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Article

Study the Effect of eHMI Projection Distance and Contrast on People Acceptance in Blind-Spot Detection Scenario

Ali Hassan Shah [1,†], Xiaodong Sun [2,†] and Yandan Lin [1,2,*]

[1] Department of Light Sources and Illuminating Engineering, School of Information Science and Technology, Fudan University, Shanghai 200433, China; hsali19@fudan.edu.com
[2] Academy for Engineering & Technology, Fudan University, Shanghai 200433, China; 19110860042@fudan.edu.cn
* Correspondence: ydlin@fudan.edu.cn
† These authors contributed equally to this work.

Abstract: External human-machine interaction (eHMI) road projections are a new feature for automotive lighting to improve vehicle communication with other road users. These modalities are used to draw users' attention and awareness to specific situations. However, such advanced capabilities are still being debated to be used on the road in the context of whether or not such road projections can provide a clear and understandable message to road users in a specific scenario or lead to anticipation and change in the driving behavior. Therefore, it is necessary to investigate human factors aspects, such as the feeling of safety, useability, understanding, acceptability, and driver behavior. This study investigates the change in distance and luminance contrast and its effect on human driving behavior and acceptability in blind spot detection scenarios on the highway. A lab experiment with 12 participants is performed to analyze: understanding, satisfaction, usability, visibility, safety, workload, and driving behavior towards eHMI projection while varying projecting distance and luminance contrast. Video recordings and a designed questionnaire were used during the whole process. Results show that ego vehicle drivers prefer a projection distance between 5 to 10 m. However, a distance of 5 m is preferred by overtaking vehicle drivers in terms of visibility and safety. Luminance contrasts have no significant effect on the symbol's visibility in 5 m and 10 m projection distances. In contrast, participants in overtaking vehicles feel difficult to understand the situation for 15 m condition, which increases their overall workload significantly ($p < 0.019$). No significant effect is recorded in terms of change in driving behavior.

Keywords: eHMI projection system; autonomous vehicles; human factors

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1. Introduction

According to the world health organization report, in 2020, 1.35 million people died, and another 50 million people were injured in road accidents across the globe [1]. In other words, after every 21 s, someone dies in road accidents across the globe, which ranks road accidents as the 8th leading cause of death worldwide. In 2020, only in Germany, around 157,912 people were seriously injured in road-related accidents involving passenger vehicles, accounting for 49% of the total serious injuries across all road-related accident categories [2]. Passenger vehicles are one of the main accident perpetrators, accounting for 62% of the total accidents in Germany, while 4% of car accidents happen during the overtaking maneuver. Many national and international agencies are working to reduce road accident fatalities [3,4]. Automated vehicles (AV) have the potential to reduce these fatalities. AVs are expected to outperform a human driver by mitigating errors and violating traffic restrictions. Other benefits include energy savings, overall traffic flow efficiency, mobility for the disabled, and increases in social cohesion [5].

In 1997 a new innovative road safety policy was introduced by the Swedish parliament under the title of "Vision Zero" [6]. A long-term purpose of this policy is that no one should be killed or seriously injured in road-related accidents. From 2000 to 2010, a 60% decrease in road accidents was reported in Sweden after formally implementing this policy [7]. Efforts have been made by countries including Norway, Denmark, the UK, Australia, and several cities in the USA to adopt the policy on their road [8–10]. However, to achieve the goal of "Vision Zero" through AVs, first need to gain a significant portion of social acceptance [11,12]. The gradual launch of AVs on the public roads in mixed traffic highlights the need to design different interaction modalities between AVs and other road users, enhancing safety and effectiveness on the road [13,14]. Previous studies in a naturalistic environment for the driver to driver and driver to other road users showed that people try to anticipate other road users' intent and communicate their intent using implicit and explicit clues [15–17]. Implicit clues include speed variation and lateral position variations. On the other hand, explicit clues involve flashing lights and hand and head gestures [18]. External human-machine interaction (eHMI) is one of the approaches to show the modern AV's intent to its surrounding environment on the road. These are displays screen [19], light strips [20,21], and projection systems [22–24]. These devices allow AVs to indicate their status [25], perception, or intention in interactive scenarios such as parking lots [26], T-junctions [27], overtaking scenarios on the highway [28], and bottleneck situations [29].

1.1. Literature Review

On-road projections offer a wide possibility for designing new ways of communication for road users and drivers. In the past, projection systems attracted the attention of many researchers, particularly in the field of human factors for transportation. Studies show that the on-road projection of two straight parallel guided lines helps new drivers to maintain the vehicle in the center of the lane [30]. Similarly, the visibility of the projection symbols, such as the luminance contrast of the on-road projection, was investigated. Twelve subjects were involved in the nighttime experiment keeping the distance and size of the projection symbol fixed and concluded that positive contrast symbols are easily visible to the subject drivers [31]. In another study, The impact of road projection symbols on road users, i.e., pedestrians, cyclists, and drivers, was considered in the backing up situation in parking lots. A total of thirty-two subjects were involved in this experiment [32]. Results showed that on-road projection in the backing up situation increases the on-road awareness, understanding, and perception of the whole situation. In another study related to the rear-end collision cases. A delay of 0.1–0.2 s in the brake reaction time was observed in response to the on-road assistant projection system [33]. Nevertheless, the feeling of safety is still under discussion in the research community [34,35]. In the field study of overtaking scenarios with an on-road projection, eye-tracking data of thirty-nine subjects were collected to observe the distraction potential offered by the projection symbol. Few glances away from the front road ahead were observed. However, no significant difference was found [24]. Thus, the study focused on the distraction potential imposed by the on-road projection symbol and completely ignored the impact on user satisfaction, feeling of safety, workload, and acceptability towards a system in driver-driver interaction. Some other researchers focus on the optimal position of the projection symbol. The user readability rating of the oncoming vehicle showed that a 15 m distance from the front of the projection vehicle to the center of the projection symbol with a 50 K luminance value is optimal [33]. Similarly, particular to overtaking maneuver, eye glances data right before overtaking on the highway shows that people significantly distribute a higher percentage of eye glances towards their shoulder to check for a blind spot before maneuvering [36].

1.2. Objective

In contrast to the existing study, the present study focuses on the human preference for using on-road projection symbols for blind spot detection scenarios. By varying distances of eHMI projection and contrast, we try to explore;

1. Understanding the situation
2. Satisfaction and usefulness of the system

3. Visibility of the projection
4. Safety perspective of the eHMI projection
5. Overall useability if the system
6. Change in driving behavior

1.3. Structure of the Article

Section 2 describes the study design. Section 3 explains the methodology utilized in this study, and Section 4 describes the procedure adopted. In Section 5, the results will be presented. Section 6 explains the results based on the previously established literature, and finally, in Section 7, a broad conclusion will be presented.

2. Study Design

2.1. Scenario Selection

A scenario-based research method has been employed to investigate the human factor perspective of on-road eHMI projection for blind-spot detection. Scenario-based research design is a powerful tool widely adopted in human factor engineering research for the automotive field [37–40]. The complete overtaking process has been divided into four phases [41].

An approaching phase where a driver approaches and realizes that the front vehicle is slower and decides to take over. The second phase is steering away, where the driver executes the lane change maneuver and applies force on the steering wheel. The third phase is passing, where an overtaking vehicle passes the front vehicle at a relative speed. For some time, it is in the blind spot of the front vehicle. The fourth and last phase is returning. The overtaking vehicle returns to its original lane where it started, but that is not mandatory.

This study only considers the passing phase, where the overtaking vehicle is in the blind spot of the ego vehicle. The blind spot scenario within the passing zone is represented as vignettes because it concisely summarizes a single event. Vignettes depict a fictional scene based on an actual incident. Participants are asked to express their feelings and opinions through comments [42]. Due to the involvement of many dynamic parameters, it is not easy to investigate all the parameters simultaneously, so phases approaching, steering away, and returning are out of this study design. Figure 1 shows the complete overtaking scenario, whereas the dotted line represents our selected logical scenario for the study design.

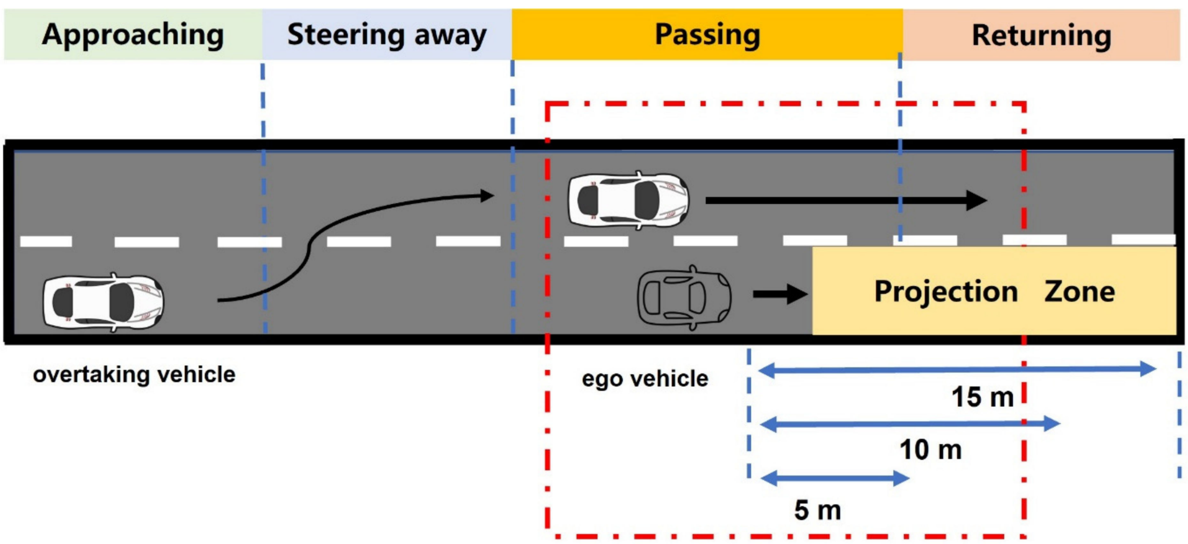

Figure 1. Overtaking scenario (the red dotted line represents the concerned time when the overtaking vehicle is in the blind-spot area of the black ego vehicle).

2.2. Parameter Selection

Previously reported literature showed that based on the readability and visibility of the eHMI projection, 15 m is an optimal distance [33]. However, the visibility of the eHMI depended on many factors, including size, scenario, distance, and contrast. While exploring the advantages of eHMI, some other researchers utilized a contrast value [24]. Hence for this particular study, we select three distances of 5, 10, and 15 m from the ego vehicle with two positive weber contrast values of 2 and 1.48 for middle-aged Chinese drivers to explore further the effect of distance and contrast on driver preference and behavior. In the rest of the article, we represent contrast values 2.00 with "a" and 1.48 with "b" in the remaining portion of the article. Similarly, "5a" means a projection symbol with a 5-meter distance of a 2.00 contrast value.

2.3. Field Environment

The complete study was carried out in a controlled indoor environment. At current, eHMI projection is not allowed to be tested on the real outdoor road. Figure 2 shows the indoor environment settings for the experiment.

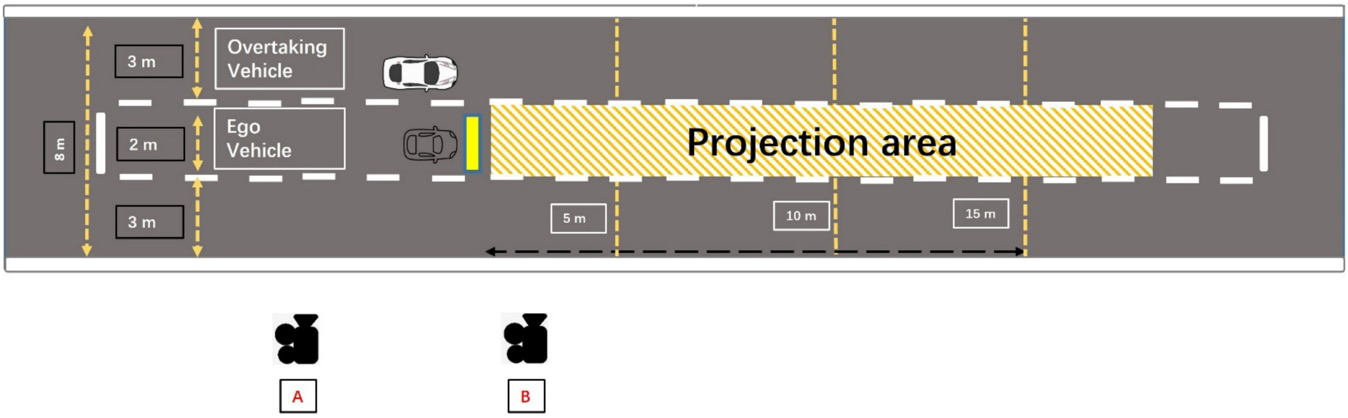

Figure 2. Experiment setup.

The floor of the indoor lab was made up of a natural road material that depicts the actual highway condition. The total width of the space is 8 m, enough to simulate a standard two-lane highway. The left lane was used to simulate an overtaking vehicle. The central lane simulates ego vehicles with an eHMI projection system. To keep the consistency during the experiment right lane was used to make a U-turn and return to the original position for the subsequent trial. The total length of the track was 48 m. An 8 m was used to make a 180-degree U-Turn at both ends. The "overtaking vehicle" was a small patrol vehicle, whereas the "ego vehicle" was an actual vehicle. The small patrol vehicle was used because the vehicle's turning radius was minimal, around 3–4 m, and could easily be turned inside the small space. The feel of the patrol vehicle was similar to the small electric vehicle. Subjects can easily handle and drive this vehicle inside the laboratory. The standing "ego vehicle" was a black-colored SUV.

2.4. eHMI Realization

It is necessary to keep all other parameters fixed to investigate the effect of distance and luminance contrast of eHMI projection on the driver-driver interaction. An initial video-based survey with 130 Chinese people has completed for the blind spot detection scenario. Twelve different symbols were designed and shown to the participant for the blind-spot detection scenario [43]. Figure 3 shows an eHMI projection symbol used. The size of the projection symbol was fixed at 1 m × 1 m. Other parameters include a dynamic frequency and dark time; values are set at 1 Hz and 0.5 s [24]. Konica LS 150 luminance meter is used to measure the luminance of the projection symbol. By using a tripod, the luminance meter was fixed and placed 1.4 m above the road surface. For each experimental condition, luminance is measured on five different spots on the projection symbol, and an average value is utilized to calculate the weber contrast in the end. All of these luminance values were measured from the perspective of an ego vehicle driver.

Figure 3. On-road eHMI projection symbol.

3. Study Methods

3.1. Questionnaires

In this study, several questionnaires were used to investigate the research question profoundly. Most of the questionnaires used in this study are pre-existing in the literature. NASA-TLX [44], Van der Laan user acceptance scale [45], an affinity for technology interaction scale [46], system usability scale [47], and safety scale [48] were employed. However, some custom self-designed questionnaires were considered by employing an already established unified theory of acceptance and use of technology (UTAUT) model [32,49,50]. Table 1 shows the questionnaire used in this study. These questionnaires have been extensively evaluated and validated in human factor research.

Table 1. The questionnaire used in the study.

Name	Type	Purpose
General demographic questionnaire for participant hiring	Open-ended	To recruit participants
Van der Laan user acceptance scale	Semantic differential scale	System acceptance based on usability and satisfaction rate
NASA-TLX	Rating scale	To measure workload
Affinity for technology Interaction Scale	Rating scale	person's tendency to actively engaged in technology or avoid it
System usability Scale	Rating scale	measuring perceived ease of use
Safety scale	Semantic differential scale	Measure the safety feeling toward new the technology

3.2. Field Observation

In the field of human factors for automotive research, field studies are extensively used. Both quantitative and qualitative data are being collected to measure a variety of variables, including fatigue [51], driver distraction [52], and driver communication [18]. Similarly, a video recording technique was used to capture the participants' driving behavior throughout the field observation in this study.

Four action cameras (Apexcam M90 pro by Apexcam, Shenzhen, China) were fixed at different locations to capture the scene. Two cameras were mounted inside the patrol vehicle. The first action camera is placed in a way that it can capture the broad front view of the lane when subjects are driving. The second camera was positioned to capture their braking and speeding response while passing through the ego vehicle. The other two cameras were placed in the lab to capture the whole scene. The sole purpose was to measure the total time taken by the "overtaking vehicle" to pass by the ego vehicle. These cameras capture the scene when the car enters the blind spot region and then passes by the vehicle. All these cameras were synchronized with each other through an open-source software named open broadcaster studio (OBS).

4. Procedure

The complete experiment was divided into several stages.

1. **Recruitment:** Subjects were hired through an online advertisement. An Online advertisement includes an information sheet that includes questions about age, nationality, driving experience, technology adaptation test, and prior knowledge about AV Out of 65 willing subjects. Twelve participants with gender-balanced representation were hired. The average age of hired participants was 35.8 ± 1.32 years. All hired participants have their cars with a valid Chinese license. Moreover, all hired participants' previous month's driver was around 100 Kms. All hired participants were familiar with AVs' notion, with an average score of 3.8 ± 0.7 on a 5-point Linkert scale. To implement the solution across other countries, the affinity for technology interaction (ATI) scale was used to assess their tendency to engage in intensive technology interaction or avoid it. This scale is significant in transportation and new technology studies [53]. The average score for female subjects was 4.57 ± 0.51, whereas, for male subjects, the average was 4.85 ± 0.16. The average score of all 12 hired participants was 4.71 ± 0.42, representing a very high affinity for technology interaction. A score between 4 and 5 represents a "high affinity for technology interaction". Figure 4 shows the individual ATI score of each participant.
2. **Contracting:** Each hired participant needed to bring driving licenses to verify they were a legal driver on the experiment day. After verification, each participant got a piece of verbal information and a written information sheet about the experiment. The information sheet had all the relevant information, including time taken to finish, demo questionnaires, COVID-19 restrictions, data protection, gift money, and contract forms. Subjects had to read and sign this carefully and return the two copies of the contract to the person in charge. It was particularly ensured that the hired participants did not know about the purpose of the experiment.
3. **Zero session:** Participants are allowed to sit in a patrol car. Volunteers gave the instruction and two rounds of a ride to each participant inside the laboratory to get familiar with the patrol car system. After this, participants can drive the patrol car while a volunteer sits beside them to monitor their driving skills. Subjects got enough time to get used to the dark environment and the system. During these zero sessions, cameras inside the patrol vehicle (overtaking vehicle) were adjusted.
4. **Session Overtaking:** The first session was with a patrol vehicle (overtaking vehicle). Each participant has to drive the vehicle and complete 21 rounds (trials) in the lab. During this experimental condition are shown to the driver in random order. At the end of each trial, participants stop the vehicle at the stopping point and fill out a questionnaire.
5. **Session Ego:** The second session was in the ego vehicle. Each participant had to sit comfortably in the stationary vehicle (ego vehicle) to pretend he was driving on the highway while the other person was driving a patrol vehicle (overtaking vehicle). During this experimental condition are shown to the driver in random order. When the subject stopped the patrol vehicle, the subject in the stationary vehicle was instructed to fill out a questionnaire.
6. **End of the experiment:** At the end of each session, participants fill out the Plutchiks wheel of emotion and system usability scale questionnaire.

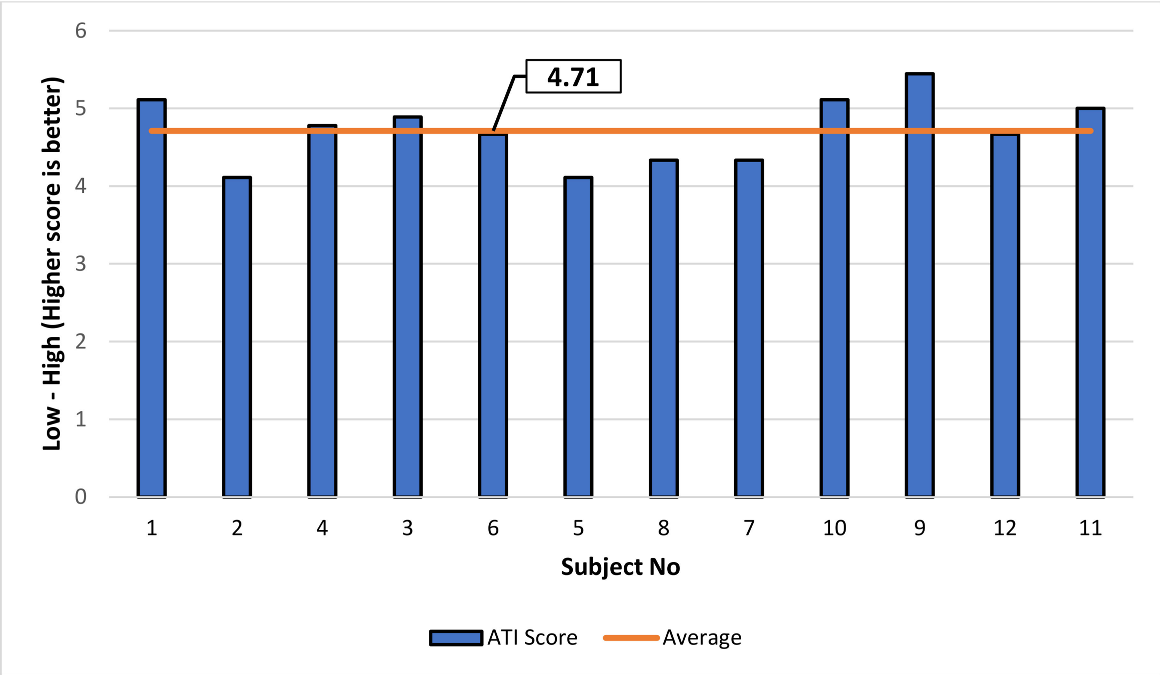

Figure 4. Individual Affinity for Technology Interaction (ATI) Scale Score.

The whole experiment was conducted on a pair of two subjects. One subject drives a patrol vehicle, and the other sits in the ego vehicle. Experimental conditions were randomly distributed, and each condition repeats 3 times during the experiment. During this whole process, participants were unaware of the actual purpose of the experiment. Instead, we told them about the testing and getting data on the remote sensors inside the vehicle at different points. Figure 5 shows the hierarchical process of the experiment.

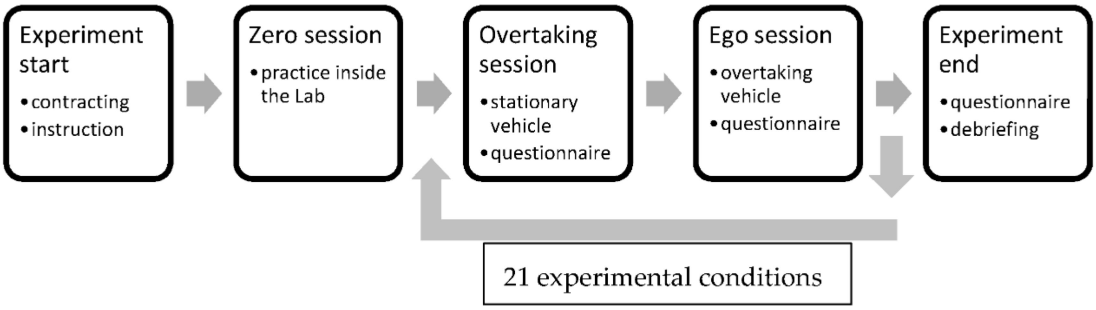

Figure 5. Procedure of the experiment.

5. Results

5.1. Understanding

To evaluate the understanding of vehicle drivers toward on-road eHMI projection for blind spot detection systems, Two questions were asked to the participants.

- Q1: I perfectly understood the meaning of the light signal
- Q2: I fully understood the situation

Figure 6 shows the overall rating for Q1 and Q2 based on all the experimental conditions. On the 5 points Linkert scale, in the ego vehicle session, Participants give a higher rating for conditions 10a and 10b. On the other hand, in overtaking vehicle session, conditions 5a and 5b get a higher score. Moreover, For 15a and 15b conditions, the least subjective rating has been observed. The non-parametric statistical tests (Friedman test and Kendall's coefficient of concordance) in SPSS with an alpha value of 0.05 were used to analyze the data further.

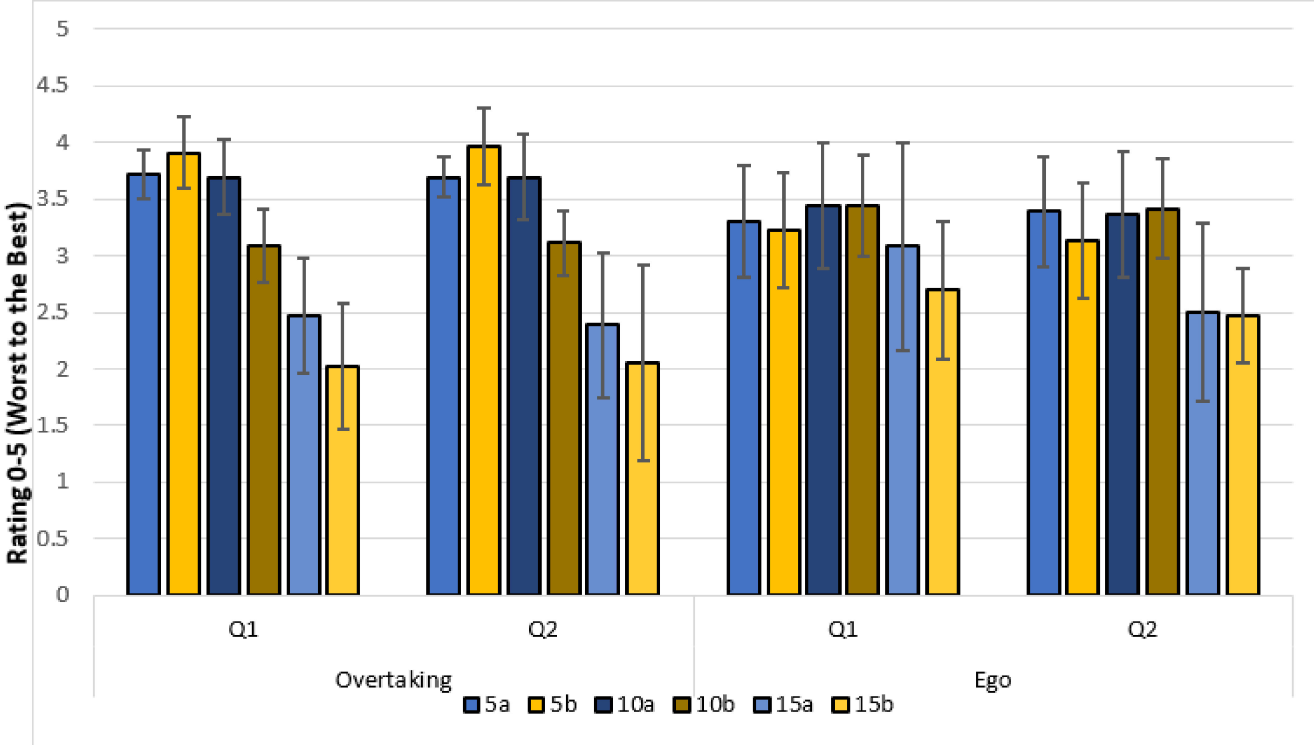

Figure 6. Subjective rating for understandability (a & b represent two contrast values, 2.00 and 1.48, whereas 5, 10, and 15 represent the distance values in meters.

For the ego vehicle session, the Friedman test with a significant level of 0.05 revealed that there is no statistical difference by changing the distance (5, 10, or 15 m) while keeping the contrast value (a or b) the same in understanding the meaning of the light signal with $p = 0.110$ and $p = 0.081$, respectively. Similarly, there is no statistical difference by changing the contrast values (a or b) while keeping the distance the same (5, 10, or 15 m) in understanding the meaning of the light signal with $p = 0.506$, $p = 0.901$, and, $p = 0.101$ respectively. Q2 about the understanding of the situation, the Friedman test shows that for a contrast value "a" by changing distance values (5, 10, or 15 m), there is no statistically significant difference $p = 0.117$; however, for the contrast value of "b" changing distance shows a statistically difference $p = 0.040 < 0.05$. Post hoc analysis revealed that conditions "5b–10b" have no statistical difference, whereas "10b15b" show a statistically significant difference $p = 0.025 < 0.050$. In contrast, keeping the distance values the same (5, 10, and 15 m) and varying contrast values (a or b), there is no statistically significant difference $p = 0.259$ and $p = 0.394$, and $p = 0.121$ respectively.

For overtaking vehicle sessions, the Friedman test with a significant level of 0.05 revealed that there is a statistical difference by changing the distance (5, 10, or 15 m) while keeping the contrast value (a or b) same in understanding the meaning of the light signal with $p = 0.031$ and $p = 0.023$, respectively. Post hoc analysis revealed that conditions "5a" and "10a" have no statistical difference, whereas "10a" and "15a" show a statistically significant difference $p = 0.008 < 0.05$, however for conditions "5b–10b", "10b–15b" and "5b–15b" have a statistical difference $p = 0.024$, $p = 0.028$, $p = 0.012$ respectively. Similarly, statistical analysis for changing the contrast values (a or b) while keeping the distance the same (5, 10, or 15 m) in understanding the meaning of the light signal shows that, for conditions "5a–5b" and "15a–15b" there is no statistically significant different while for "10a–10b" shows a statistically significant difference $p = 0.012$. Q2 about the understanding of the situation, the Friedman test shows that for a contrast value "a" by changing distance values (5, 10, or 15 m), a statistically significant difference was found $p = 0.006$ and $p = 0.005$. Post hoc analysis revealed that conditions "5a–10a" have no statistical difference, whereas "10a–15a" show a statistically significant difference $p = 0.008 < 0.05$, however for conditions "5b–10b", "10b–15b" and "5b–15b" have a statistical difference $p = 0.012$, $p = 0.005$, $p = 0.007$ respectively. In contrast, keeping the distance values the same (5, 10, and 15 m) and varying contrast values (a or b), there is a statistically significant difference $p = 0.006$ and $p = 0.758$ for "10a–10b" and "15a–15b" however no significant differences found for condition "5a–5b".

5.2. Satisfaction and Usefulness

To estimate the usefulness and satisfaction with the system based on the experimental condition Van der Lann's acceptance score was calculated for all seven conditions, including the baseline condition where no eHMI projection was used for ego and overtaking sessions. It consists of 9 items, usefulness, pleasant, nice, effectiveness, assistive, desirable, and alertness. The higher the score, the better usability and satisfaction with the system. Figures 7 and 8 show the average score for seven conditions for both ego vehicle and overtaking vehicle sessions.

Figure 7. Van der Lann Acceptance score for an ego vehicle driver.

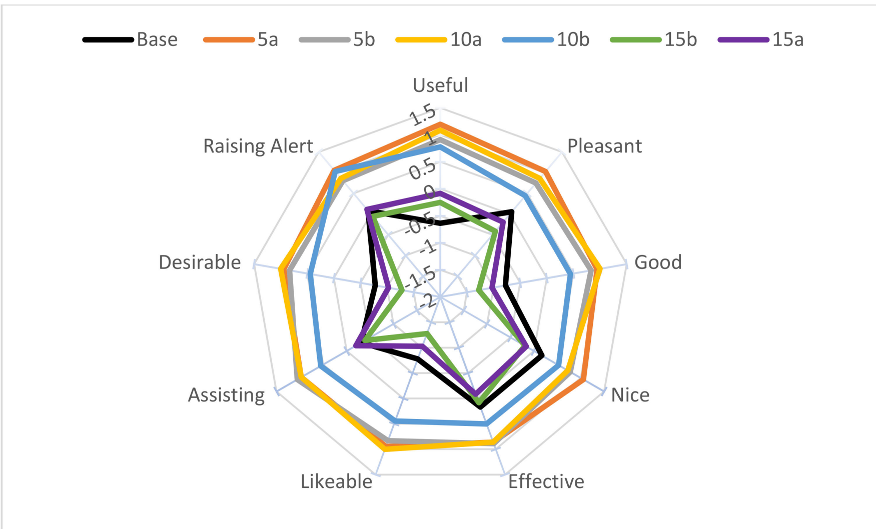

Figure 8. Van der Lann acceptance score for the overtaking vehicle driver.

For an ego vehicle session, conditions 10a, 10b, and 5a got a higher score; however, for conditions 5a, 5b, and 10a, higher subjective scores were observed in overtaking vehicle sessions.

5.3. Visibility

In terms of visibility, participants have asked a question to rate the projection in terms of easiness and visibility. Participants underrate the 15a and 15b conditions in both ego vehicle and overtaking vehicle sessions. At the same time, all other conditions got a higher mean score. Figure 9 shows the average score for the visibility of the eHMI projection.

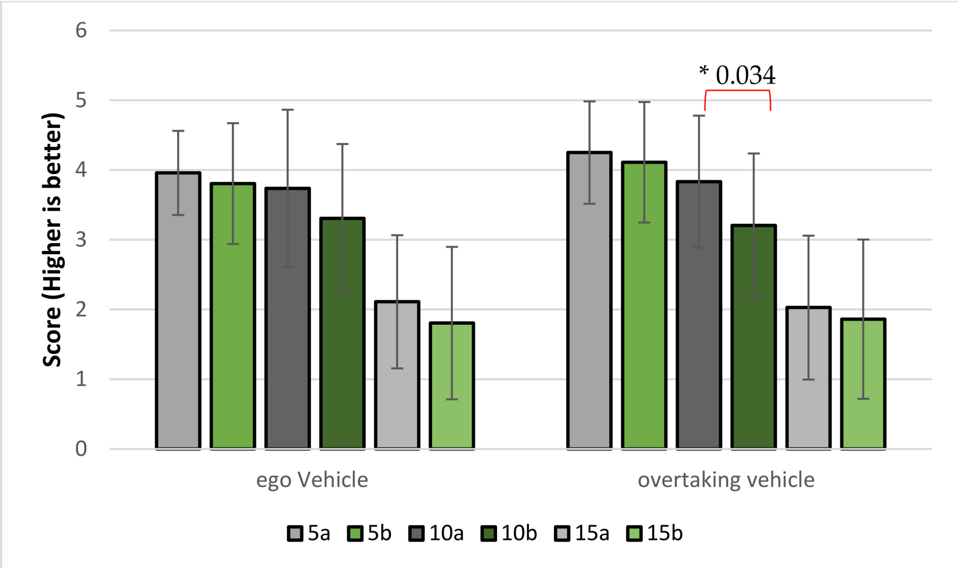

Figure 9. The average score for visibility (* represents the significance value < 0.05).

Furthermore, the non-parametric statistical tests (Friedman test and Kendall's coefficient of concordance) in SPSS with an alpha value of 0.05 were used to explore and analyze the data.

For the ego vehicle session, the Friedman test revealed a significant difference with $p = 0.001 < 0.05$. further employing a Kendall's test with an alpha value of 0.05 reveals that conditions 5a, 5b, 10a, and 10b have a no significant difference $p = 0.298$. In contrast, conditions 15a and 15b significantly differ from the other four conditions with $p = 0.001 < 0.05$.

Similarly, for the overtaking vehicle session, the Friedman test revealed a significant difference $p = 0.001 < 0.05$. Further employing a Kendall's test reveals that conditions 5a, 5b, 10a have no significant difference with $p = 0.326$. at the same time, conditions 15a and 15b have no significant difference from each other with $p = 0.480$; however, 10a and 10b show a difference with $p = 0.034 < 0.05$.

5.4. Safety Feeling

Many different methods were employed to investigate the safety feeling of the on-road eHMI projection. Participants were asked four questions about their safety feelings based on surprise and dangerous factors.

- I was extremely surprised by the light signal
- I consider that the projection of this light signal could have been dangerous
- I was extremely surprised by the situation
- I consider the situation could have been dangerous

Table 2 shows the percentage of total number of positive, neutral, and negative responses to the safety of ego and overtaking vehicles session. For both sessions, participants clearly did not report the feeling of surprise or danger. However, for 15a and 15b, participants showed a different response compared to the other four conditions and feel more surprise from the situation.

Table 2. Total Number of responses for surprise and dangerousness.

Condition	5A		5B		10A		10B		15A		15B	
Session	E (%)	O (%)	E (%)	O (%)	E (%)	O (%)	E (%)	O (%)	E (%)	O (%)	E (%)	O (%)
Negative	73.53	67.36	78.68	66.43	80.15	64.58	80.56	60.71	66.91	53.47	63.84	47.14
Neutral	18.38	20.83	9.56	23.57	15.44	27.78	11.81	26.43	16.18	27.08	20.98	30.71
Positive	8.09	11.81	11.76	10.00	4.41	7.64	7.64	12.86	16.91	19.44	18.18	22.14

E: Ego vehicle session & O: overtaking vehicle session.

To further investigate participants' feelings, participants were asked to rate their feelings on 5 points semantic scale. Participants rated their feelings between "Anxious vs. Relaxed", "Agitated vs. Calm", "Quiescent vs. Surprised". The higher the average score, the participants feel more relaxed and calm; however, higher scores for "Quiescent vs. Surprise" make people more surprised.

Figure 10 shows the self-reported feeling for safety during an ego vehicle session. The average reported score for conditions 15a and 15 b was low for "Anxious and Relaxed". Similarly, for "Agitated and Calm", the score was less than the other four conditions.

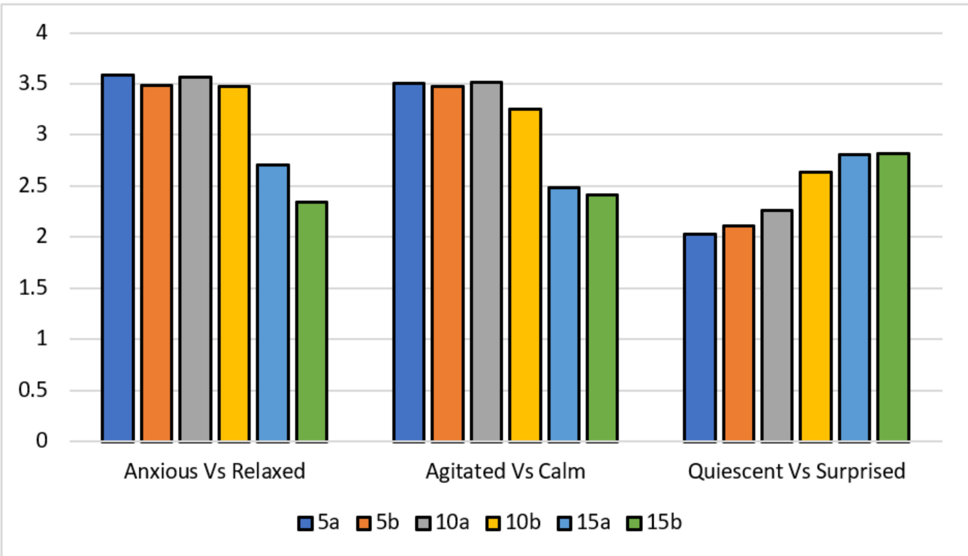

Figure 10. Self-reported feeling for safety for an ego vehicle session.

In the case of overtaking vehicles, the average reported score for conditions 15a and 15b for an overtaking vehicle is low for "Anxious and Relaxed". Similarly, for "Agitated and Calm", the score was less than the other four conditions. Figure 11 shows the self-reported feeling for safety during an overtaking vehicle session.

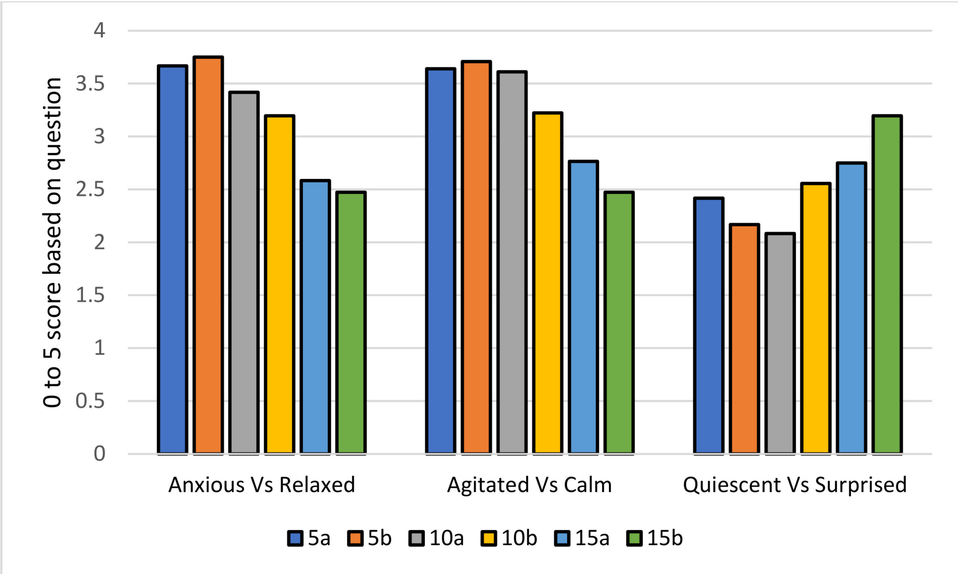

Figure 11. Self-reported feeling for safety for an overtaking vehicle session.

At the end of the experiment, the Plutchiks wheel of emotions was used to assess participants' overall feelings. Participants were instructed to choose five words to express their feelings. For an ego vehicle session, 60 words are chosen by 12 participants. Out of these words, only 17 words refer to negative feelings. Similarly, for an overtaking vehicle session, 60 words are chosen by 12 participants, with 21 referring to a negative feeling for the system. Most of the negative words chosen by the participants were anticipation for both an ego vehicle and overtaking vehicle session. Figure 12 shows the occurrence of negative word selection from the Plutchiks wheel of emotion chart.

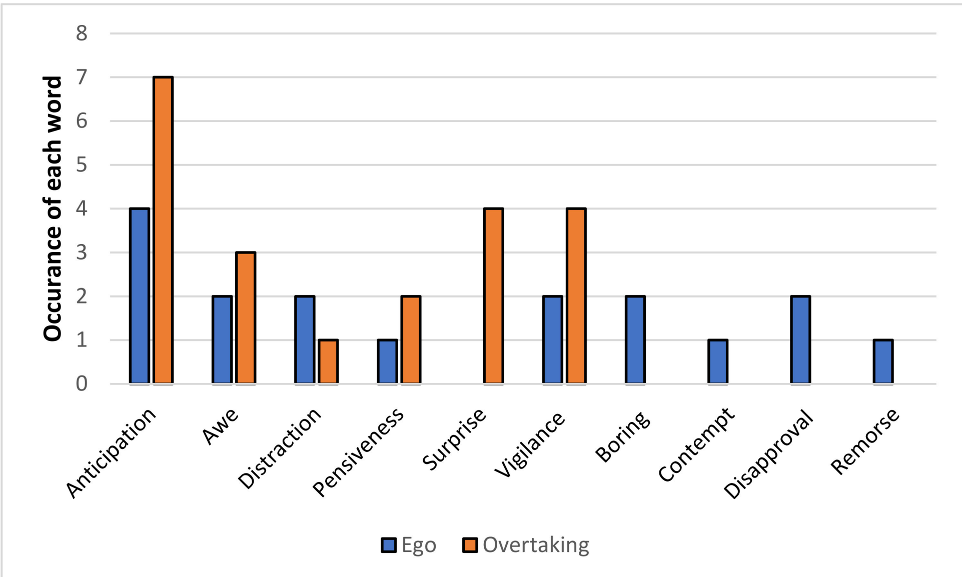

Figure 12. Occurrence of negative words.

5.5. Workload

Mental Demand, Physical Demand, Temporal demands, Performance, Effort, and Frustration were measured using the NASA task load index (NASA TLX) for both an ego vehicle session and the overtaking vehicle session. Figures 13 and 14 show the average score for all the six parameters of the NASA-TLX for ego and overtaking vehicles.

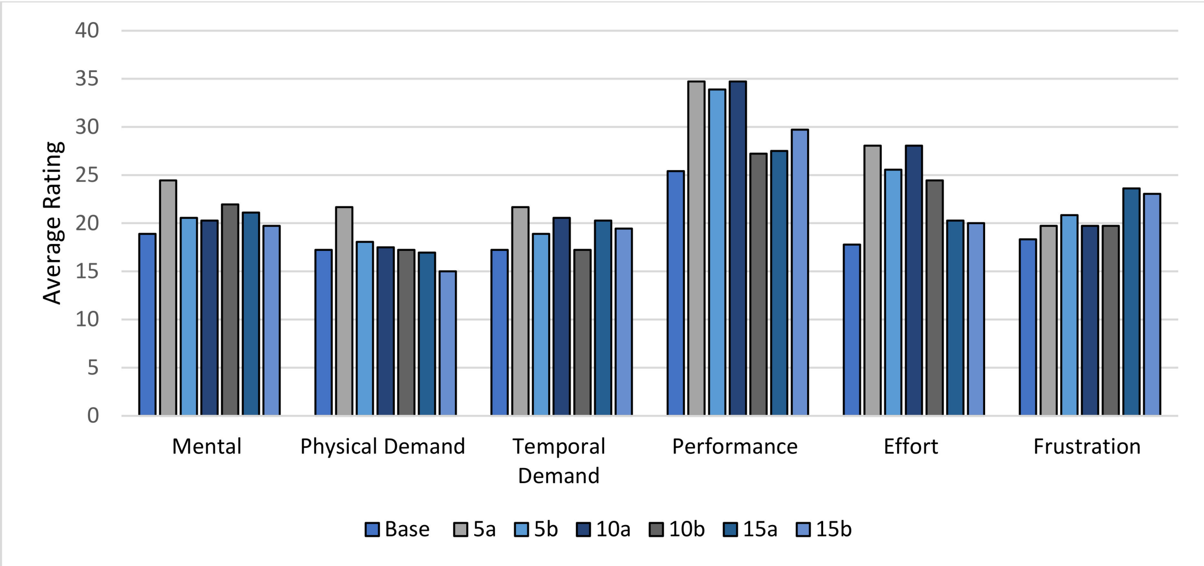

Figure 13. Average rating of NASA-TLX for an ego vehicle session.

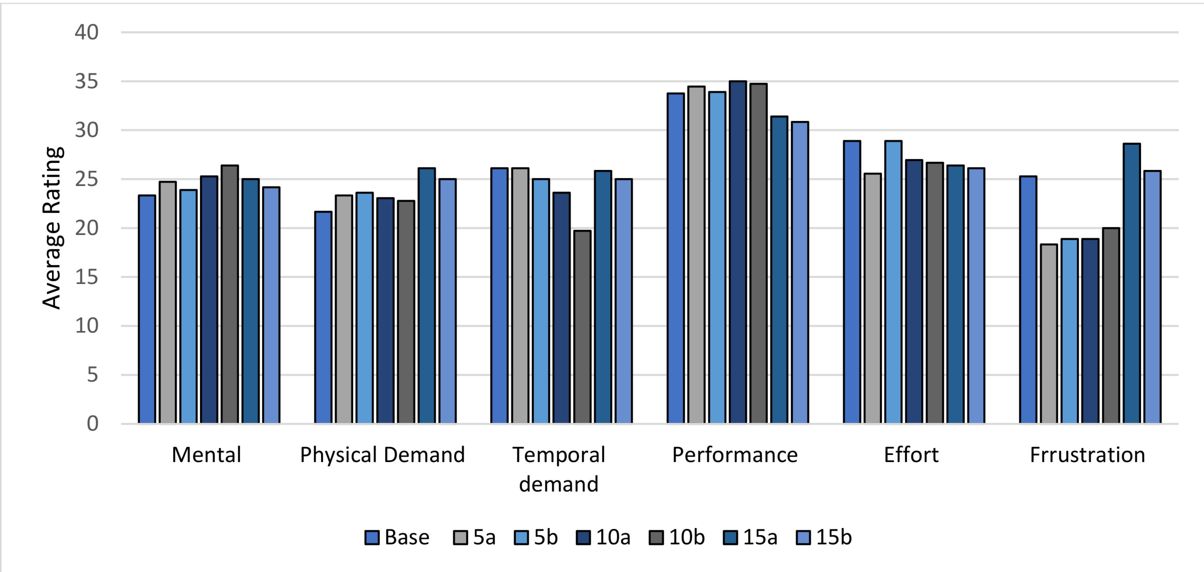

Figure 14. Average rating of NASA-TLX for an overtaking vehicle session.

Furthermore, "Friedman's test" was employed to explore the significant differences. In the case of the ego vehicle, It is clear that there is no significant difference in any parameter of the NASA task load index (NASA TLX) score in each condition (baseline, 5a, 5b, 10a, 10b, 15a, 15b). Table 3 shows the significant values for the NASA task load index (NASA TLX) score.

Table 3. Significant values for NASA-TLX score in ego vehicle session.

Conditions	z-Value	*p*-Value
Mental Demand	6.910	0.329
Physical Demand	6.824	0.337
Temporal Demand	3.389	0.759
Performance	12.293	0.056
Effort	8.330	0.215
Frustration	12.293	0.756

Significance value < 0.05.

In the case of an overtaking vehicle, there was no significant difference in any parameter of the NASA task load index (NASA TLX) score for Mental Demand, Temporal Demand, Performance, Effort, and Frustration in each condition (baseline, 5a, 5b, 10a, 10b, 15a, 15b) was found. Table 4 shows the significant values for the NASA task load index (NASA TLX) score. However, for "Physical demand", a significant difference was found with $p = 0.019$.

Table 4. Significant values for NASA-TLX score in overtaking vehicle session.

Conditions	z-Value	*p*-Value
Mental Demand	3.569	0.735
Physical Demand	15.174	* 0.019
Temporal Demand	8.971	0.175
Performance	6.432	0.377
Effort	2.457	0.873
Frustration	9.653	0.140

Significance value < 0.05. * Shows the significant difference if $p < 0.05$.

A pairwise analysis was done to explore the differences further. Physical demand for the 5b condition to the base was different with a *p*-value of 0.004, whereas 15b was significantly different from the base value *p*-value of 0.089. 10b was also a different form base with a *p*-value of 0.14.

5.6. System Usability

To investigate the usability and acceptability of eHMI projections for blind spot detection in a future vehicle specifically for the Chinese market, the system usability scale was used. It has a ten-item five-response option from strongly agree to strongly disagree. The system usability scale has been widely adopted in the automotive industry to investigate future human-centric products [54]. Based on the literature survey, the score distribution of this scale is as follows; greater than 80.3 "Excellent", in-between 68–80.3 "Good", exactly 68 "Okay", in-between 51–68 "Poor", and less than 51 "Awful".

This questionnaire was used at the end of the experiment for both an ego vehicle session and an overtaking vehicle session. Figure 15 shows the results of the system usability score. The score for an ego vehicle session lies in the category of Good (72); however, the score for the overtaking vehicle is only 50, which lies in the category of "Poor". Generally speaking, participants in ego vehicles found this system useful, whereas participants in overtaking vehicles do not find it useful.

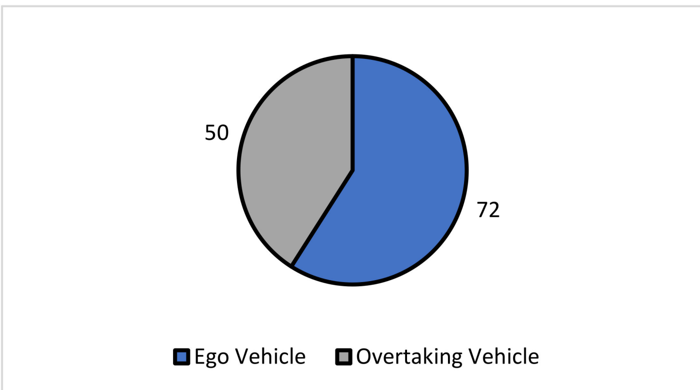

Figure 15. System usability score.

5.7. Driving Behavior

To determine the change in user behavior while using the eHMI projection system, four cameras were used in total to monitor the driving behavior of the overtaking vehicle. Two cameras were placed inside the overtaking vehicle, and the remaining two of them were fixed at the infrastructure to monitor the passing time and possible distracted behavior of the driver.

Frame by Frame analysis of the videos into the software "Corel Video Studio" was completed. The Passing time was around 1 ± 0.3 s. However, no brake response was found during the passing time. That shows that people did not feel surprised by using the eHMI projection even in their first driving trial. The total time to complete one trial was different due to insufficient turn space inside the laboratory, so we did not consider this in this study.

6. Discussion

Several methods have been used to investigate the effect of distance and contrast on understanding, satisfaction, visibility, safety feelings, workload, system useability, and acceptability for an on-road eHMI projection for blind-spot detection. Previously most of the reported articles did not consider the perception of the ego vehicle driver [24]; instead considered the perception or distraction potential for other vehicle drivers.

Regarding the understanding of on-road eHMI projection, results show that ego vehicle drivers prefer a distance of between 5 and 10 m. varying contrast does not affect. However, when the distance of the eHMI projection increased to 15 m, a change in understanding and interpreting the situation was noticed. Similarly, for satisfaction and usefulness, contrast also plays an important role. Results show that for the projection distance of 5 m, contrasts show a large change in people's satisfaction and understanding. In the same way, the safety results indicate that people feel relaxed and calm when the distance of the projection is 10 m and clearly visible to the subjects. As the distance increases, the symbol's visibility decreases, increasing the people's safety concerns in the system. Luminance contrast also showed the same behavior for the visibility and safety feeling. Workload using the on-road eHMI projection system and changing varying contrast and distance within the eHMI projection system does not show any effect. However, the rating for performance improved with using the eHMI system. This resulted outcome is the same as some other researchers showed while using their eHMI projection system for bottleneck situations [22].

For the overtaking vehicle, the understanding of the scene decreases as the distance increases. There is no significant difference between 5 and 10 m; however, after 10 m, t varying contrast affects more. Similar trends have been shown in the people's preference for satisfaction and usefulness of the system. For the feeling of safety, the near the projection, the better the person feels toward the safe feelings. The possible answer lies in the visibility results. As the distance or the luminance decreases, the visibility rating decreases, and subjects need to make more effort to understand the whole situation completely. Although it does not affect driving behavior, overtaking vehicle drivers feel that the system is not useful for them but increases their workload. The same can be seen in the research society, where the on-road projection did not significantly affect other people's driving; however, the result shows a slight disturbance distribution [55].

7. Conclusions

Different aspects like user preference, visibility, feeling of safety, satisfaction, workload, and understanding have been investigated to explore the preferred distance for the on-road eHMI projection. Based on the results, we found that people clearly see and understand the meaning of eHMI projection when the projection distance is between 5 to 10 m. People did not feel anxious or worried about the system's overall design. Furthermore, the investigation shows that people feel much more relaxed, and no workload is noticed when the projection distance is 10 m. However, lower luminance contrast affects the visibility and understanding of the situation, increasing the workload. Driving behavior regarding braking response and varying speed shows no difference for all conditions, including baseline. Further research is needed to explore this direction.

8. Limitations and Future Work

This study provides a basic understanding of the people's preference for the on-road eHMI projection symbol in terms of luminance contrast and distance for blind-spot detection. Due to a small number of participants and demo vehicles, we cannot explore the exact relationship of luminance contrast with the distance of the projection symbol. In the future, we will redesign the experimental setup, possibly involve objective parameters, and explore the exact trends for the luminance contrast and distance. Preferably also consider the involvement of the vehicle's speed on the proper test track.

Currently, different standards are available, depending on the situation. According to the American Association of highway and transportation officials (AASHTO), the perception-reaction time is 2.0 s [56]. According to the National highway traffic safety administration (NHTSA), an average reaction time is 1.5 s [57]. Similarly, for a simple stimulus in the driver's field of view, the average response time is between 0.7 and 0.85 s [58]. Reaction time, stopping distance, and response time are other aspects that can also be further explored.

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