitive capture and issues associated with it. Additionally, the symbols have been colour-coded depending on the vehicle's distance to the object of interest (e.g. a road turn or other vehicles). Symbol size variability also indicates the speed of the vehicle in relation to the lead vehicles, i.e. indicates the pace of approach.

Another aspect of interface design for successful human–machine collaboration is the ability of the system to be quickly assimilated by the user. According to Nelson the main criterion for assessing this ability is the rule of ten minutes (Nelson 1980). This rule suggests that a novice user should be able to learn the function of an interface within a maximum time frame of ten minutes; otherwise the interface has failed to convey properly the intended functions. This problem seems to be a significant shortcoming in the effective usage of these systems, provided that the complexity of the interfaces themselves surpasses the complexity of the actual incoming data (Rubinstein and Hersh 1984). Therefore, our intention was to avoid the constant appearance of confusing alphanumeric data (i.e. distance from front vehicle), or complicated icons that would exacerbate the visual cluttering and eventually lead to the cognitive capture effect. The design follows the mantra of "form follows function" and the visual cues have been presented in a minimalist manner.

3.2 Final proposed interface

The proposed HUD interface design, has settled, after several iterations, to the form depicted in Fig. 2. The design and implementation process was preceded by a study examining the tasks users perform in a vehicle when overtaking objects in possible collision scenarios under low visibility; we studied the driver's cognitive, behavioural, anthropomorphic and cultural characteristics. The empirical measurements and statistical analysis of the early simulation stages helped further evolve the interface to its final form. Through the stages of development, a recurring pattern was applied, namely that of design, test, evaluate and analyse (then looping back to design), in order to achieve the required performance from the system and meet the drivers' requirements. The merits of this methodology have been noted and it has been shown to lead to successful designs and implementations of interfaces that convey information to a human agent either from a machine or computer (Cacciabue 2004; Gould and Lewis 1985; Preece et al. 2002).

Overall, there are four main types of notification elements in the interface which offer orientation aid and collision warning functionality. These are the *lane symbol*, the *lead vehicles* symbol, the *traffic congestion* symbol and the *road turn* symbol; each is now briefly outlined in turn.

The *lane symbol* offers an easily identifiable "virtual pathway" which provides a point of reference for the

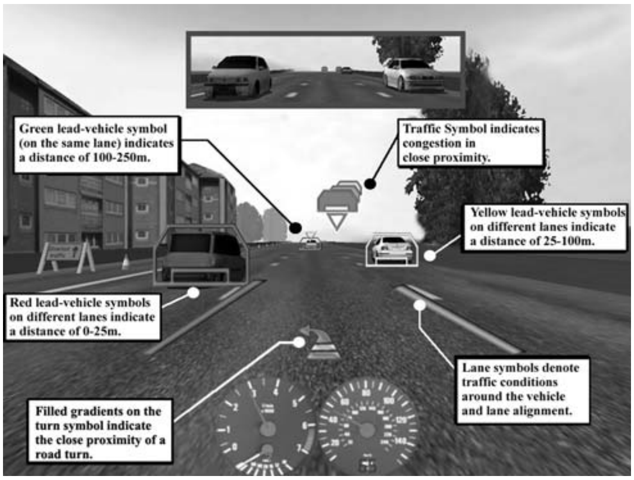


Fig. 2 HUD elements and their functions

vehicle's position on the road and helps avoid accidental lane departures. Further, the lane symbol also acts as a warning for the existence of obstacles in near vicinity of the vehicle (like an overtaking car or a lane barrier). The latter functionality is achieved by the colour coding of the lane symbol; a green colour on a lane strip indicates the absence of an obstacle at that side of the vehicle, whilst red colouring denotes some obstruction being present.

The *lead vehicle* symbol is superimposed on the first row of leading vehicles and acts as a collision avoidance mechanism by notifying the driver of the position of other vehicles of interest. The symbol itself is also colour-coded and varies in size so as to denote distance and level of risk.

The *traffic congestion* symbol alerts the driver to the presence of other groups of vehicles, moving slowly or being stationary at some point along the route and in the near vicinity. The presence of this prompt hints to the driver to reduce speed in anticipation of a slower traffic flow.

The *road turn* indication symbol acts, as the name suggests, as an indicator of a nearby road turn. The coloured stripes on the turn arrow indicate the proximity of the road turn and, predictably, the arrow points to the turn's direction.

Note that all the above symbols were designed to offer information without distracting but also be able to command immediate attention when the need rises. A thorough justification of the symbol design used, as well as a discussion on the symbol's positioning on the HUD, is included in our previous work (Charissis and Papanastasiou 2006).

4 Simulation set-up and experimental rationale

This section contains a brief description of the simulator employed to evaluate the effectiveness of the HUD system, presents the design rationale of the user trial scenarios and outlines the experimental procedure used.

4.1 Driving simulator set-up

The efficiency of the proposed HUD interface was tested via user trials with a driving simulator. The physical set-up of the simulator mirrored the interior of a medium-sized vehicle and included driving instruments as found in most automobiles (steering wheel, foot pedals, gear stick and so on). The user trials were carried out with the intent to gauge driver's performance when utilising a HDD, featuring a functioning tachometer and speedometer (as expected from a contemporary dashboard), against using the simulated full-windshield HUD interface, as portrayed in Fig. 2. Notably, during the trials, video footage was captured by two remote-controlled video cameras, with one focusing on the simulator's monitor and the other on the driver. As a result, apart from the measurements obtained by recording simulation data, it was possible to conduct a subjective appraisal of the driver's alertness state and emotional response to simulation events. The trials themselves were accommodated in the E-Motion Lab of Glasgow Caledonian University over a period of two weeks during which 40 drivers of both sexes and various skill levels participated. Further information on the driving simulator may be found in Charissis et al. (2006).

4.2 Experiment design rationale

As an initial design to test-bed experiments, we have considered two commonplace driving situations based on a "car following" scenario (Daganzo 2000, Kiefer et al. 1999, Smith et al. 2003). Figure 3 contains a schematic overview of both scenarios and a short descriptive outline of each follows.

The first scenario, as depicted in Fig. 3a, involved 20 vehicles spread across the track, led by a law-abiding driving artificial intelligence. At the beginning of the scenario the driver's vehicle was set behind two vehicle groups, which were composed of automobiles with varying speed characteristics. Then, and at a predetermined time instance the leading vehicles would brake instantly, forcing the driver to brake to a halt or proceed to perform an avoidance manoeuvre. After the driver had successfully circumnavigated the braking group, at a distance of 500 m another braking group was present, further challenging the driver to take evasive action. In the event of a crash with either group the simulator would halt and the scenario was considered to be complete. The particular aim of this set-up

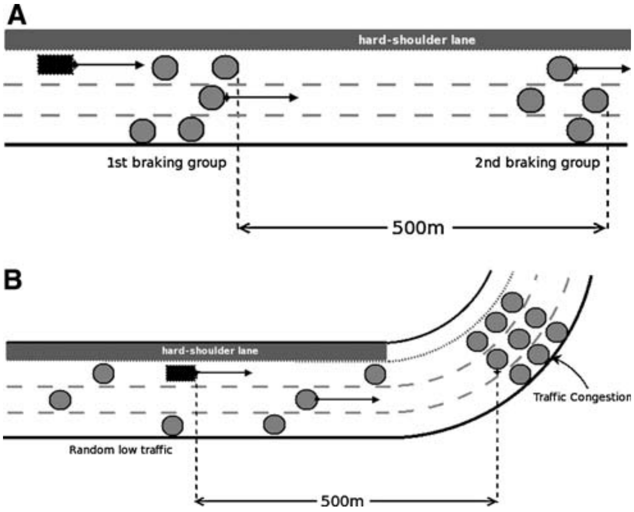


Fig. 3 Simulation Scenarios. **a** Sudden brake scenario. **b** Traffic congestion scenario

was to evaluate the driver's reaction to an unexpected event which would prompt for immediate action if collision was to be avoided (Kiefer et al. 2003).

The second scenario, shown in Fig. 3b, recreated a traffic-congestion scene with 20 participating vehicles. In this case, a traffic "bottleneck" would be positioned in a blind turn under a bridge, which presented a significant accident risk. As opposed to the previous set-up, drivers were expected in this case to be in a somewhat heightened alert status as they should have been aware that road turns are inherently more hazardous to navigate because of limited visibility at the point of turn. Note that the appropriate driver's reaction would be to brake until the vehicle has reached a full stop as there was no way to navigate around the traffic jam.

It should also be mentioned that both cases were of particular interest to the Glasgow Strathclyde police department (2004) as in an internal report of interest, similar settings has shown to generate the majority of accidents of car-following collisions. Both scenarios have been tested in a simulated track built to mirror the actual layout of the existing motorway complex between the cities of Glasgow and Edinburgh in UK. The track as well as landmarks of this area were modelled and imported into the simulation engine. In both simulations a low visibility factor was introduced in the form of simulated fog which allowed for approximately 5% visibility (being able to discern objects up to 50 m in front).

During trials, several metrics were collected to appraise driver performance; the collection interval was set to 0.05 s. At the course of a trial run and for a given user, the vehicle speed, lane position and distance from the leading vehicle were recorded. These measurements can largely reveal driving behaviour and reaction to a particular event. At the end of each trial run it was critically noted whether the driver managed to avert a collision.

5 HDD–HUD interface comparison

The proposed HUD system was contrasted with a traditional dashboard (HDD) during user trials based on the scenarios as outlined in the previous section. This section elaborates on the comparison and offers supportive evidence to the HUD's efficacy. At first, a typical user reaction to the first simulation scenario (sudden brake—Fig. 3) is presented. Such an inspection provides insight on the average driving response and offers some justification of the merits of the system. Then, the actual effectiveness of the system is appraised by considering the number of collisions averted when the HUD was used to augment a traditional dashboard in the user trials. Finally, the perceived effectiveness of the proposed design is considered through questionnaires, where trial participants were asked to gauge the HUD's effectiveness and provide their overall impression of the proposed interface.

5.1 Evaluating a typical user reaction

A common user reaction to the first simulation scenario can be observed in the graphs of Fig. 4. The data recorded during this trial are indicative of a typical reaction to the "sudden brake" scenario as shown in Fig. 3a, and the discussion that follows is instructive as to the effectiveness of the HUD interface in the general case. It should be noted that this participant first drove through the "sudden brake" scenario using the HUD interface and then using a standard dashboard. In between the scenarios of sudden brake (with and without HUD utilisation), we tested the second scenario (traffic congestion) in order to minimise the chances of the subject memorising the events. Additionally, the low visibility conditions created a seamless transition between the trials, thus preventing the driver from identifying the pattern and positions of the other vehicles (Charissis et al. 2007).

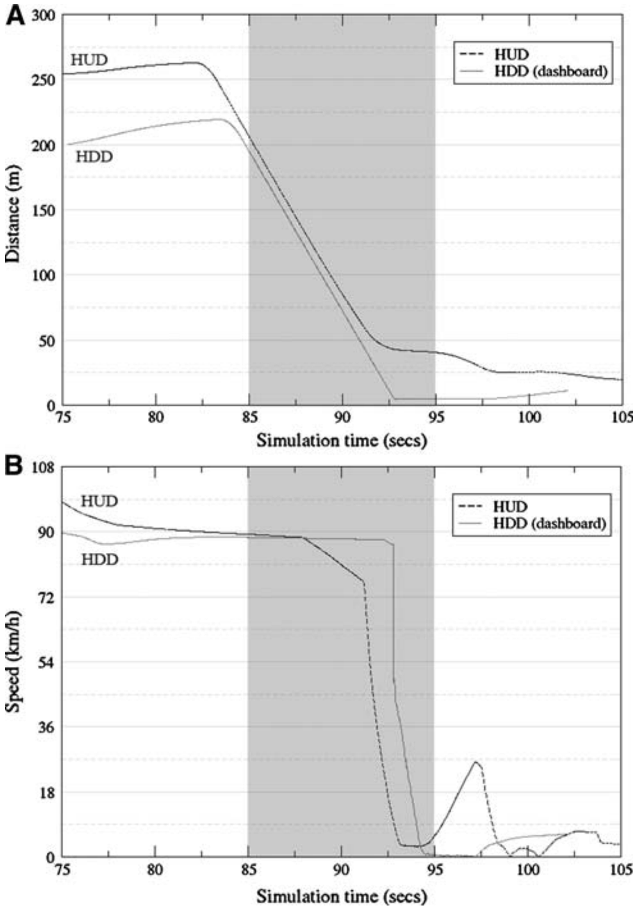


Fig. 4 User reaction during first simulation scenario. **a** Distance from leading vehicle over time. **b** Vehicle speed over time

Figure 4a, b denotes distance from the leading vehicle and driving speed, respectively, against simulation time. In each figure, the dashed line indicates data collected when the driver's vehicle was equipped with the proposed HUD, whilst the solid line denotes use of an HDD dashboard only. The grey box in each figure places emphasis on the time interval of 85–95 s during simulation, which covers the point in time where the front vehicle group is approached by the driver (85 s) until a few seconds after a crash has occurred in the case of an HDD used (95 s). Note that the collision was averted when using the HUD interface.

Significantly, throughout the simulation time, the driver has maintained a greater distance to the first braking group when using the HUD, as shown in Fig. 4a. This comes as a result of the added information provided by the HUD which not only indicates the presence of neighbouring vehicles but through use of colour coding also offers a distance estimate. Such information allows the driver to throttle the vehicle's speed and maintain a reasonably conservative approach vector until the other vehicles have come into view; in the case of the traditional dashboard this information is not available and the driver resorts to more immediate and extreme speed reduction.

As an example of the above claim, consider the time frame of 87–97 s in Fig. 4b, where the vehicle's speed is plotted as the braking group comes in close vicinity. When the HUD is used and at around 87–92 s, the driver applies a gentle brake, as indicated by the mild downwards slope of the speed curve in the vehicle speed graph. Such a driving response is triggered by indication in the HUD of the presence of neighbouring vehicles, which causes the driver to slow down and inspect the road ahead carefully as visibility conditions are poor (clear visibility extends to about 50 m). After the 92 s mark, the braking group comes into view (note that the distance graph at that time frame indicates a distance difference of less than 50 m) and so the driver resorts to a sharp and immediate brake. On the other hand, when the HUD is not used the driver maintains almost constant speed for a substantial period of time and so when the braking group becomes visible (at the 92 s mark), a panic brake manoeuvre is performed. By that time the vehicle is moving at too high a speed to stop quickly and hence a collision occurs (at approx. 97 s). Note that in both cases, i.e. with and without a HUD interface, this driver applies a hard brake when the vehicle group becomes visible as a reaction to an immediate collision threat. The difference between the two cases is that with a given degree of forewarning (as provided by the HUD) the driver performs the hard brake at a lower speed than when just using the dashboard and, in many cases, faster (as the view of nearby vehicles does not come as a surprise—it is expected).

After the panic brake reaction and having avoided a collision, this particular driver opted to accelerate and place the vehicle close to the braking group, which explains the increase in speed shortly after 94 s. In the case of HDD use, the simulation was considered complete as soon as the crash had occurred, so any data in after the 97 s mark in Fig. 4a, b should be disregarded and are only presented here for completeness. Overall, the above example indicates two important functions of the HUD system. Firstly, the HUD interface provides the user with an incentive to decrease speed (and, thus, increase manoeuvrability) when other vehicles are in close proximity. Essentially, this reduction in speed is a typical reaction when the driver becomes aware of a potential collision threat and the HUD system timely indicates such threats. Secondly, by raising awareness of the presence of other vehicles, the HUD system increases the driver's alertness in such risky situations and hence decreases the response time to a collision event. Those two effects can largely account for the effectiveness of the proposed HUD design as is evident from the evaluation results presented below.

5.2 Evaluation results

An initial but, nonetheless, informative appraisal of the effectiveness of the HUD system may be attempted by taking into account the number of crashes per trial with and without the HUD interface. Such data is presented in Chart 1 for the two simulation scenarios.

Notably, using a HUD resulted in a dramatic drop in collisions for both scenarios. Specifically, when the HDD interface was used 90% of participants experienced a collision at the first trial scenario and 37.5% at the second. When the HUD system was deployed there was sharp decrease in collisions whereby only 27.5 and 5% of participants experienced a crash in the first and second scenarios, respectively. These results indicate that in some aspects the HUD interface can be more efficient than a contemporary HDD by leading to a decrease in the number of driver errors and possibly allowing for faster response times.

Interestingly, a study of the video-recordings has revealed that using the HUD has a positive effect on the driver's emotional state compared to simply utilising a traditional dashboard. In particular, close inspection of the driver's facial expressions and overall posture indicates a heightened level of stress while driving in low visibility conditions in both cases; however, the effects of stress seem more pronounced when not using the HUD. As this is a subjective appraisal and thus open to interpretation, it is stated here as speculation rather than factual observation. Importantly, the vast majority of users approved of the HUD design and function and, in general, thought of the system as an effective and intuitive way for assisting

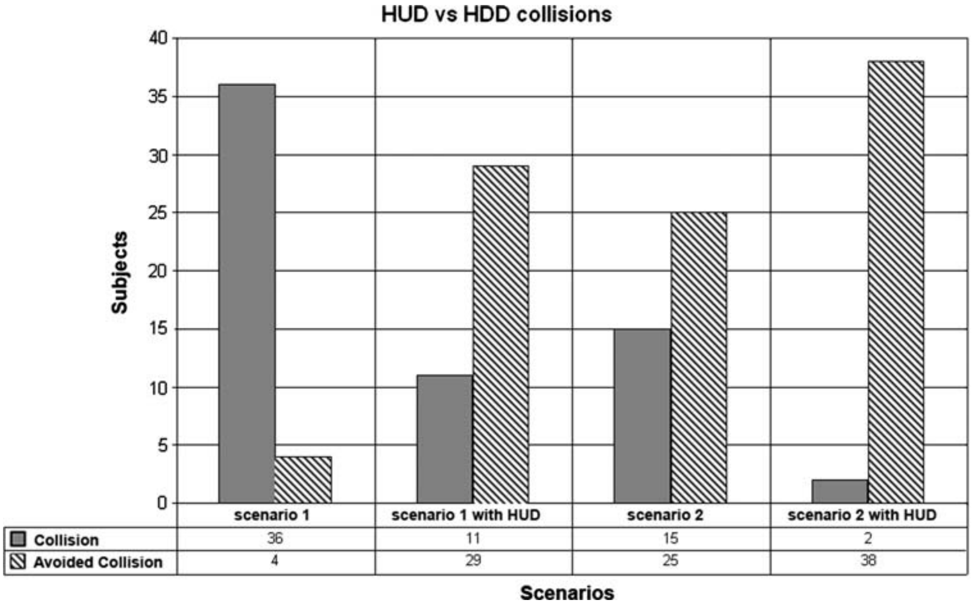


Chart 1 Number of collisions recorded with and without the HUD interface

driving in low visibility conditions. The following section expands on this statement.

5.3 User impressions

After having participated in the trials, each driver was asked to complete a set of two questionnaires which gauged user impressions of the HUD. The first set focused on the user's opinion of the HUD symbols whilst the second solicited feedback on the design as a whole. The results from each set are now presented in turn.

5.3.1 Symbol feedback

The first questionnaire presented to trial participants recorded their opinion on the visual elements. Chart 2 outlines results on the user assessment of the design of the HUD symbols. The users were asked to evaluate the system's features on a scale ranging from "Not helpful at all" to "Extremely helpful". A brief discussion for the results on each symbol follows.

The lane symbol revealed some interesting results for both its functions. The first function, namely lane navigation, was assessed as "extremely helpful" by 35% of participants while 55% thought it was "very helpful". It was stressed that the primary function of the lane symbol was to assist users to maintain the vehicle position within the lane boundaries. Its second function of facilitating overtaking was ranked as "Extremely helpful" by 30% of the users and as "Very helpful" by 47.5%. Further analysis of the data showed that 22.5% of users who had rated the function as "Neutral", had not tried it out, as they had preferred to remain in the slow speed lane and avoid any lane changes. Some users even suggested that the second function of the lane symbol (overtaking) should preferably be manually activated by the indicators (if technically possible).

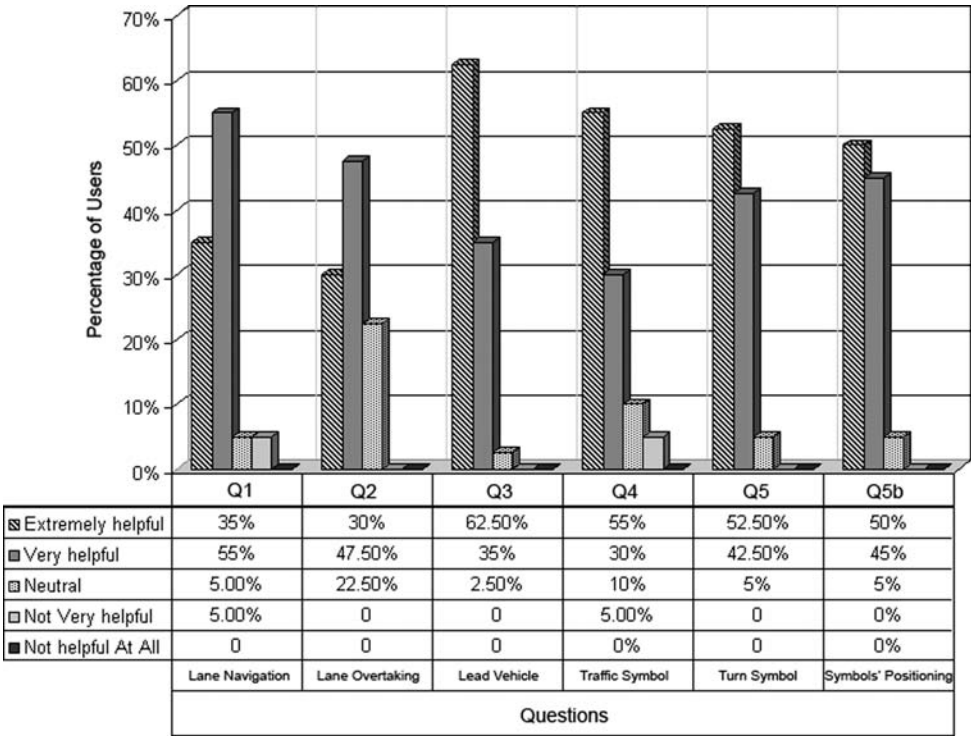
The most highly rated symbol was the lead-vehicle warning as 62.5% of the drivers ranked it as "extremely helpful", 35% as "Very helpful" and only 2.5% as "Neutral". Drivers reported that the symbol was boosting their confidence by increasing their spatial awareness and significantly reducing distance misjudgement. Note that although the symbols provide approximate distance information (through colour coding and size altering), this proved to be more than adequate for enhancing spatial awareness, or at least the perception of it.

The traffic symbol received equally good feedback and was deemed an useful addition to the HUD. Specifically, 55% of the interviewees considered it as "extremely helpful", 30% as "Very helpful", 10% as "Neutral" and 5% regarded it as "Not very helpful". A few users suggested to emphasise further the traffic warning information by making the icon bigger or accompanying it with an audio cue.

Finally, the turn symbol was rated as "Extremely helpful" by 52.5%, "Very helpful" by 42.5% and "Neutral" by 5%, which marks it as fairly successful. This was somewhat expected as it mirrors a feature found in many GPS systems and some drivers were already familiar with it. Overall, the feature seemed to succeed in its role of augmenting the already existing road signs, by providing the driver with crucial information on tricky road turns.

Overall, the participants were happy with the symbols and their positioning, as 95% expressed positive sentiment to the designer's choices (Question 5b). The vast majority

Chart 2 Subjective evaluation of symbols



	Q1	Q2	Q3	Q4	Q5	Q5b
▨ Extremely helpful	35%	30%	62.50%	55%	52.50%	50%
▩ Very helpful	55%	47.50%	35%	30%	42.50%	45%
▦ Neutral	5.00%	22.50%	2.50%	10%	5%	5%
☐ Not Very helpful	5.00%	0	0	5.00%	0	0%
■ Not helpful At All	0	0	0	0%	0	0%
	Lane Navigation	Lane Overtaking	Lead Vehicle	Traffic Symbol	Turn Symbol	Symbols' Positioning

of participating drivers felt that the symbols would help in some way and did not express particular objections to their positioning or level of prominence on the HUD.

5.3.2 *Overall design feedback*

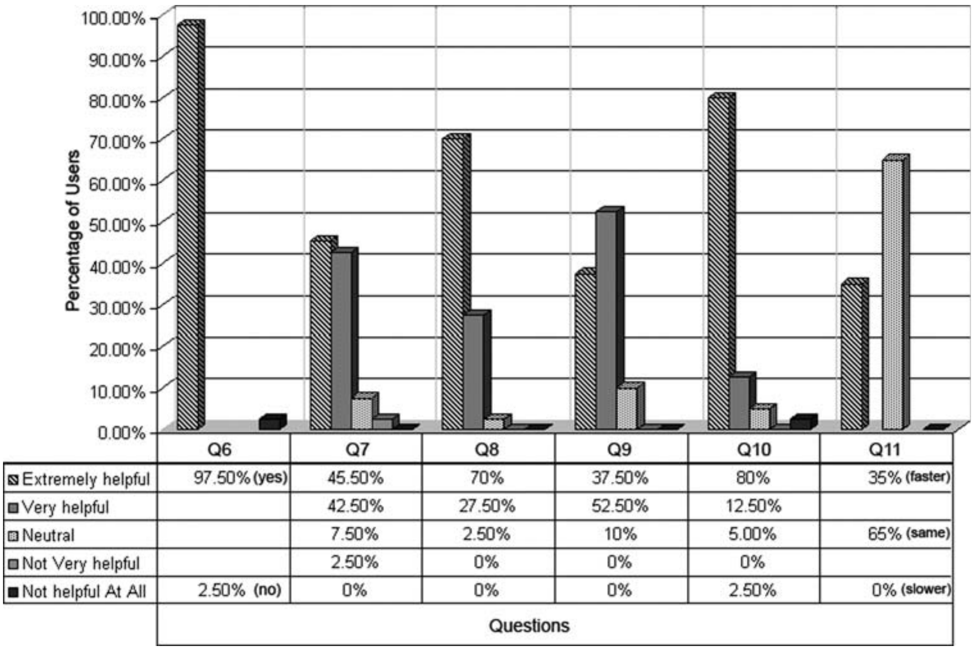
The relevant content of the second questionnaire set as well as the corresponding user responses are outlined in Chart 3. The user's scaled replies are complementary to the trial evaluation results presented in Sect. 5.2. Notably, the trial results indicate the actual effectiveness of the interface, whilst the users' impression of the system hints at its perceived effectiveness.

Interestingly, the feedback received from post-trial questionnaires and interview responses did not accurately reflect the numeric findings of the trial data. In particular, when drivers were asked whether they were driving faster with or without the HUD, 26 (65%) of them felt that their speed was the same in both situations. However, analysis of the actual data indicates that all 40 drivers drove faster by an average of 10–25 km/h when utilising the HUD. This indication shows an idiomorphic driving style—driver's engaging in a more risky behaviour by misusing the benefits of the safety system—which can be further analysed by the theory of Risk Homeostasis (Wilde 1994). Note, however, that even though a noteworthy acceleration in the pace of driving had taken place when using the HUD, crashes were considerably fewer compared to using a traditional dashboard. It should be further stated that the average speed when using the HUD did not, in any case, exceed the legal motorway speed limit. Also noteworthy is the fact that 32 (80%) of the drivers experienced fatigue while driving without the HUD and felt it was particularly difficult to keep the car within the lane boundaries. Apart from improving the driver's response times, the HUD also gained the approval of the vast majority (97.5%) of participants who indicated that they would like to use it under low visibility conditions and most (90%) would also like to see it integrated in future vehicles.

Finally, when asked to estimate their stress levels during trials (Questions 9, 10 in the questionnaire in Chart 3), participants confirmed our subjective impression stated earlier, namely that stress levels seemed to be significantly reduced when the HUD system was present. Specifically, 90% of the users claimed that the HUD system had some stress alleviating effect when driving under low visibility conditions, while 92.5% found the HUD to reduce stress to a higher degree as opposed to using the traditional HDD interface. Overall it would be fair to assess that although driving under adverse visibility conditions may require high alertness of the driver and induce stress, use of the proposed HUD can mitigate such effects to a certain degree.

6 Conclusions

We have presented our initial evaluation of a proposed HUD design, which aids driver awareness in low visibility conditions. To facilitate an appraisal of the system, user



	Q6	Q7	Q8	Q9	Q10	Q11
▨ Extremely helpful	97.50% (yes)	45.50%	70%	37.50%	80%	35% (faster)
▩ Very helpful		42.50%	27.50%	52.50%	12.50%	
▤ Neutral		7.50%	2.50%	10%	5.00%	65% (same)
▩ Not Very helpful		2.50%	0%	0%	0%	
■ Not helpful At All	2.50% (no)	0%	0%	0%	2.50%	0% (slower)

Chart 3 Subjective evaluation of HUD effectiveness

trials were conducted to compare the HUD design with a contemporary HDD interface (dashboard). The initial results indicate that drivers can navigate effectively, with the assistance of the HUD interface through very demanding, accident prone situations and under low visibility conditions. In contrast, the HDD interface was deemed inadequate in supporting the driver with the necessary information required to overcome imminent collision. The users seemed to regard the system positively and stated to be inclined to adopt it for everyday use.

Our future research aims are threefold. Firstly, we aim to examine the behaviour of drivers in scenarios where faulty, or otherwise incomplete, information is available. This should help simulate more closely real-life conditions, where vehicle sensors provide false positives and intermittent mechanical failures occur. Secondly, we aspire to tweak the symbol colour scheme to provide sufficient contrast when used in a prototype HUD implementation. Finally, we are also working towards realising a fully functional HUD in an actual vehicle, which should allow us to evaluate its performance in a more realistic setting. Through this effort it should be possible to closely capture the majority of the perceptual clues available to the driver which may not be adequately represented in our simulation model. Concluding, it is our belief that human–machine interaction can be improved substantially in the future if the interface design focuses primarily on human-centred systems, as a means of augmenting human abilities.

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