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Perceived Importance of Automotive HUD Information Items: a Study With Experienced HUD Users

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ABSTRACT Despite the long history of automotive head-up displays (HUD) systems and their increasing importance in the human-vehicle interface design, a question still remains about what they should display to best serve the driver. As an effort to contribute to the ergonomics design of automotive HUD systems, this paper determined the perceived importance of different HUD information items—fifty-one drivers with significant prior HUD use experience subjectively evaluated twenty-two information items in their importance. The information items were those displayed by existing commercial HUD systems. The results indicated that the information items varied greatly in perceived importance, and current speed, speed limit, turn-by-turn navigation instructions, maintenance warning, cruise control status, and low fuel warning were of highest importance. Also, participants' prior experience of using an information item was found to greatly impact the average importance rating, suggesting that information items' importance must be evaluated by those with sufficient information item use experience.

INDEX TERMS Experienced users, head up display (HUD), importance of information items, information needs.

I. INTRODUCTION

Conventional in-vehicle displays located in the dashboard area require the driver to lower their gaze to access information, and, thus, divert attention away from the road scene ahead – these displays are called head-down displays (HDD). In contrast to HDD, head-up displays (HUD) present various information directly onto the driver's forward field of view (FFOV) and allow the driver to acquire necessary information without looking away from the road ahead [1]–[5]. Considering the reduction in both the eyes-off-the-road and re-accommodation times, a HUD system is thought to have the potential to address the shortcomings of the conventional HDD system, and, thereby, help improve driving performance and safety [1], [3], [6], [7].

Automotive HUD systems are becoming increasingly powerful leveraging the recent technological advances; some existing systems are capable of displaying multiple static and dynamic images at various locations throughout the entire driver's FFOV realizing augmented reality visualization [1], [8]–[11]. Such capability provides a platform on which plenty of useful applications can be developed [8], [12], [13]. However, presenting many information items indiscriminately on HUD can cause undesirable consequences, such as information overload, visual clutter and cognitive capture, which can adversely affect driving performance and safety [1], [6], [10], [14], [15]. To minimize such negative consequences, only the necessary and important information must be selected and adequately presented according to the driving situation at hand [16]. Thus, understanding the user's information needs becomes crucial for the design of automotive HUD systems [1], [8], [10].

Several studies have been conducted to determine the automotive HUD users' information needs. Moon and Park [17] determined the preference priority of nine HUD information items through a user survey. The priority order was, from highest to lowest, low fuel warning, engine overheat warning, turn signal indicators, battery warning, brake warning, speed, door open warning, seat belt warning, and hazard warning. Bergman [18] conducted a survey study where seven participants drove their own cars with a prototype HUD system in real traffic for four days; the features found to be necessary for the HUD system were system warnings, GPS information,

TABLE 1. Twenty-two information items displayed by existing commercial HUD systems.

Current speed	Turn signal indicators
Speed limit	Forward collision warning
Turn-by-turn navigation instructions	Battery voltage
Maintenance warning	Lane departure warning
Cruise control status	Current time
Audio player status	Eco status (Instantaneous/average fuel consumption or ECO indicator)
Traffic sign	Engine operating status (Engine temperature or oil pressure)
Distance to destination	Daily information (Date, weather)
Gear position	Call information (Incoming call, caller's ID, call history, or phone book entries)
RPM	HVAC status (Heating, ventilating, and air conditioning status)
Low fuel warning	Driving distance

speeding indication, traffic/road condition information, traffic camera/police warnings, turn indicators, radio information, and temperature information. Park *et al.* [16] determined the perceived importance of HUD information items displayed by existing HUD systems through a survey; current speed, gear position, fuel status, and speed limit were found to be the high-importance items. Huang *et al*. [19] conducted a questionnaire survey on the importance of different driving information items; speed-related information items, such as current speed and speed limit, were identified as the items of high importance. Guo *et al*. [10] conducted a survey with 539 drivers on driver preference on HUD information items. Driving speed, relative speed and distance to the leading car, and traffic condition were identified as the most necessary elements.

Despite the previous research efforts above, however, the available knowledge on the driver's information needs for automotive HUD systems seems still limited. Two limitations of the existing research studies are as follows: first, the existing studies mostly surveyed drivers without enough prior experience of using HUD systems. The authors are not aware of any previous studies that examined a large sample of experienced automotive HUD system users. While inexperienced users can certainly offer meaningful information, it is reasonable to think that experienced users provide the most relevant insights regarding the user's information needs based on their actual long-term use experience. Second, each of the previous studies examined only a small subset of various information items that automotive HUD systems currently display. Evaluating a large set of information items within one study, which covers most of what were intended for automotive HUD systems, is needed to gain a complete picture of the relative significance of the relevant information items and accurately characterize the HUD users' information needs.

Therefore, as an effort to contribute to the future ergonomics design of automotive HUD systems, the objective of the current study was to determine the perceived importance of various automotive HUD information items by surveying users with significant prior experience of using automotive HUD systems. Fifty-one drivers (average years of HUD experience: 2.59 years) participated and subjectively evaluated a total of twenty-two information items in perceived importance. The twenty-two information items were those displayed by existing commercial automotive HUD systems. The study also examined the impacts survey participants' prior experience of using a HUD information item (that is, 'information item experience') has on its perceived importance rating.

II. METHOD

A. SURVEY PARTICIPANTS

A total of fifty-one drivers participated in this survey study. The participants' mean age and mean driving experience were 36.0 years (SD = 6.82, Range: 23-50) and 13.7 years (SD = 6.25, Range: 3.5-25), respectively. All of the participants had at least one year of experience with automotive HUD systems – their mean HUD experience was 2.59 years (SD = 2.00, Range: 1-10). On average, the participants drove 1.97 hours per day (SD: 0.98, Range: 0.5-5). The driving contexts varied, including commute, school run, shopping, and business and

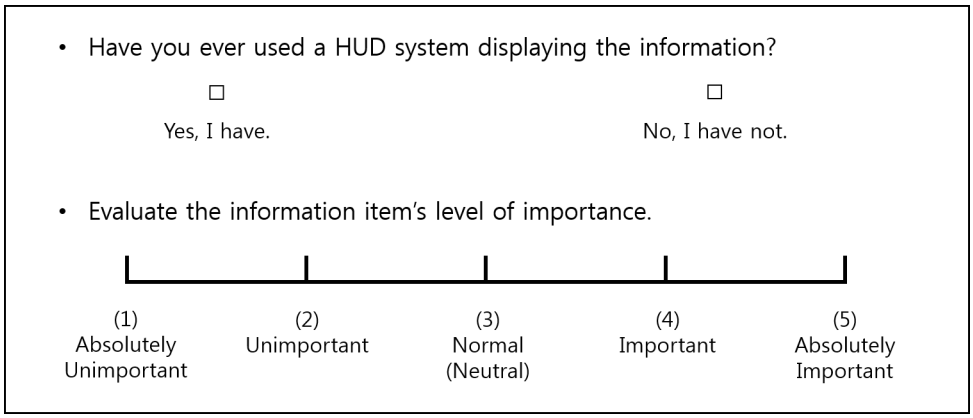

FIGURE 1. The survey questions on the importance of information.

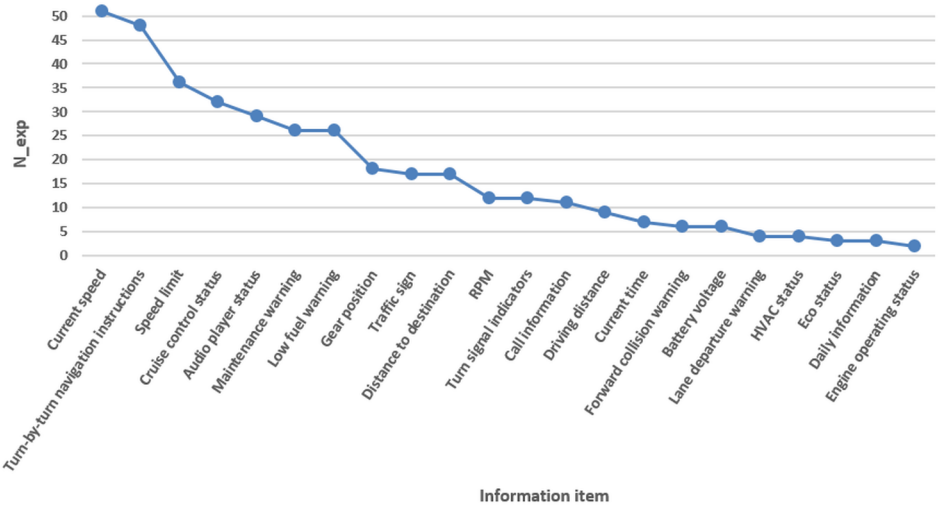

FIGURE 2. The number of participants with prior 'information item' experience (N_exp) for each information item.

pleasure trips. The participants owned a total of fifty-three vehicles (one participant owned three vehicles.) According to the car classification system of the European Commission [20], among the fifty-three vehicles were seventeen D-segment large cars, nineteen E-segment executive cars, three F-segment luxury cars, thirteen J-segment sport utility cars, and one S-segment sport car.

B. DATA COLLECTION AND ANALYSES

This study considered information items displayed by existing commercial automotive HUD systems. A total of twenty-two information items (Table 1) were identified by examining Original Equipment Manufacturer (OEM) HUD systems available as built-in options from the seventeen major automakers (Audi, BMW, Buick, Cadillac, Chevrolet, Citroën, Honda, Hyundai, Kia, Land Rover, Lexus, Mazda, Mercedes-Benz, MINI, Peugeot, Toyota, and Volvo) and various aftermarket HUD systems mostly integrating with smartphone applications (e.g., Carloudy, Exploride, Garmin HUD, HUDWAY, Navdy, and SenseHUD).

For each information item in Table 1, the study participants were asked to indicate if they had used any HUD systems displaying it, that is, if they had prior 'information item experience' – note that while everyone of the fifty-one participants had prior experience of using some HUD systems ('HUD experience'), each participant had seen only a fraction of the twenty-two HUD information items because existing HUD systems display different subsets of the twenty-two information items. Also, each participant was instructed to subjectively rate the level of importance of the information item regardless of whether he had had prior information item experience for the item. As for the response format, a five-point semantic differential scale was employed based on the research finding of Friborg *et al.* [21] that in measuring positive psychological constructs (such as 'importance' investigated in the current study), the semantic differential

TABLE 2. Tabular summary of survey results.

Information	R_all (N)	R_exp (N_exp)	R_inexp (N_inexp)
Current speed	4.73 (51)	4.73 (51)	N/A (0)
Speed limit	4.59 (51)	4.64 (36)	4.47 (15)
Turn-by-turn navigation instructions	4.37 (51)	4.48 (48)	2.67 (3)
Maintenance warning	3.98 (51)	4.69 (26)	3.24 (25)
Cruise control status	3.80 (51)	4.38 (32)	2.84 (19)
Audio player status	3.45 (51)	3.90 (29)	2.86 (22)
Traffic sign	3.35 (51)	3.65 (17)	3.21 (34)
Distance to destination	3.25 (51)	3.47 (17)	3.15 (34)
Gear position	3.24 (51)	3.5 (18)	3.09 (33)
RPM	3.24 (51)	3.83 (12)	3.05 (39)
Low fuel warning	3.02 (51)	4.12 (26)	1.88 (25)
Turn signal indicators	2.96 (51)	3.42 (12)	2.82 (39)
Forward collision warning	2.94 (51)	3.17 (6)	2.91 (45)
Battery voltage	2.67 (51)	3.17 (6)	2.6 (45)
Lane departure warning	2.55 (51)	2.75 (4)	2.53 (47)
Engine operating status	2.45 (51)	4.5 (2)	2.37 (49)
Current time	2.43 (51)	3.29 (7)	2.30 (44)
Eco status	2.43 (51)	2.67 (3)	2.42 (48)
Daily information	2.08 (51)	2.33 (3)	2.06 (48)
Call information	1.94 (51)	3 (11)	1.65 (40)
HVAC status	1.82 (51)	2.5 (4)	1.77 (47)
Driving distance	1.78 (51)	2.56 (9)	1.62 (42)
Grand Mean	3.05 (1122)	4.06 (379)	2.53 (743)
Grand SD	1.42 (1122)	1.06 (379)	1.30 (743)

scale format produced less acquiescence bias than the Likert scale without lowering psychometric quality.

The related survey items are shown in Fig. 1.

For each information item, the number of participants with prior information item experience and that of the participants without such experience were determined (hereafter, simply N_exp and N_inexp, respectively). Also, for each information item, the averages of the importance rating scores were computed for three different groups of participants – 1) all participants, 2) the participants with prior information item experience and 3) the participants without prior information item experience, respectively (hereafter, simply R_all,

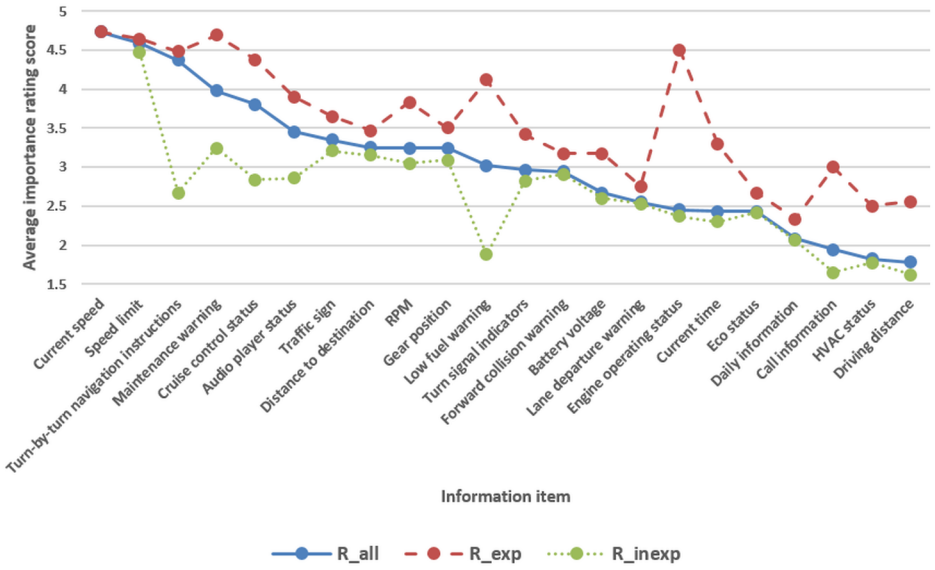

FIGURE 3. The three average importance rating scores for each information item: the averages for 1) all participants (R_all), 2) the participants with prior 'information item' experience (R_exp) and 3) the participants without prior 'information item' experience (R_inexp).

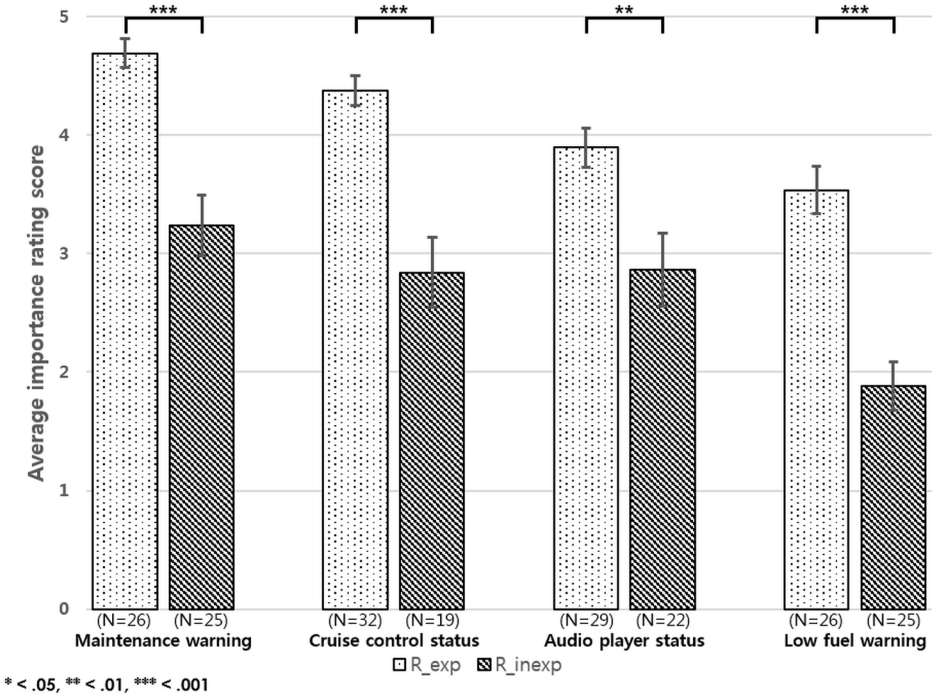

FIGURE 4. The statistically significant differences between the average importance rating scores for the participants with prior 'information item' experience (R_exp) and the participants without the 'information item' experience (R_inexp).

R_exp, and R_inexp, respectively). This was to characterize the information item's perceived importance level.

For some of the information items, N_exp and N_inexp were both large enough to allow statistical testing of the mean difference without concerns about low statistical power. For these information items, t-tests were conducted to understand the impact of user's prior information item experience on the evaluation of the item's importance. The statistical tests were conducted at an alpha level of 0.05 using SPSS 21.0 (SPSS Inc., Chicago, USA).

III. RESULTS

Table 2 provides a summary of the survey results. For each of the twenty-two information items considered, it presents R_all, R_exp and R_inexp. It also provides N_exp and N_inexp for each information item.

Fig. 2 graphically illustrates the variation in N_exp across the twenty-two information items.

Fig. 3 visually depicts the variation in each of the three average importance rating scores (R_all, R_exp, and R_inexp) across the information items.

Eight out of the twenty-two information items allowed statistical comparisons of R_exp and R_inexp. They were: speed limit, maintenance warning, cruise control status, audio player status, traffic sign, distance to destination, gear position, and low fuel warning. Four information items showed statistically significant difference between R_exp and R_inexp – they were maintenance warning, cruise control status, audio player status, and low fuel warning. Fig. 4 presents the group means (R_exp and R_inexp) and the t-test result for each of the four information items.

IV. DISCUSSION

This study investigated the perceived importance of various automotive HUD information items by surveying drivers with significant prior experience of using automotive HUD systems. Fifty-one drivers (average years of HUD experience: 2.59 years) participated and subjectively evaluated a total of twenty-two information items in perceived importance. The information items were those displayed by existing commercial automotive HUD systems. The study also examined the impacts of survey participants' prior experience of using a HUD information item (that is, 'information item experience') on its perceived importance rating.

N_exp was found to vary greatly across the twenty-two information items (Fig. 2). All of the fifty-one participants had prior experience of using current speed; and, forty-eight had experience with turn-by-turn navigation instructions. Most of the existing commercial HUD systems support these two information items [19]. On the other hand, for fifteen out of the twenty-two information items, N_exp was less than half of the total number of the participants. Also, five information items, that is, lane departure warning, HVAC status, eco status, daily information and engine operating status, had N_exp less than five. The large variability in N_exp seems to reflect the fact that commercial automotive HUD systems display different sets of information items, which have a small number of common elements [16], [18], [22]. It appears that no consensus currently exists as to the choice of information items for automotive HUDs among the manufacturers of automotive HUD systems, except for a few information items such as current speed and turn-by-turn navigation instructions.

The twenty-two information items varied greatly in the three average perceived importance ratings, that is, R_all, R_exp and R_inexp (Fig. 3, Table 2). R_all ranged from 1.78 to 4.73 on the five-point scale shown in Fig. 1. Only three information items had R_all greater than four (''important''). They were: current speed, speed limit and turn-by-turn navigation instructions. R_exp ranged from 2.33 to 4.73. Seven information items had R_exp greater than four. They were: current speed, speed limit, turn-by-turn navigation instructions, maintenance warning, cruise control status, low fuel warning and engine operating status. R_inexp ranged from 1.62 to 4.47. Only speed limit had R_inexp greater than four - note that R_inexp was not computed for current speed as all fifty-one participants had prior information item experience for it.

A notable observation from Fig. 3 was that R_exp was larger than R_inexp, consistently across the information items. The differences between R_exp and R_inexp (R_exp - R_inexp) ranged from 0.17 to 2.24 points with an average difference of 0.88 points. The results of the t-tests conducted on the eight information items (Fig. 4) further indicated that prior information item experience was associated with a statistically and practically larger mean importance rating for half of the information items considered. The above results are thought to indicate that: even among the drivers with significant prior HUD experience, those who have experienced using a particular HUD information item tend to better recognize and appreciate its importance than those without such information item experience. It would be reasonable to regard the collective judgment of those with prior information item experience as more accurate than that of those without such experience.

While it is not entirely clear what gave rise to the above tendency associated with information item experience in the subjective importance rating, it is thought that assessing the importance of an information item without real use experience and therefore solely based on mental simulation may be cognitively difficult for most drivers. Actual information item experience in the real or realistic HUD use contexts may be essential for properly evaluating information items' importance. Relatedly, Bergman [18] reported a finding that lends support to the importance of actual use experience in the evaluation of automotive HUD systems - in this study, the participants filled out a questionnaire measuring the attitude towards the use of HUD such as willingness to use before and after using a prototype HUD system in real traffic for four days. The study found that the participants' responses became more positive after experiencing the prototype HUD system. It further suggested that participants evaluating automotive HUD systems should have enough HUD experience such that HUD use is a natural part of their driving experience.

In light of the impacts of prior information item experience described above, the results shown in Fig. 3 must be interpreted with caution. As for the information items for which N_exp was large, R_exp can be considered good estimates of their true importance. However, for the information items for which N_exp was small, R_exp cannot be regarded as reliable estimates due to the small sample size; and, R_all may underestimate their true importance. For these information items,

further studies with more participants with prior information item experience are needed.

As mentioned earlier, current speed, speed limit, turn-by-turn navigation instructions, maintenance warning, cruise control status, low fuel warning and engine operating status had R_exp greater than four (''important''). For engine operating status, N_exp was only two; thus, its R_exp could not be considered a reliable estimate of information item importance. For the other six information items, R_exp were computed based on a large number of data points (N_exp ranged from 26 to 51). Hence, these six information items were considered the high-importance items.

Among the six high-importance items, only the current speed and speed limit were identified as important by the majority of the previous studies that examined drivers without prior HUD experience [10], [16], [18], [19]. The other items (turn-by-turn navigation instructions, maintenance warning, cruise control status, and low fuel warning) were not among the high-priority items. These differences in the results are thought to indicate the significance of actual HUD experience in subjectively evaluating the importance of information items - again, recruiting experienced HUD users is deemed essential for user studies on automotive HUDs [18].

The high-importance items (current speed, speed limit, turn-by-turn navigation instructions, maintenance warning, cruise control status, low fuel warning) seem to have some distinct characteristics when compared with the rest. They are as follows:

- They are directly related to vehicle longitudinal or lateral control, and, therefore, demand frequent or continuous attention from the driver,
- They demand fast perception and reaction from the driver,
- They are critical for driving performance and safety, and, therefore, demand correct information processing, and/or
- They cannot be obtained from the outside road view.

It is worth noting that the six high-importance information items correspond to the primary tasks of the driving task classification scheme described by Bubb [23] while the rest of the items correspond to secondary and tertiary tasks. The primary tasks are the ones necessary for the driver to keep the vehicle on the road and to proceed according to the planned route. The secondary tasks are not essential for keeping the vehicle on the road but need to be performed to support the primary driving tasks. The tertiary tasks do not directly contribute to the driving itself but enhance the driver's convenience.

The current result that the high-importance items for automotive HUD systems pertain to the primary driving tasks is consistent with the design recommendation by Tonnis *et al.* [24]. The study attempted to determine the optimal allocation of information items to different in-vehicle displays. It recommended that the information items related to the primary tasks be best shown in the windshield area through HUD. The current result is also congruent with the recommendation from SAE J2831 [25] that visual messages related to driving control activities be presented near the driver's centre of attention so as to minimize looking away from the road way.

Interestingly, audio player status was perceived as a relatively important information item even though it is concerned with a tertiary driving task – its R_exp was 3.90 (N_exp = 29) (Fig. 3, Table 2). This finding seems to reflect the fact that listening to the radio or music while driving is common among drivers and it is an important part of the overall driving experience [26].

It may be worth pointing out that forward collision warning and lane departure warning were not identified as high-importance information items despite their relevance to driving safety - their R_exp were 3.17 and 2.75, respectively. Again, their true importance levels cannot be accurately estimated on the basis of the current study results as the sample sizes for them (N_exp) were too small (six for forward collision warning and four for lane departure warning). Nonetheless, the authors speculate that their importance levels are not high, on the basis of the following:

- The information necessary for avoiding forward collision or lane departure can be directly obtained from the outside road view. The visual warnings would be useful only when the driver is inattentive to the outside road view,
- Images displayed through HUDs could mask the critical visual information in the real world and actually hinder its effective processing, especially if they are not designed well, and
- Visualization through HUD alone may not be effective in delivering the warnings to the driver. Existing human factors guidelines, for example, those in Green *et al.* [27], generally recommend that warnings needing immediate attention should be provided through an auditory channel.

Perhaps, an effective solution might be to display the two information items via multiple channels simultaneously (e.g., visually through a HUD and also in an auditory channel) and only when needed. The multimodal HUD [2], [28], [29] and driver state monitoring technologies [30] could be utilized in combination to create such 'active HUD' systems [4], [31], [32]. Further studies are needed to explore and evaluate different design alternatives for delivering the two information items.

The current study results have some practical implications: first, this study identified six high-importance information items. They are: current speed, speed limit, turn-by-turn navigation instructions, maintenance warning, cruise control status and low fuel warning. These information items may serve as the default information items for automotive HUD systems. Additional optional items could be determined based on an individual driver's information preference and needs, and, may be presented to the driver adaptively according to the driving context at hand.

Second, as pointed out earlier, the six high-importance information items identified in this study exhibit some

common characteristics: demanding frequent or continuous attention, requiring fast perception and reaction, necessitating correct information processing, and/or being unobtainable from the outside road view. These characteristics may be utilized as general criteria for predicting a certain information item's perceived importance level and further making design decisions on whether to introduce new information items into a HUD system.

Third, the current study demonstrated that survey participants need actual information item experience in order to adequately evaluate the importance of HUD information items. Thus, future research efforts for evaluating information items' importance must involve data collection from drivers with not only HUD use experience but also relevant information item experience. For novel information items for which drivers with prior information item experience cannot be found, it may be useful to provide some simulated information item experience to the study participants using a realistic driving simulator prior to data collection - further empirical studies are needed to confirm the efficacy of such simulated information item experience approaches.

Finally, some future research ideas are provided here:

For many of the information items considered in this study, the number of participants with prior information item experience (N_exp) was small. Further studies with large N_exp are needed to provide more accurate estimates of their importance.

Also, the current study considered only the information items that existing commercial HUD systems display. Research studies are needed to determine the importance of newly proposed information items. For example, Cha and Park [33], Politis *et al.* [34], Walch *et al*. [35], Wulf *et al*. [36], and Kim *et al.* [37] proposed HUD information items for automated vehicles.

In addition, the current study did not examine automotive HUD users' situation- or context-dependent information needs. Further studies are needed to provide relevant knowledge. Such knowledge would be highly useful in developing adaptive automotive HUD systems that selectively present information according to the driving situation at hand.

Lastly, it should be noted that this study did not consider the user interface aspects of HUD system design. In addition to the identification of the high-importance HUD information items, how to best present them in terms of the graphical design of displayed items (e.g., size, luminance, layout, etc.) must be addressed.

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