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In-Vehicle Customized AR-HUD Design to Provide Driving Safety Information Based on User Mental Model

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“*Research is formalized curiosity. It is poking and prying with a purpose. It is a seeking that he who wishes may know the cosmic secrets of the world and they that dwell therein.”*

Zora Neale Hurston

Abstract

Han ZHANG

In-Vehicle Customized AR-HUD Design to Provide Driving Safety Information Based on User Mental Model

In recent years, the continuous development of in-vehicle information systems has dramatically enriched the driver's driving experience while also occupying the driver's cognitive resources to varying degrees and causing driving distractions. With this complex information system, effectively managing the complexity of information and further improving driving safety has become a critical issue that needs to be addressed in-vehicle information systems. At present, a new interaction method that incorporates AR (augmented reality) and HUD (head-up display) into in-vehicle information systems is gaining widespread attention. It superimposes each in-vehicle information into a real driving scenario, meeting the needs of complex tasks while improving driving safety. As a result, studying AR HUD information architecture is essential for understanding how the in-vehicle information system can efficiently handle information complexity while improving driving safety.

This study applied AR-HUD technology to the in-vehicle navigation system and designed a customized AR-HUD interface based on beginner and skilled drivers' driving behavior and information needs. The design interface of the system is studied to construct information organization guidelines and visual design strategies for the in-vehicle AR-HUD interface.

In order to verify the effectiveness of the proposed custom AR-HUD interface in the target group, this study used the AR-HUD interface to assist driving behavior as an entry point to prove that the AR-HUD interface can improve drivers' driving behavior and reduce the information recognition load.

The main research work is structured as follows:

1. Researched and analyzed target users' driving situations and behaviors through qualitative research methods of questionnaires and interviews. In-depth exploration of users' information needs and conduct information structure layering based on the user's mental model to avoid the problem of too much or too little information displayed during the driving process.

2. Completed the information module construction (HUD) and the AR-HUD interface's status module (AR) design based on the interface design principles. Additionally, the route and interaction designs are based on four of Japan's most common road situations. In the icon design, we tested the cognitive evaluation of visual elements to ensure that users could rapidly understand the semantics of the HUD.

3. The impacts of the in-vehicle AR-HUD system on the driver's eye movement behavior and responsiveness while driving was analyzed using a mix of descriptive statistics, box-line plots, and non-parametric tests. Additionally, we evaluated the effectiveness of the AR-HUD interface by developing a hierarchical evaluation index system for the AR-HUD interface based on driver driving behavior. The study results show that in terms of eye-movement behavior, AR-HUD can significantly reduce the attention time of drivers looking down at the H area while can improve the attention of beginners to the dangerous interest area when driving in the urban road. The AR-HUD interface

can significantly reduce the participants' perception of hazardous driving situations in terms of reaction time.

keywords: AR-HUD, Navigation, Driving Safety, User Mental Model

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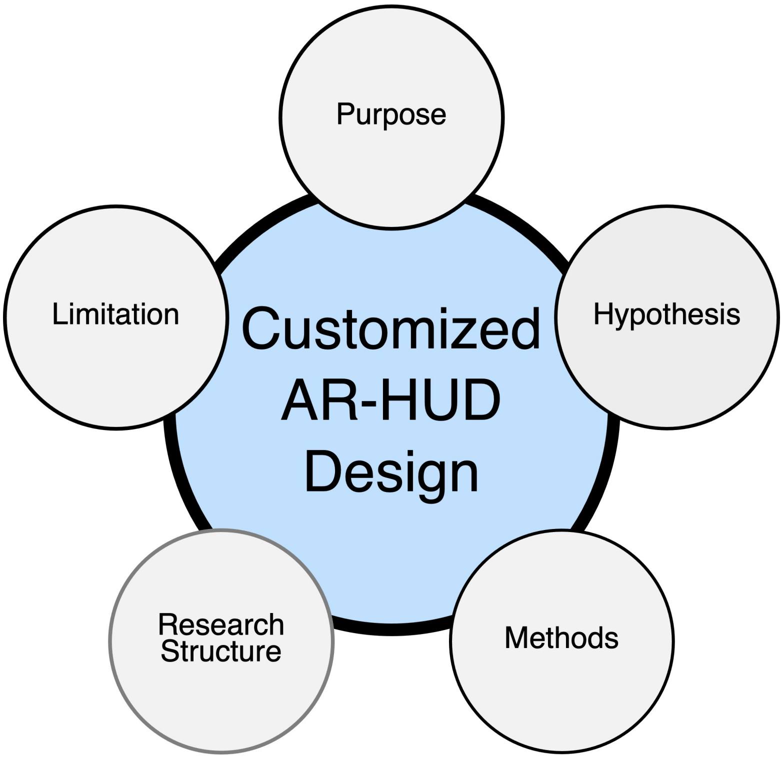
List of Abbreviations

AR	**A**ugmented **R**eality
HUD	**H**ead **U**p **D**isplay
HDD	**H**ead **D**own **D**isplay
HMI	**H**uman **M**achine **I**nterface
GPS	**G**lobal **P**ositioning **S**ystem
FOV	**F**ield **O**f **V**iew
UI	**U**ser **I**nterface
SMS	**S**hort **M**essage **S**ervice
SART	**S**ituation **A**wareness **R**ating **T**echnique
DBQ	**D**riving **B**ehavior **Q**uestionnaire
DALI	**D**riving **A**ctivity **L**oad **I**ndex
VSP	**V**irtual **S**torage **P**latform

Chapter 1

Introduction



The beginning of each chapter throughout this thesis presents a short overview of the topics in the chapter. This chapter outlines the goal and methods of this research to enable the reader to understand the whole study before reading the main thesis.

1.1 Purpose of the study

Advanced positioning technology supports the development of the Global Positioning System (GPS), making it more convenient for users to find roads while driving. However, it is still costly for drivers to understand navigation instructions, especially with complex turnoffs that take longer to understand, leading to missing key intersections at high speeds, even if only for a few seconds. Augmented reality head-up display (AR-HUD) presents a more natural way to process images with breakthroughs in optics. Moreover, the technology has also become the primary development trend of automobile human-machine interface (HMI) [1].

However, superimposing an excessive amount of virtual information on the actual traffic environment can lead to driver distraction, annoyance, or masking other road users [2][3]. In particular, the AR impacts the allocation of visual attention more strongly during the decision-making phase. Conse- quently, before AR-HUD can be used in production vehicles, one more chal- lenge must be overcome: how to manage the complexity of in-vehicle infor- mation systems efficiently while also improving driving safety.

In terms of AR-HUD design improvements, the most widespread use of HUD is in luxury automobiles manufactured by BMW, Mercedes-Benz, Lexus, and Audi [4]. Manufacturers often provide a deactivation option for driver assistance information to limit visual distractions in AR-HUD information display settings. Nevertheless, these designs underestimate that the driver's familiarity with driving affects the amount of information required. For example, whether navigation may require and how much information is needed. In the existing AR-HUD interface design process, the estimating structure used in the information database does not provide a comprehensive view of the effects of driving experiences. The road traffic accidents caused by beginner drivers who have little practical experience and cannot make accurate judgments and responses facing changing traffic conditions are much higher than that of skilled drivers [5]. With automotive manufacturers confronted with the problem of integrating AR-HUD functionalities into mid-segment vehicles, further study is required to determine whether driving experience influences information requests.

Moreover, the current studies have focused on the development of a system that offers driving-safety information to the driver through various modalities in the technical parts [6]. Numerous researchers aim to address the technical problem of in-vehicle AR-HUD detection of pedestrians, vehicles, and traffic signals projected into the road ahead of the driver [7][8]. There is a shortage of studies on the information structure of AR-HUD interfaces in various road environments with different navigation instructions.

This study analyzed the needs of beginner and skilled drivers for car navigation system functions and interactions. The purpose of this study is to ***design a customized AR HUD interface based on the user's mental model to effectively manage the system's complexity while improving further driving safety and driving experience.***

1.2 Hypothesis

The research hypothesis is that the AR-HUD system can significantly improve beginner drivers' attention to dangerous areas of interest, reduce reaction time to process information and cognitive load. Meanwhile, it can improve the driving experience of skilled drivers, who can read navigation information more effectively on unfamiliar and complex roads.

1.3 Significance of the study

This research focuses on the variability of the information needs of the driving experience. The findings of this research will contribute to the creation of standards or recommendations for the information structure of AR-HUD. Additionally, this is crucial for how in-vehicle information systems can efficiently handle information complexity, improving driving safety and experience for different user groups. The primary significance of the study are summarized below:

(1) Established a database of information requirements for various driving experiences.

(2) Created an information structure for the AR-HUD interface in various driving conditions. However, many researchers proposed the prototypes of in-vehicle AR-HUD systems project information such as detected pedestrians, vehicles, and traffic signals directly into the driver's forward view. There is a scarcity of studies on the information structure of the AR-HUD interface in a variety of driving scenarios.

(3) Evaluation of the effect of AR-HUD interface on driver's eye movement behavior. The system's effectiveness is primarily determined by the driver's

danger reaction time, with minimal consideration given to the influence of the AR-HUD interface on the driver's eye movement behavior.

1.4 Research Methods

The theoretical research part of this paper mainly uses the literature review summarising method. The user mental model research part uses questionnaire survey method and user interview method. The information architecture research uses card classification and cluster analysis methods. The interface design part uses a subjective measurement method. The validation experiment uses physiological evaluation and reaction time analysis methods.

Literature review and summarising method: In combination with the research topic, we used desktop research to compile a vast number of relevant material to get a thorough grasp of HUD and technological principles supporting AR-HUD, including the current state of development and design trends in AR-HUD. Discuss the current difficulties that AR-HUD systems confront. To investigate the theoretical background and methodologies for developing a user mental model and the mapping connection between the user mental model and AR-HUD design features. Summarize the concepts and principles of user experience design and the visual design guidelines and processes.

Questionnaire method: We conducted a quantitative analysis of the beginner and skilled driver groups' standard features and driving behavior characteristics by inviting them to complete the questionnaires.

User interview method: Invited target users for in-depth interviews and conducted a qualitative analysis of their AR-HUD functionalities and information requirements.

Card Sorting Method: We require participants to categorize and prioritize the information cards in the AR-HUD information requirement table in accordance with the navigation directions, effectively constructing a mental model of the interface's information architecture for the target users.

Cluster analysis method: The card classification results were transformed into a matrix. The distance matrix of the card classification results was analyzed using EZSort software to create the information structure for beginners and skilled drivers.

Subjective measurement method: Used the Likert-type scale to quantify effectiveness in conveying meaning and visual attractiveness related to icon quality in the AR-HUD interface design part.

Physiological evaluation method: Collected eye-trajectory feedback data from eye-tracking devices and analyzed the impact of AR-HUD information display on drivers.

Reaction time analysis method: We recorded the real-time response times of participants while turning the steering wheel and touching the directional lights.

1.5 Thesis structure

Each chapter starts from a visual schematic of the thesis and a short description to guide the reader through the whole document. The detailed structure of this thesis is shown in the figure 3.1:

- Chapter 2 presents this research's background and introduces the manufacturer's work and current research face on AR-HUD design.
- Chapter 3 presents the design concept: Design a customized AR-HUD interface that users can freely choose the driving mode which suits their driving type to assist driving.
- Chapter 4 presents how to collect the interface information of target user groups (beginner and skilled) based on the user mental model.
- Chapter 5 presents a detailed description of constructing an AR-HUD information structure.
- Chapter 6 presents the design process of the AR-HUD interface layout and visual elements.
- Chapter 7 presents a detailed description of the Experiment results on the effect of AR-HUD on driving behavior by statistical analysis.
- Chapter 8 presents the result of the AR-HUD design cognitive effect evaluation experiment.
- Chapter 9 presents the conclusion and future directions of this research.
- Show all the references used in this thesis.
- An Appendix section is located at the end of this thesis with extra information on the research. It contains the surveys, experimental consents, and other documents used during this study.

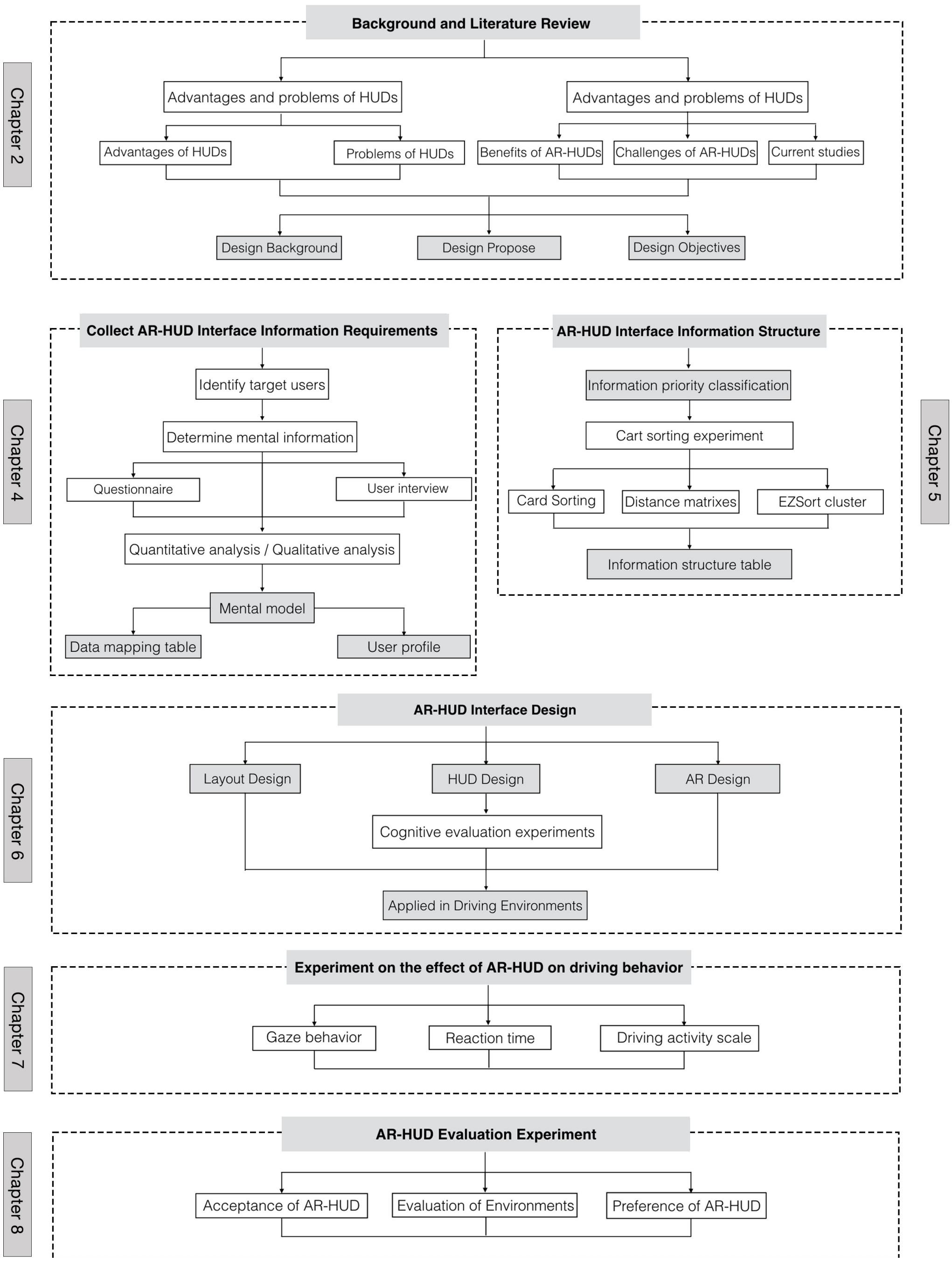


FIGURE 1.1: Research flow framework of the thesis

1.6 Limitation and Assumptions

1.6.1 Limitation

There were some limitations of this study that should be mentioned. Participants need to be in an absolutely quiet environment for experiments 1. Second, the cultural background of the participants was limiting factor of this study.

1.6.2 Assumptions

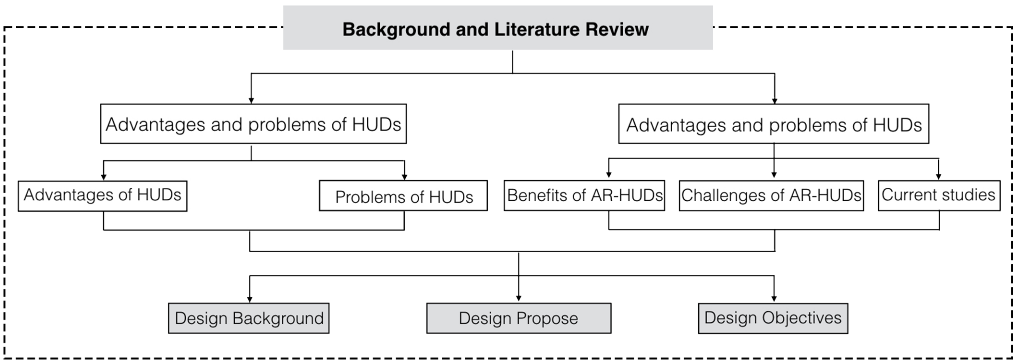
Some unrelated factors in the study are beyond the control of the researcher. We can only assume that our research was conducted under certain required conditions. For example, we have to assume that the evaluation survey will be answered honestly and objectively, and all participants will focus their attention on the experiments.

1.7 Ethical Considerations

All participants took part in the research voluntarily after being informed of the research details (Appendix A.1-4). Documented informed consent was obtained via a dedicated survey item asking whether the participants had read and understood the experiment instructions and signed the Agreement Form (Appendix A 5-13). This study's research ethics review materials were submitted and approved (Appendix B).

Chapter 2

Background and Literature Review



The chapter presents the background and literature review of ***the problem of AR-HUD system.*** Faced with this issue, the measures taken by the government, new technologies and designs introduced by car manufacturers. It also presents the current AR-HUD interface information database that we can refer to develop interface concepts in this research.

2.1 Advantages and problems of HUDs

2.1.1 Introduction of HUDs

The task of driving a car requires the driver to constantly perceive the scenario, understand the situation, decide which action needs to be taken and execute it [9]. Accordingly, assisting drivers with these sub-tasks may help them perform better throughout, which directly impacts safety. As a result, automobile manufacturers have created assisted or feedback systems for more than a century (e.g., dashboard interface). While these technologies have shown to be beneficial and have increased road safety, they also risk introducing driver distraction. The standard dashboard display was augmented with an extra display located directly in front of the driver's eyes to maximize information absorption and avoid distractions. HUDs are reflected off the windshield, resulting in a transparent image that floats above the top of the automobile (see Figure 2.1).

FIGURE 2.1: The second generation head-up display from Continental is also in series production in the Audi A6 and A7

2.1.2 Advantages of HUDs

According to previous studies, drivers get the majority of pertinent driving information through vision [10]. While display technologies such as in-vehicle navigation systems and central touch screens may give convenient and immediate information, the complex information displayed on the interfaces of these systems can also add to the processing load on the driver's visual system [3]. Additionally, drivers must divert their attention away from the road in order to get pertinent information from the system, which may confuse drivers, impair driving safety, and potentially exacerbate traffic dangers [11].

Confronted with this issue, HUDs were initially developed to show primary sensor data in the pilot's usual field of vision during an aircraft flight, since displaying instrument data in the forward field of view increases the pilot's ability to use both instrument and environmental data. General Mo- tors introduced the first passenger motor vehicle with a monochrome HUD in 1988 as a technological advancement over the frequently utilized head-down display (HDD) interface in the automobile industry [12]. By displaying the appropriate information directly into the driver's field of vision, the HUD de- creases the frequency and length of the driver's gaze wandering off the road [13]. This allows the driver to maneuver effortlessly, and to react fast with road conditions and communication systems [14][12].

To assist drivers in reducing the time required to shift their attention from the road ahead to the associated visual display interface and readjust [14] [15], the HUD looks to be a feasible and superior alternative or secondary visual display interface [15].

2.1.3 Problems of HUDs

Although some studies indicate that drivers using HUDs are better at recognizing unexpected route changes and keeping a consistent driving pace than drivers who use standard in-car navigation systems. Furthermore, drivers spend less time on the HUD than they gaze on the central interface in the car [15] [16].

However, due to the complexity of driving road traffic circumstances, automobile drivers often utilize the surroundings as a quickly shifting backdrop for seeing the HUD. Consequently, things in the surroundings may cause some visual strain and distortion for drivers who must concentrate on objects at various depths in their field of vision concurrently [15]. According to certain research, when drivers concentrate on the information presented on the HUD, objects in close vicinity experience a phenomenon known as "shrinking" [17] in which automobiles or people in close proximity shrink in size in comparison to the information displayed on the HUD. As a result, drivers might overestimate the distance between their turns, posing a threat to oncoming traffic [17] [15].

Simultaneously, since the HUD display interface is miniaturized, it is impossible for the driver to extract the critical information that impacts driving decisions in the first instance, rendering the HUD's function obsolete. Furthermore, because the HUD is typically presented on a transparent interface, its legibility is compromised in bright sunlight and is subject to weather variations. Consequently, there is still a significant risk of making decisions purely based on the information supplied by the HUD. The capacity of the HUD to minimize the time required to divert attention away from the road while focused on the information ahead, letting the driver respond more quickly, still needs to be verified.

2.2 Benefits of AR-HUD System

Advanced positioning technology supports the development of the Global Positioning System (GPS), making it more convenient for users to find roads while driving. However, it is still costly for drivers to understand navigation instructions, especially with complex turnoffs that take longer to understand, leading to missing key intersections at high speeds, even if only for a few seconds.

AR-HUD presents a more natural way to process images with a breakthrough in optics. The technology also becomes the primary development trend of automobile human-machine interface (HMI) [18]. The entire front windshield of the car is used as the HUD medium, and the displayed image information is combined with the current road environment. Unlike traditional HUDs, graphics are projected to further out, appearing as natural extensions of the drivers field of view (FOV). By placing graphics directly in the drivers line of sight that interacts with augmenting real-world objects, AR-HUD can significantly improve driver situational awareness [19].

2.3 Technical Challenges of AR-HUDs

The extent to which AR visuals can be used effectively in automotive systems is greatly influenced by the way which they are presented.To a large extent, the freedom of AR HUD interface designers to provide information to the driver remains limited by the HUD technology. In the past, research has pointed to design and usability limitations imposed by low screen resolution, low dominance levels, and a limited field of view (FOV) [2]. Although the FOV of HUDs is expected to continue to grow, current commercially available HUDs offer relatively small FOVs (6-15 degrees) compared to head-mounted AR displays, which can only display a limited amount of information [20]. Such displays have the potential to fail to capture the driver's attention (in cases where the cues are too small) or have the potential to demand too much visual attention, making it difficult to see or discern important details in the graphics without looking at them for long periods of time [2].

In terms of interface design, there is controversy over placing AR cues in the most effective area of the driver's forward field of view. On the one hand, if virtual images are placed directly in the center of the driver's field of view, they may obscure real-world, immediate information or reduce the driver's recognition of hazards due to the excessive presence of virtual information [20].

In fact, the semiotic symbolic placed within a 5-degree radius of the eye sockets is often perceived by drivers as annoying and usually ineffective [22]. On the other hand, creating a fully immersive AR HUD is not a solution in itself, as a larger canvas of virtual design is likely to attract too much visual attention and distract the driver from the road ahead [20]. To present dynamic information that correctly informs, the HUD should generally be placed behind the steering wheel directly in front of the driver or in a third area to the right of the steering wheel and no more than 30 degrees from the driver's field of view [20].

The limited field of view of the current HUD combined with the HUD placement options limit the practical applicability of conformable AR HUD graphics-that is, user interface (UI) designers can only annotate real-world objects within the limited FOV of the AR HUD, which is arguably the most important subset of real-world objects and hazards encountered by the driver. Thus, the conformable approach to AR HUD design is likely to be less than ideal in nature. With these potential limitations, positioning AR HUD visu- als will become a challenging and complicated task. Designers must consider how to effectively use visual displays to attract and guide the driver's attention while minimizing disturbances to the driving environment.

2.4 Current studies of AR-HUDs

Drivers using AR systems are affected not only by the technical design and system limitations but also by the graphics' complexity. Currently, many HUD interface designs provide simple two-dimensional graphics in a fixed location (e.g., current speed). As a result, these designs are limited in their ability to provide drivers with depth or spatial cues about their environment [12]. Fixed focal plane displays with a relatively short depth of focus (e.g., 3 m) increase the cost of attentions transitions from the HUD to the primary task, which may result in drivers missing more external hazards, delaying reactions to external events, or suffering longer transition times to return attention from the HUD to the road scene [2].

Moreover, it is critical to investigate how driving behavior changes over time how driver behavior changes when the HUD's graphical display transforms from a static 2D type to a genuine conformable or "world-oriented" style. Gabbard et al.[2] assist in conceptualizing the design space for an automobile augmented reality interface from the user's standpoint. While screen-fixed augmented reality graphics are rendered at a fixed location on the HUD and are not spatially (or perceptually) "attached" to any particular object in the scene. Conformable augmented reality graphics are rendered using real-time geolocation, pose estimation, and 3D rendering software and are therefore assumed to exist in a specific location in the real world [6].

In simulations, most widespread use of HUDs is being deployed in top-of-line automobile manufacturers, like BMW, Mercedes, Lexus, and Audi visuals have been shown to draw attention to real-world references placed inside the HUD FOV (field of view). For instance, one research has shown that providing pedestrians with line-of-sight correspondence signals helped prevent accidents when tested in a simulator [21]. On the other hand, accurate conformal presentation is often difficult to analyze on the road since it necessitates vehicle-based approaches. Nevertheless, genuinely conformal presentation is often challenging to research in on-road studies. It requires a technical vehicle-based implementation that supports real-time, geo-referenced 3D rendering of graphics outdoors at speed. Recent research has shown promising outcomes when comparing 3D augmented reality visuals to typical 2D head-up displays, including increased task performance [21] [22], and quicker brake reaction times and smoother braking curves [21] [22] [6]. However, few studies examine conformal graphics' performance in real-world driving settings.

2.5 Manufactures

The most widespread use of HUDs is being deployed in top-of-line automobile manufacturers, like BMW, Mercedes, Lexus, and Audi [6]. The current mainstream AR-HUD products include the following information functions: current speed, ACC adaptive cruise control, driving assist, distance warning, lane change alert, ambient pedestrian warning, lane departure warning, and forward vehicle warning. However, in an actual application in the driving system, the amount of information and the visual design way of expression is different by each manufacturer.

In this study, we have summarized the AR-HUD designs of automobile manufacturers and technology companies. As shown in Figure 2.2, although companies use different visual communication methods for information display, their information is mainly divided into driving information, car status information, and driving assistance information. The currently applied design is based on technical limitations and can provide far less information than the conceptual design proposed by technology companies.

Although the majority of automobile manufacturers allow the driver to choose the variety of information display categories in the AR-HUD system's information configuration. For instance, driver assistance information may be disabled under the AR-HUD information display settings to minimize visual distractions. However, the quantity of information required is determined by the categories of information and by the driver's personal preferences, driving experience, and road familiarity. Considering that most AR-HUDs are developed with a single mode, studying the design of AR-HUD modes based on driving experience requirements will be significant for the future automotive society.

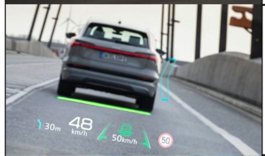
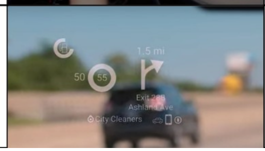
Manufacturers (Already installed)		**Technology companies (Design concept)**	
	**BMW** Speed, navigation instructions, optical signals for collision warning, speed limit, lighting status, door switch status		**Panasonic** Speed, speed limit, navigation, moving object detection, sudden vehicle warning, low night pedestrian zone, merge guidance, forward collision warning, lane enhancement, spatial exit guidance, bike/pedestrian detection, detect beyond elevation, parking search assist
	**Audi** Speed, navigation instructions, speed limit, reference vehicle departure warning		**Envisics** Speed, speed limit, navigation, compass, direction visualization, automatic cruise control, point of interest, hazard warning, destination marking
	**Lexus** Speed, navigation instructions, driving assist information, compass, audio, gauge information		**Wayray** Speed, navigation, speed limit, reference vehicle, departure warning, forward collision warning, lane enhancement, parking search assist, destination marking
	**Cadillac** Speed, speed limit, navigation, automatic cruise control, hazard warning, destination marking, points of interest		**Carloudy** Speed, speed limit, navigation, destination, gas, SMS reminder, forward collision warning, lane enhancement

FIGURE 2.2: Comparison of the AR-HUD interface in manufactures and technology companies

2.6 Summary

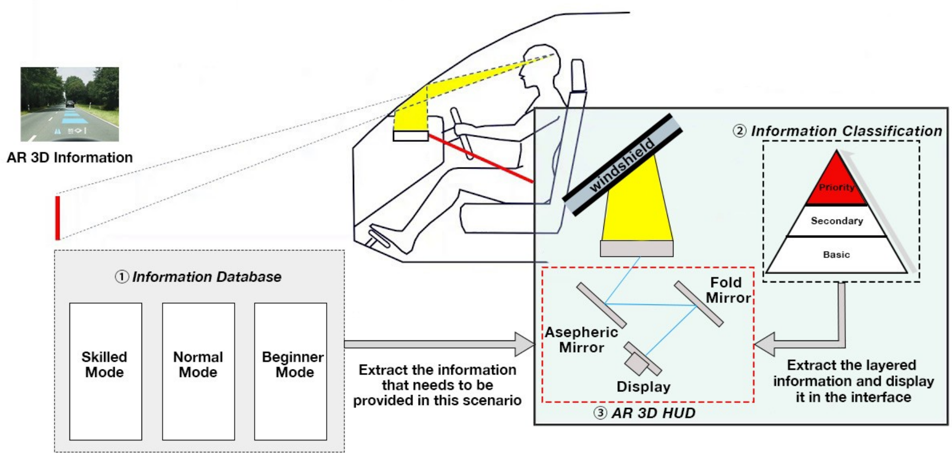
With the maturation of advanced driver assistance systems (ADAS) and AR technologies, future AR-HUDs will enable a FOV of 10 degrees or greater for overlaying images directly onto the real world [13], as illustrated in Figure 2.3. It further means that the driver can receive more information simultaneously. However, superimposing an excessive amount of virtual information onto the real-world traffic environment might result in driver distraction, irritation, or masking of other road users such as pedestrians or bicyclists [23].

FIGURE 2.3: Future AR-HUDs will allow for a FOV of 10 degrees or more and overlay graphics directly onto the real world

The present research has concentrated on the variations in information requirements between gender, age, and visual interference in technical sections. Nerveless, the estimating approach used in the AR-HUD interface's information database does not provide a comprehensive view of the effects of driving experiences. Additionally, it implies that all drivers with comparable experience driving on the road are capable of capacity assessment. The number of road traffic accidents caused by inexperienced drivers who lack practical experience and are unable to make correct judgments and replies in response to changing traffic circumstances is much greater than the number caused by professional drivers. Additionally, research on measuring the variables affecting beginner and competent drivers is still missing. With automotive manufacturers confronted with the problem of integrating AR-HUD functionalities into mid-segment vehicles, further study is required to determine whether driving experience has an effect on information requests.

Chapter 3

Methods



This chapter discusses the methodologies used in the research. The first part introduced the design concept of designing a customized AR-HUD inter- face ***to provide driving safety information***. The second part presented ***user mental model*** to understand the target user group's requirements.

3.1 Introduction

According to our review of related literature, an effective AR-HUD system should display the most critical or desired information directly related to the performance of the technical task. The interactive design would allow drivers to navigate instructions and detect risks or warnings more clearly and easily. On the other hand, an AR-HUD that does not focus on technical tasks increases visual attention allocation and may distract the driver's decision-making.

The design of AR-HUD is directly related to the strategic tasks of driver reasoning and conception. The future AR-HUD interaction design and user experience will significantly affect driving safety. Dazzling dynamic special effects and excessive pursuit of design aesthetics in visual design are not necessarily beneficial to driving safety. Most current research experiments focus on AR-HUD vehicle information interface technical aspects and user information perception processing. However, the impact of driving task proficiency with different user groups on the information demand of the AR-HUD system lacks a further discussion. In addition, the existing interface designs are display interfaces in a single user mode at the design level. There is a lack of a comprehensive design framework for the amount of information provided for different user groups and road familiarity.

To close this gap, we propose a customized AR-HUD interface design concept to provide driving safety information. Investigate the information requirements of various user groups (beginning driver vs. skilled driver) based on the user's mental model. Provide a reasonable and effective information framework for the AR-HUD interface.

3.2 Design concept

In the following, we propose a customized AR-HUD interface framework shown in figure 3.1. The information database contains 3 AR-HUD modes: skilled mode, normal mode and beginner mode. Users can freely choose the mode that suits their driving type to assist driving. For the beginner mode, because beginner drivers have less driving experience, they may need more driving assistance information to help them drive safely. In the skilled mode, will hide some unnecessary information, and entertainment or information of Short Message Service (SMS) will increase. When beginner drivers have accumulated driving experience or skilled drivers are driving on unfamiliar roads, they can switch between different modes at any time to obtain the most suitable navigation assistance support.

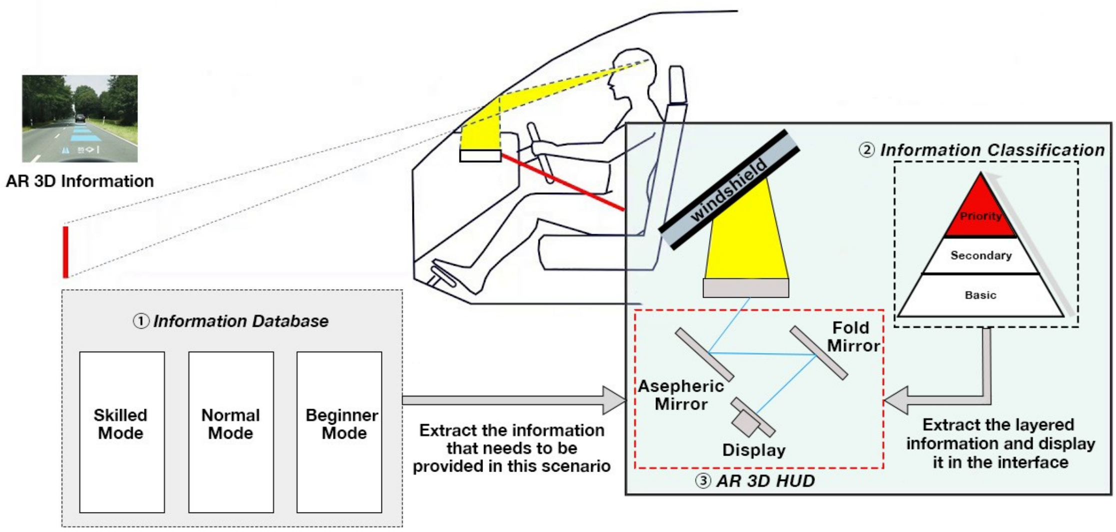


FIGURE 3.1: Customized AR-HUD interface design conceptual framework

When the driver selects the mode, the system will provide necessary information to the AR-HUD interface in real-time according to changes in driving conditions. The interface will automatically divide the information database's information into priority, second and basic groups through information classification. The information will be put into the AR-HUD interface when the information classification is completed. In front of the driver, AR-HUD generates a virtual image through the windshield through mirror projection optics and maps it on the road based on the perceived eye position.

3.3 User Mental Model

3.3.1 The introduction of the user mental model

The definition of Kieras & Bovair specifies mental models as "some kind of understanding of how the device works in terms of its internal structure and processes [24]. Indi Young explains that mental models give a deep understanding of people's motivations and thought processes, along with the emotional and philosophical landscape in which they are operating [2]. Nowadays, the user model is considered the primary method to understand the deep needs of users. It is widely used as the basis and premise of the human-computer interaction design process [25].

3.3.2 The significance of user mental models for AR-HUD interface design

The user's mental model can be divided into three different parts: cognitive model, behavioral model, and user emotional model [26]. Norman also details distinctive processing layers that cause different kinds of experiences, including visceral, behavioral, and reflective, they correspond to the three different parts of the mental model[27]. He posits that a product is perceived and automatically assessed through its look and feel (visceral) and its purpose and functionality (behavioral), leading to action. Above these, the reflective level represents conscious thought and reflection of that experience [27]. As shown in the figure 3.2, these three components influence each other and have an important guiding role in the different levels of HMI design.

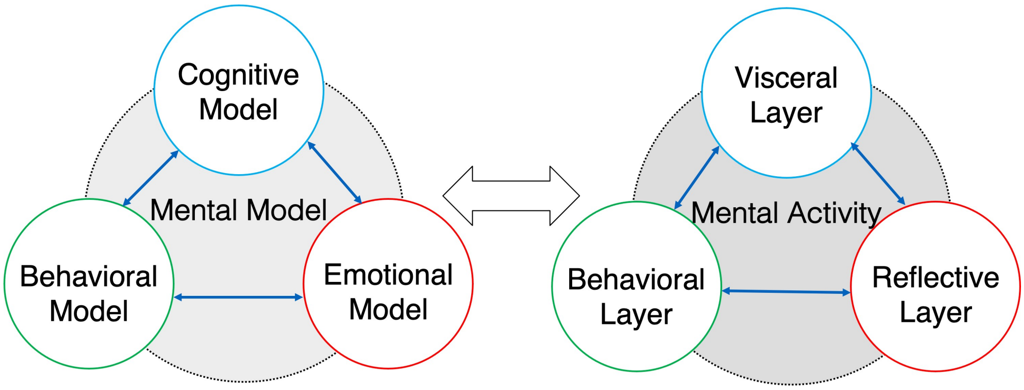


FIGURE 3.2: Correspondence between mental models and mental activities

The cognitive model can extract external information through the human body's five senses, process it by the brain, and use the processed information to deal with problems. It is the process of generating feedback to external things [24]. The user's cognitive behavior is derived from instinctive energy, so it corresponds to the visceral layer of the user's mental activity. Regarding AR-HUD interface design, the user's visual cognitive behavior is the main channel to obtain information. Visual elements that highly conform to the user's cognitive model can allow users to understand and access the information contained in the interface more quickly, reducing the user's cognitive burden and bringing a more user-friendly experience.

The user behavior model is a behavioral activity or a series of behavioral activities that a user performs to achieve a certain goal. It corresponds to the behavioral layer of the user's mental activity [24]. In terms of AR-HUD interface design, the user's behavioral model is the basis for guiding the interface information architecture. An interface information architecture that conforms to the user's behavioral model can improve the efficiency of information reading by the user.

The user emotional model refers to a series of emotional factors gener- ated by users in experiencing external things. The counterpart is the reflective layer of the user's mental activity. When a driver uses AR-HUD, whether the amount and correctness of information conveyed by the interface satisfy the user's needs can affect the user's driving stress and the experience.

By specifically refining the user's mental model into the five elements of user design, the following AR-HUD mental model mapping relationship table can be obtained (as shown in the Table 3.1). The cognitive model corresponds to the performance layer and framework layer of design. It is a direct guide to the AR-HUD interface's color selection, graphics, dynamics, and interface layout. The user behavioral model corresponds to the structural layer mainly for building the information architecture of the AR-HUD interface.

Following the user-centered design principle, each stage of the AR-HUD design process in this study needs to be performed by the user's mental model. The specific guiding role of each model in the interface design of this study is shown in the Figure 3.3.

TABLE 3.1: Mapping table of mental information and interface design elements

User Mental Model	***AR-HUD interface design elements***		
Cognitive Model (Visceral Layer)	Performance Layer	Visual Design	Interface color scheme, icons, dynamics
	Framework layer	Information Design	Interface layout
Behavioral Model (Behaviral Layer)	Structural layer	Information Architecture	Structure and layering of information content
Emotional Model (Reflective Layer)	Range layer	Information content	The functions achieved by the interface, the meaning of the information conveyed by the interface
	Strategic layer	Design Value	Impact on users' driving experience and emotional factors

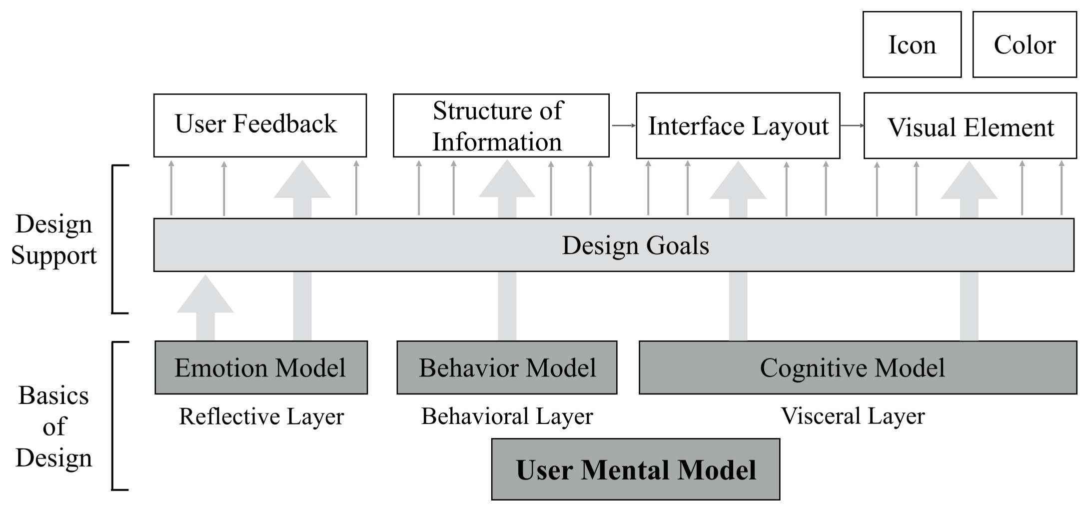


FIGURE 3.3: Flowchart for designing the AR-HUD interface based on the Mental Model

3.3.3 The process of constructing a user mental model

As shown in Figure 3.4, the process of developing a user mental model for the AR-HUD interface in this study can be divided into three stages: construct information structure (behavioral model), design AR-HUD interface (cognitive model), and validation of the AR-HUD driving experiments (emotional model).

(1) Construct information structure

The information structure is constructed based on accurate mental information about the target user groups. The most frequently used methods for collecting mental information are questionnaire surveys, user interviews, and user observation. In this study, two questionnaire survey and phone interview was conducted and quantified the essential information about the target users. For information priority, use card sorting experiment to get information structure tables in different driving environments.

(2) Design AR-HUD interface

Based on the information constructions, we created the HUD interface's layout, the visual components of the AR and HUD and conducted semantic assessment experiments to verify that the AR-HUD elements were clear and simple to understand.

(3) Validation of the AR-HUD driving experiments

To determine whether two modes of AR-HUD can effectively improve driver attention and assist in safe driving. Two types of validation experiments were conducted: objective assessments of driving behavior and subjective evaluations of the AR-HUD.

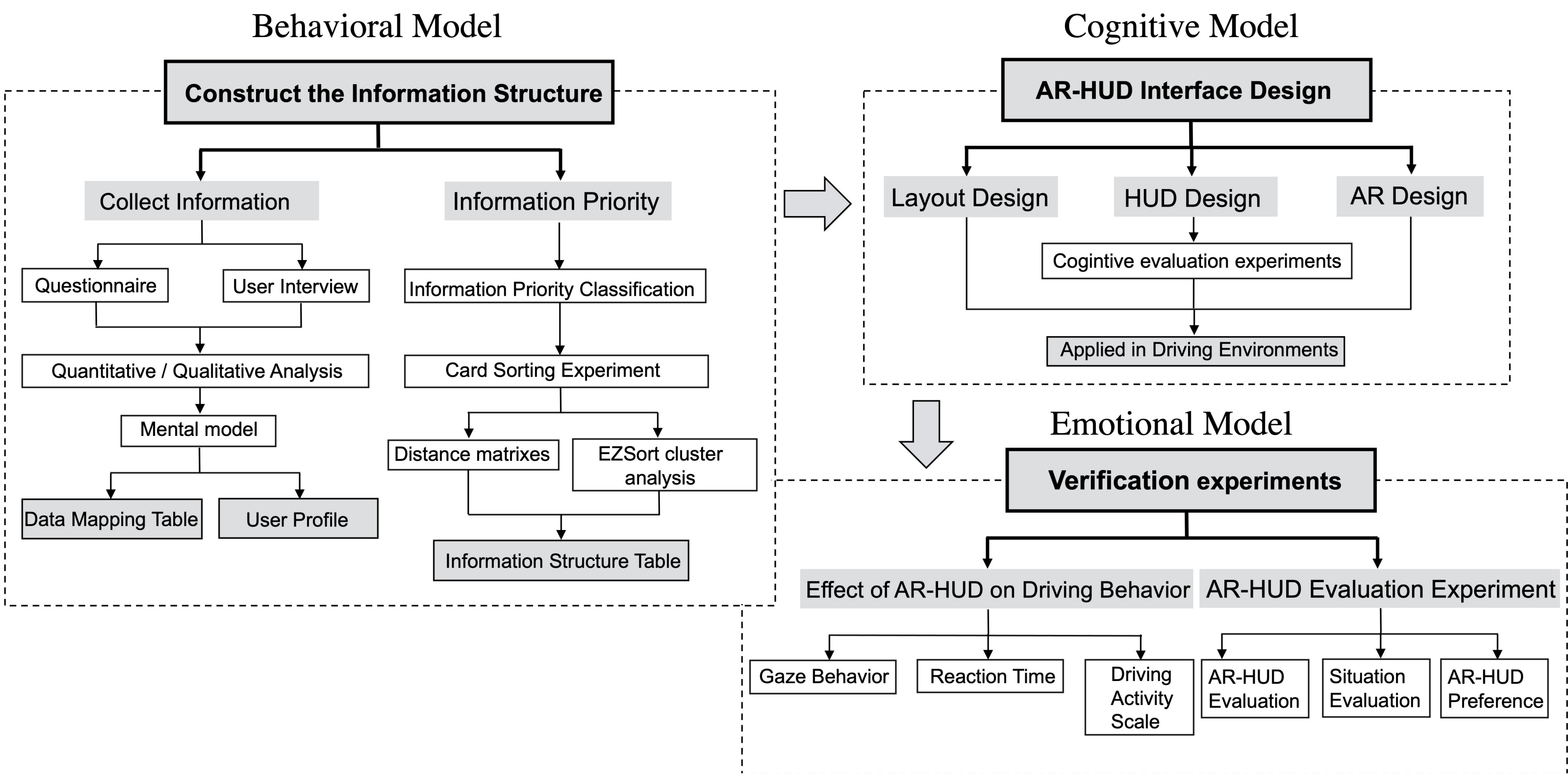
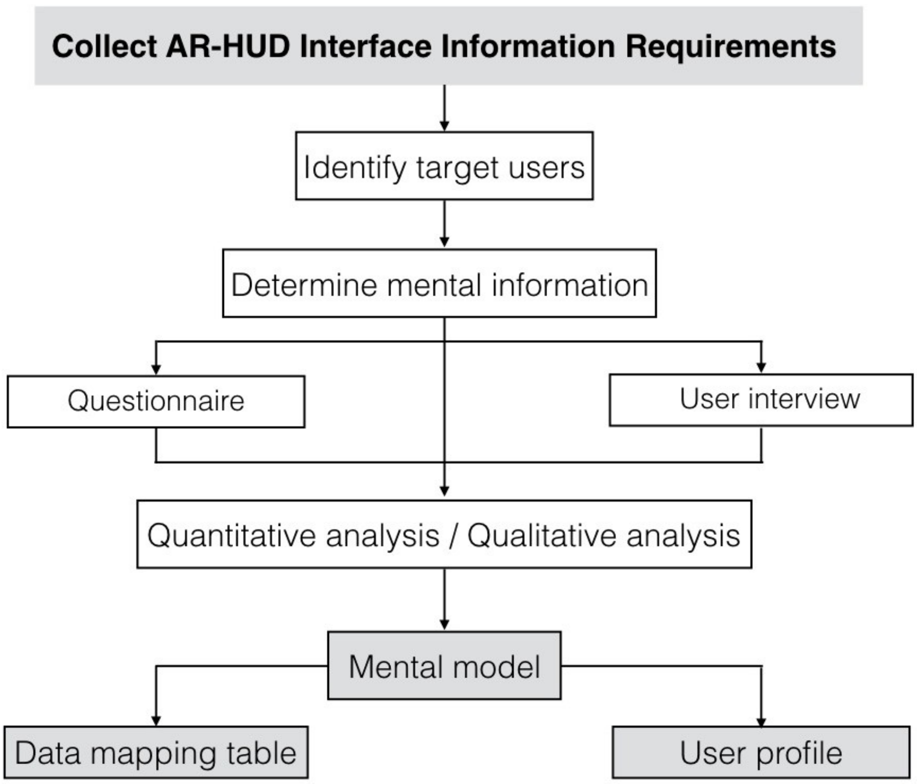


FIGURE 3.4: Customized AR-HUD mental model construct process

Chapter 4

Collect AR-HUD Interface Information Requirements



This chapter presents how to collect the interface information requirements of target user groups (beginner and skilled) based on user mental model, analyze the driving behaviors and situation description to construct the information database.

4.1 Introduction

In this chapter, the contribution of the research has three parts:

(1) Discussing the types and layout requirements of AR-HUD interface information.

(2) Comparing different user groups (beginner and skilled drivers) to explore the relationship between driving familiarity and information requirements.

(3) Using the method of constructing a user mental model to collect the driving mental information of two groups on the interface design elements' requirement.

The result is translated into design recommendation and information requirement database for our AR-HUD interface design.

4.2 Identify target user groups

Firstly, conduct a user survey of target users (beginner and skilled drivers). Use the online survey to collect target users' information needs and navigation preferences. The user groups of this study can be summarized by combining the definition based on Yang et. research [5] and Japanese traffic regulations in Table 4.1.

TABLE 4.1: Target user groups characteristics

Group	**Characteristics**
Beginner Driver	a) <2000km/year, total<20000km b) Holding driving licenses<3 years c) Have inadequate driving skills and problems with perceiving traffic conditions.
Skilled Driver	a) >5000km/year, total>50000km b) Holding driving licenses>5 years c) Sufficient driving skills and environmental adaptability

Numerous studies have shown that drivers with less than or close to three years of driving experience often lack driving abilities, frequently misjudge road traffic danger, and lack adequate vehicle driving predictability [28]. Moreover, the driving experience is also related to driving mileage. According to Japanese traffic regulations, two standards were used to distinguish beginner drivers and skilled drivers: (1) number of years for holding licenses and (2) cumulative driving mileage. The key characteristics are shown in Ta- ble 4.1. Driver with driving age of fewer than three years or with cumula- tive mileages less than 20000km was classified into the beginner group, while drivers holding licenses more than five years or with cumulative mileage more than 50000km were categorized as skilled drivers.

4.3 Questionnaires

This section presents the two user surveys on target users (beginner and skilled driver), designed to collect the two user groups' information needs and behavioral characteristics while analyzing the impact of the driving road environment on information needs. Two online surveys were mutated from validated tools such as the Situation Awareness Rating Technique (SART), and the Driver Behavior Questionnaire (DBQ). Two online surveys was conducted using Google Form. The survey was available in English, Chinese and Japanese language.

4.3.1 Research on car driving navigation information

The online survey was developed to examine several critical topics related to driving information. The main propose addressed were the following:

(1) Navigation type preference: Confirm whether age and gender have significant differences in preference for navigation systems.
(2) Necessary driving information: Filter information and establish an information database of normal mode.
(3) Environmental impact: Confirm whether there are significant differences in information requirements in different environments.
(4) Different user groups: Differences in information needs basing on driving experience.

Regarding the driving information that should be displayed on the interface, analyzed already available conventional automobiles and vehicles equipped with HUD functions. As indicated in Table 4.2, the information required by the AR-HUD interface is separated into four categories.

TABLE 4.2: AR-HUD interface display information classification

Categories	
Navigation Information	start notification, turn instructions, U-turn instructions, the current lane of the car, lane change instructions, driving route, distance from destination, change route reminder, keep straight, destination, distance reminder (turn right after 300m), park instructions, arrival notification, time to destination
Vehicle Status Information	speed, weather, remaining battery, time, temperature, audio information, gear position, air condition operating status, light status, door switch status, milage, whether the system is abnormal, seat state, accelerate/decelerate
Driving Assistance Information	other vehicle around the car, pedestrians around the car, obstacles around the car, direction visualization, departure warning, safe distance reminder, speed reminder, light adjustment reminder, turn path visualization, parking assist, overtaking assist, speed limit information, road restrictions, traffic condition ahead, vehicle service (gas station)
Entertainment Information	SMS reminder, music information, nearby restaurants information, building information, point of interest

As shown in Table 4.3, the 301 respondents (133 males and 168 females) aged between 20 and 70 years old (Mean = 34.2 years, SD = 6.5) took part in the online survey. All respondents have drivers licenses in different countries.

TABLE 4.3: Descriptive statistics of respondents in a survey of research on car driving navigation information

Variable	Mean (SD)
Age	34.2 (6.5)
Gender(%male)	44.2%
Driving experiences (years)	6.78 (4.21)
Driving times per week	4.57 (1.16)

4.3.2 Research on the beginner driving behaviors

This survey aimed to assess the qualitative analyses of beginner driver behavior and information needs.

We used a simple random sampling survey to collect specific personal attributes and information on driving behavior from beginner drivers through online responses. The survey was divided into three parts. First, general demographic questions about age gender (Q1-Q2). The second part of the survey (Q3-Q6) focused on beginner driving mistakes and driving experience. The third part used the DBQ and SART to consist of questions on driving behavior [29] and self-assessment of various driving tasks (Q7-27). The following self-assessment tasks were provided: driving proficiency in a different scenario, frequency of driving mistakes, control of vehicle speed, and driving problems. As shown in Table 4.4, the 104 respondents (70 males and 34 females) aged between 20 and 31 years old (Mean = 24.4 years, SD = 3.8) took part in the online survey.

TABLE 4.4: Descriptive statistics of respondents in a survey of research on beginner driving behaviors

Variable	Mean (SD)
Age	24.4 (3.8)
Gender(%male)	67.3%
Driving experiences (years)	0.75 (0.54)
Driving times per week	3.2 (0.83)

4.4 Interviews

Different from the quantitative research of survey, user interviews focus more on qualitative research that was conducted to achieve a higher degree of discussion between the interviewer and the interviewees. Consequently, understanding user groups views on the AR-HUD interface design can also collect more specific information needs for constructing beginner and skilled mode databases.

We developed a semi-structured interview with basic information and six open-ended questions, which allowed for extensive storytelling. The main topics addressed were the following:

(1) Basic information: age, occupation, driving experience, car brand and frequency of driving.

(2) Driving scenarios description and problems: First, introduce driving background and purpose. Then describe the issues and situations during driving. Discuss the lack of information that needs to be resolved and their own needs.

(3) Division of driving information needs: give a percentage of basic information, driving assistance, SMS reminder, direct visualization and traffic information. (4)Free talk about AR-HUD interface design.

The full semi-structured interview was 15-20 minutes due to personal differences. The recruitment of interviewees is based on the target user conditions in Table 4.1.

As shown in Table 4.5, the 40 interviewers (20 males and 20 females) aged between 20 and 57 years old took part in this telephone interview. In the beginner group, 7 females and 13 males ranging in age from 20 to 28 years with Mean = 23.5 and SD = 2.41 held a valid driving license less than three years (Mean = 1.02, SD = 0.8). The skilled driver group ranged from 29 to 57 years,

TABLE 4.5: Descriptive statistics of interviewers

Variable	Beginner Group	Skilled Driver Group
N	20	20
Age	23.5 (2.41)	37.7 (10.8)
Gender(%male)	65%	65%
Driving experiences (years)	1.02 (0.8)	14.8 (5.7)
Driving times per week	2 (1.4)	5 (0.7)

with Mean = 37.7 and SD = 10.8. The average driving experience of 7 females and 13 males was 14.8 years (SD = 5.7).

4.5 Results

This section summarizes the study results, containing the driving behavior, environment impact, information needs and subjective assessment for the beginner driver. Furthermore, the interviewer's feedback in the open questions is described and made the user portraits for two groups. All analyses were performed in SPSS (version 26.0).

4.5.1 Navigation type preference

In a user survey on car driving navigation information, we want to know the user's preferences before designing the HUD interface. The survey includes photographs and explanations of each navigation system to prevent respondents from making an incorrect decision due to a shortage of knowledge about the various navigation systems. According to the cross-analysis, the comparison figure of the two user groups' preferences for the navigation system is obtained. As shown in Figure 4.1, respondents tend to choose HUD, screen display, and AR-HUD. Most of the respondents (80% of beginner drivers and 94% of skilled drivers) want to use AR-HUD to get information to display while driving.

Interpretation of independent sample t-test Homogeneity of variance was tested using Levenes equality of variances test. As shown in the table 4.6, Non-significant results (p =.201) were obtained for the dependent variable. Indicating that the error variance of each dependent variable is equal across groups. An independent t-test was used to analyze the significant difference between two groups (beginner and skilled driver) on navigation preferences. There are no differences significantly on driving preference, t (208) = .96, p = .338 > 0.05 between the beginners and skilled drivers groups.

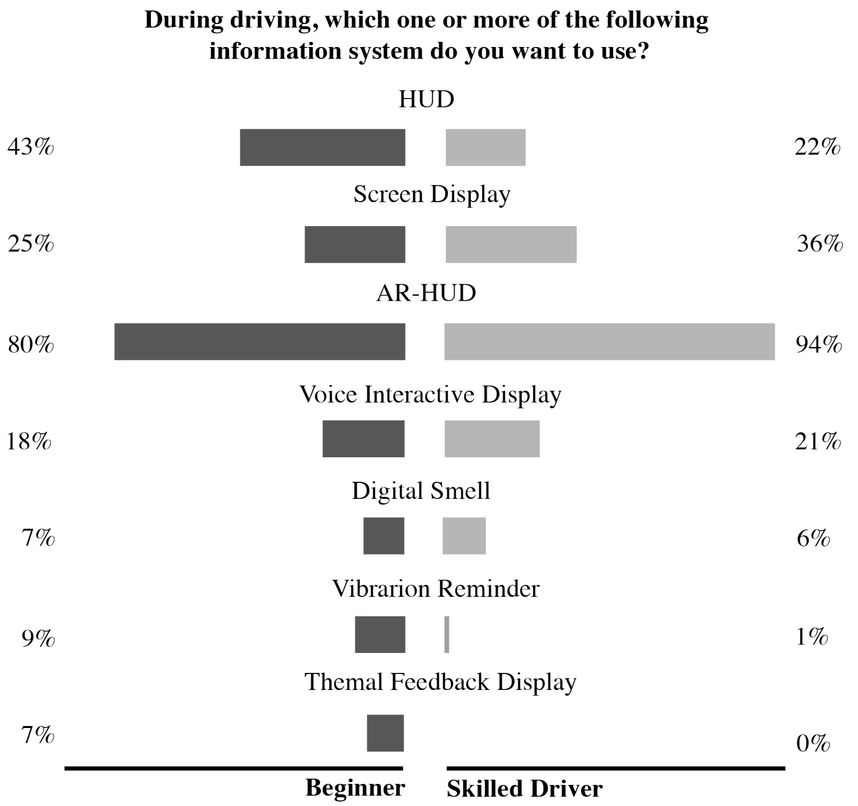


FIGURE 4.1: Independent sample t-test of navigation type preference in two groups

	Levene's Test Equally of Variances		t-test for Equality of Means				
	F	Sig.	t	df	Sig. (2 – tailed)	Mean Difference	Std. Error Difference
Equal variances assumed	1.645	.201	.960	208	.338	0.65	.15279
Equal variances not assumed	0.438	0.08	0.31	0.64	.252	0.44	.12761

TABLE 4.6: Compare the preferences of beginner and skilled driver on the type of navigation system

4.5.2 Environmental impact

The Chi-Square statistic is most commonly used to evaluate tests of independence when using a cross-tabulation. Cross tabulation presents the distributions of categorical variables simultaneously [30]. We selected four typical road environments in Japan as the survey materials, including highways, urban roads, residential areas, and countryside roads. We informed respondents to view the picture and envision themselves driving in this scenario, then choosing the system's information. The chi-square test determines whether there are significant differences in information requirements in different environments. Table 4.7 shows that the highway environment was associated with the information needs. The probability p-value corresponding to the chi-square statistic is 0.006, which is far less than 0.05.

TABLE 4.7: Chi-square tests of highway environment

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	360.000[a]	64	0.006
Likelihood Ratio	184.486	64	0.008
Linear-by-Linear Association	27.388	1	0.366
N of Valid Cases	301		

a. 80 cells (100%) have expected count less than 5. The minimum expected count is .02.

As shown in Figure 4.2 , the direction and speed information is particularly important in selecting information needs on the three types of road environments in the urban, residential and countryside. Conversely, respondents have a significantly lower demand for direction information in the highway environment than in other environments.

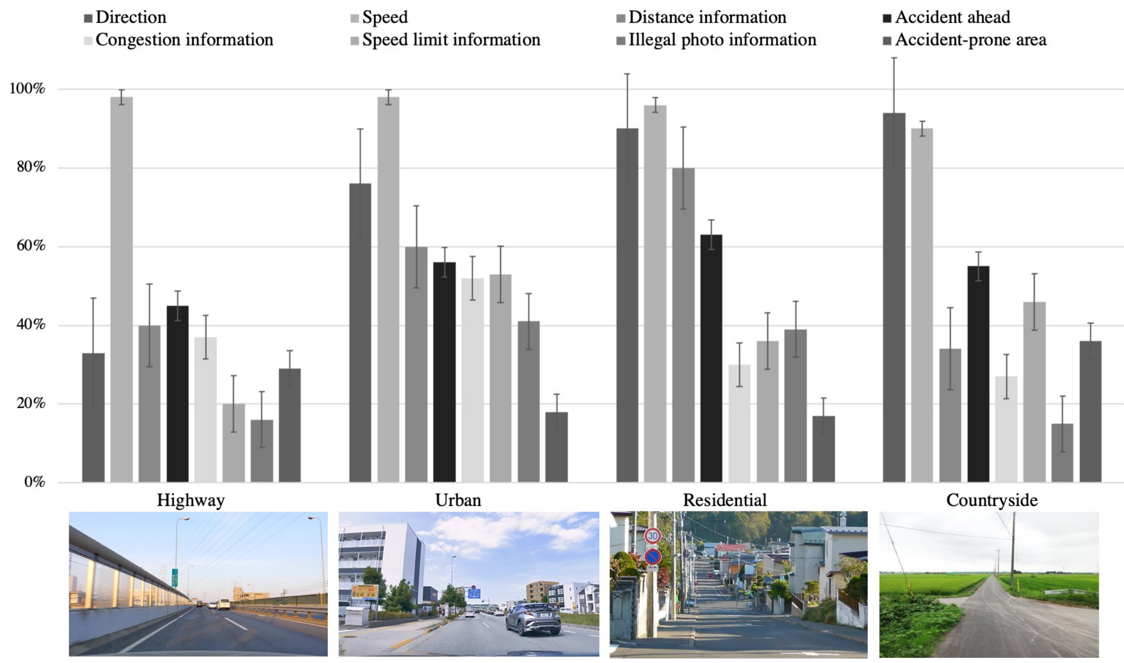


FIGURE 4.2: Information needs in four environments

4.5.3 Subjective assessment for the beginner drivers

Figure 4.3 shows that the driving state of "It is difficult to control the specified speed" often occurs for beginners far more frequently than other options. Furthermore, "Turning too hard, the tires are on the pedestrian path" this driving state occurs with few frequencies during beginner driving. For driving proficiency in various scenarios, 17.48% of beginners are not good at driving on mountain roads. In contrast, 16.5% of beginners think it is challenging to drive at night, as shown in Figure 4.4. Besides, 15.5% of the beginners think it is challenging to highway confluence, and 12.6% of the beginners are not good at parking, driving on narrow roads and unfamiliar roads.

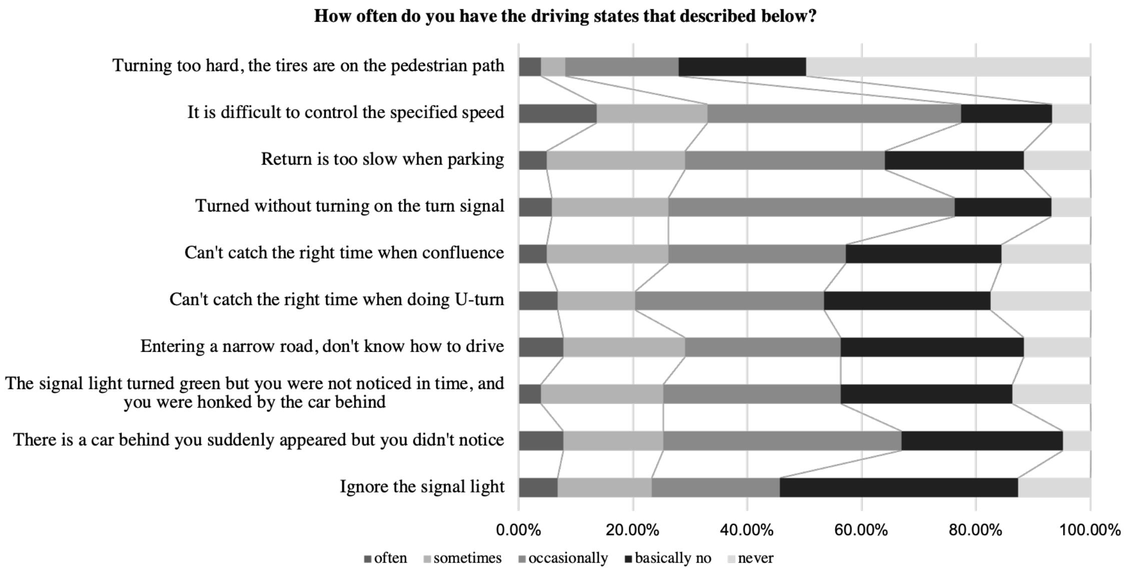


FIGURE 4.3: Statistics of beginner's driving state frequency

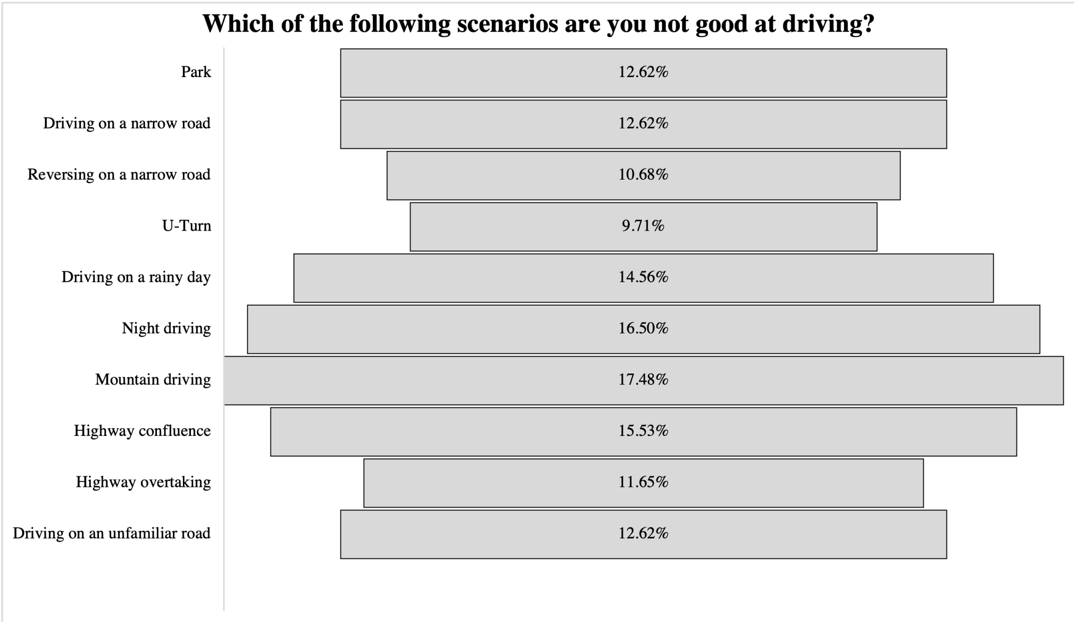


FIGURE 4.4: Driving proficiency in various scenarios

4.5.4 Interview

For the interview results, interviewees were asked to give a percentage of five driving information types. Figure 4.5 shows beginner drivers and skilled drivers both believe that basic information (driving information) is the most important.

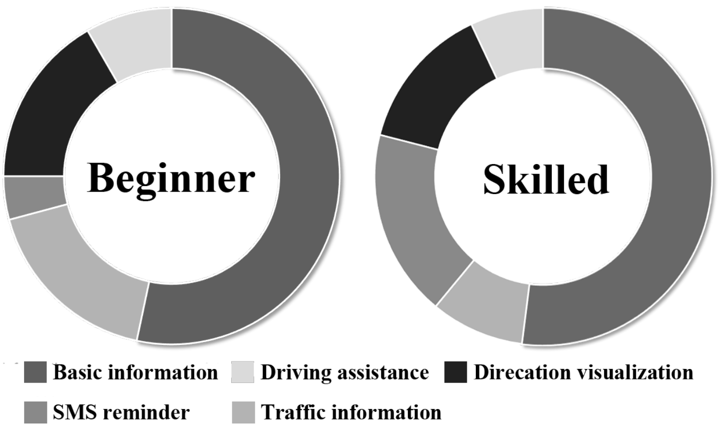


FIGURE 4.5: Division of navigation information needs

Besides, beginner drivers believed that driving assistance is required for 27%, and skilled drivers thought direction visualization is also essential.

Furthermore, we asked the interviewee to describe the problems and situations when using navigation during driving. Also, it discussed the lack of information that needs to be resolved and their expectations and needs for AR-HUD. As shown in the table 4.8 and 4.9, we collected the user driving scenario description and navigation requirements into a oral report. Whether a beginner or a skilled driver, the surroundings and duties encountered throughout the driving process significantly impact the driving situations encountered. Due to the effects of eyesight, light, and other factors, drivers are prone to impaired driving efficiency and experience severe weather such as rain, snow.

TABLE 4.8: Scenario description sample (beginner driver)

Scenario Description	Problems and Requirements
Visibility was very poor due to the heavy rain, and the wipers kept swinging, making it hard to see carefully the road ahead.	Many pedestrian and vehicle information is easily overlooked in rainy and snowy weather with poor visibility. I hope the system can warn of relevant dangerous information in advance.
When turning at an intersection, there are several interconnected points to be aware of. I do not always know where to turn when complicated traffic conditions surround me.	I'm hoping that the system will be able to clearly show the driving path.
Because I'm unfamiliar with the gear location, I sometimes have to glance down.	I'm hoping to acquire the gear details without lowering my head.
The GPS suggests a left turn 200m ahead, but I often miss the right intersection since I don't have a good sense of distance.	I'm hoping the navigation can provide more explicit turning directions.

TABLE 4.9: Scenario description sample (skilled driver)

Scenario Description	Problems and Requirements
When driving on the highway, as the speed of the vehicle increases, the dynamic vision decreases, the line of sight also becomes narrower, easily causing driving fatigue.	I hope that the system can provide an anti-fatigue reminder system to reduce fewer traffic accidents
Because of bad lighting and insufficient illumination while driving at night, I have to pay attention and observe all the time, which causes my eyes to tire. When the vehicle faces strong light stimulation from competing lights, it might generate glare.	I hope that the system will be able to detect the driving condition and trajectory of cars and people in front of us at night in order to prevent light interference.
When driving at night or in an unfamiliar residential area, often miss the intersection that needs to be turned	I'm hoping for a more efficient way of navigating direction information.
When I drive a long distance, I want to stop by the convenience shop on the way, but I often miss it because I am not paying attention.	I'm hoping that the navigation will intelligently recall some location information.

In addition, due to their inexperience, beginners cannot execute many tasks concurrently while driving. It is possible to reduce the burden of driving while keeping their attention focused on the driving vision area.

Moreover, extract the mental model from the users sentence description and driving background, as shown in Figure 4.6. For instance, an intervie- wee said, "When I was turning at an intersection, there are many intertwined points, which require constant observation. Surrounded by complicated traf- fic conditions, sometimes I dont know where to turn. I hope the system can give more specific turning information instructions". The mental information such as slow the surrounding traffic analysis, priority decision information, more efficient visual direction instruction, and fewer attention re-sources can be extracted from this sentence.

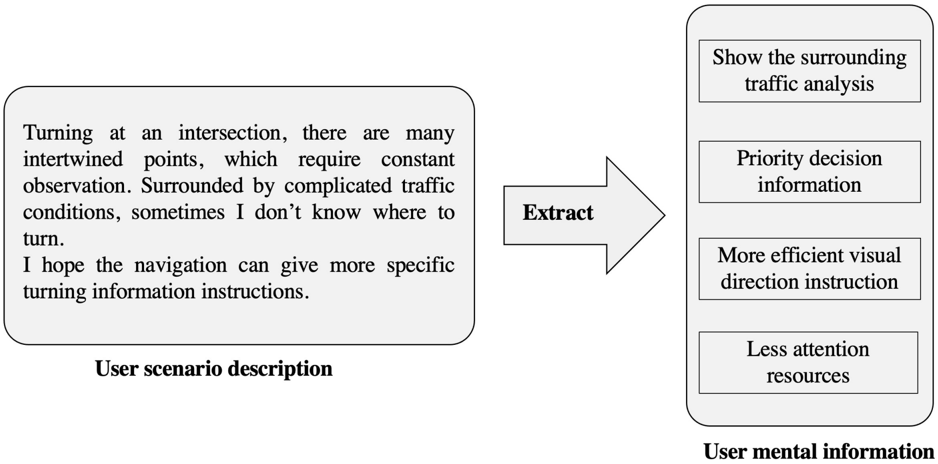


FIGURE 4.6: Schematic diagram of mental information extraction

4.5.5 AR-HUD interface information requirements for three modes

In the concept of customized AR-HUD interface design introduced above, the AR-HUD information database is divided into three modes: Skilled mode, normal mode, and beginner mode. Using survey 1 to analyze the average value of information selection when there is no distinction between user groups is based on the information classification. Eliminating the options whose can- didate ratio is less than 30% can determine the amount of information in the Normal mode as 27, as shown in Table 4.10.

In analyzing and extracting mental information, the information with similar meanings is summarized into a representative vocabulary, which is matched to the function of solving this requirement. Based on the results of the two surveys and interviews, the information needs of the user group were extracted and summarized. 36 items of the beginner mode information database and 30 items of the skilled mode information database were obtained, as shown in Table 4.10.

The information requirements for the three modes of the AR-HUD interface are determined mainly include the following aspects:

1 Navigation information: Provide the driver with navigation information consistent with the road environment to avoid driving caused by the driver looking down at the navigation Distraction.

2 Vehicle status information: Provide drivers with information about the driving status of the car. This type of information varies considerably based on the driving experience.

3 Driving assistance information: Warning potential hazards and assistance for unfamiliar driving operations. The driver has sufficient reaction time to avoid danger and regulate driving behavior.

4 Entertainment information: To guarantee that the driver's eye focuses attention in the front driving field of view while doing secondary driving tasks such as taking calls, sending messages, and listening to music.

According to the survey "research on driving navigation information" Q13: What information does the AR-HUD interface provide in real-time can help you drive? Excluding the options whose proportion is less than 30%, we obtained the information content of the normal mode in Table 3. For the information content of the beginner mode, key information is extracted from the information demand dialogue in the telephone interview. Also, increase the corresponding auxiliary information based on the subjective assessment for beginner drivers (see section 4.5.3). The beginner who lacks driving experience are easily affected by unfamiliar environments and cause driving mistakes, so "pedestrian's information," "obstacles around the vehicle," "other vehicles," "turn path visualization," and "overtaking assist" has been added to the driving assistance information. Moreover, vehicle status information is reduced in the skilled mode information database. Moreover, by information extraction of conversations based on phone interviews, supplementary information is added to remind car services such as nearby gas stations, and entertainment information contains "SMS reminder," "music information," "nearby restaurants information," and "building introduction".

TABLE 4.10: Summary of the information content of the three modes of the AR-HUD interface

Normal mode (n = 27)	
Navigation information	start notification, turn instructions, u-turn instructions, the current lane of the car, lane change instructions, driving route, distance from destination, change route reminder, keep straight, destination, distance reminder (turn right after 300m), park instructions, arrival notification, time to destination
Vehicle status information	speed, remaining battery, air conditioning operating status, light status, whether the system is abnormal
Driving assistance information	direction visualization, departure warning, safe distance reminder, speed reminder, parking assist, speed limit information, road restrictions, traffic condition ahead
Beginner mode (n = 36)	
Navigation information	start notification, turn instructions, u-turn instructions, the current lane of the car, lane change instructions, driving route, distance from destination, change route reminder, keep straight, destination, distance reminder (turn right after 300m), park instructions, arrival notification, time to destination
Vehicle status information	speed, remaining battery, air conditioning operating status, light status, whether the system is abnormal, **milage, gear position, door switch status, seat belt status**
Driving assistance information	direction visualization, departure warning, safe distance reminder, speed reminder, parking assist, speed limit information, road restrictions, traffic condition ahead, **pedestrian's information, obstacles around the vehicle, other vehicles, turn path visualization, overtaking assist**
Skilled mode (n = 30)	
Navigation information	start notification, turn instructions, u-turn instructions, the current lane of the car, lane change instructions, driving route, distance from destination, change route reminder, keep straight, destination, distance reminder (turn right after 300m), park instructions, arrival notification, time to destination
Vehicle status information	Speed, light status, door switch status, air condition status
Driving assistance information	direction visualization, departure warning, safe distance reminder, speed reminder, traffic condition ahead, speed limit information, road restrictions, **vehicle service (gas station nearby)**
Entertainment information	**SMS reminder, music information, nearby restaurants information, building introduction**

4.6 Summary

The design of the AR-HUD interface should meet the principles of human-computer interaction design on the one hand and the requirements of improving the driver's driving distraction and cognitive load during driving on the other hand. At the same time, the driving experience has a significant impact on the efficiency of extracting information during driving. We believe that it is essential to design a composite information base based on different driving experiences for driving safety, in contrast to the single information base of existing AR-HUD systems. The current study collected AR-HUD information in three modes using qualitative and quantitative survey methods based on the user's mental model approach. The survey "Research on car driving navigation information" was made to determine navigation type preference, necessary navigation information, environment needs, and the impact of driving experience on information needs. Most respondents wanted to use AR-HUD for navigation systems, and there was no significant difference between beginners and skilled drivers. For necessary navigation information, determine 28 functions and information needs for normal mode. In most driving environments, directional information and speed information are paramount. However, driving in a highway environment, where the road is one-way and the traffic speed is breakneck, speed information is more important than other information. For the different driving groups, the result shows that as the driving experience increases, functional information to assist driving will decrease.

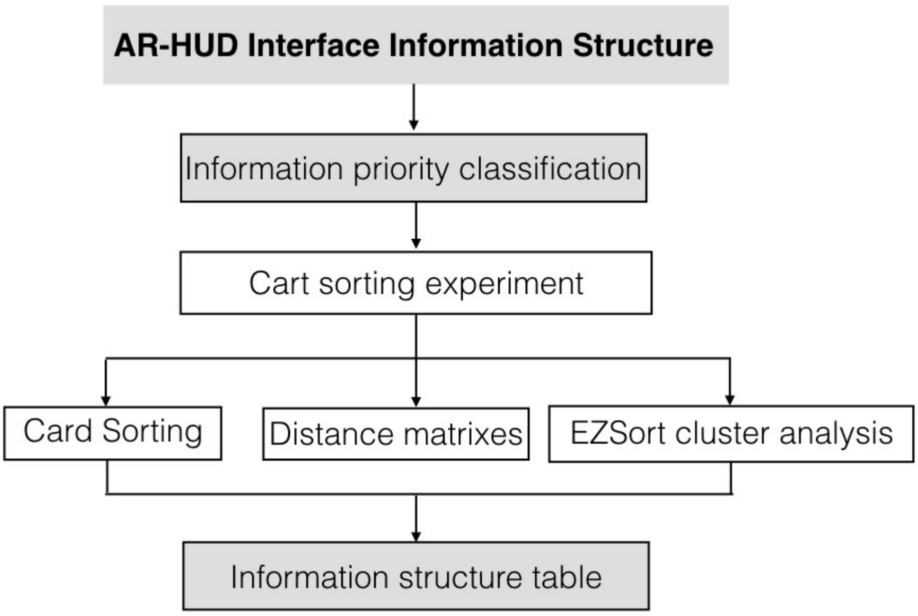
The survey "Research on the beginner driving behaviors" was designed to analyze beginner driving behavior and driving mistakes to gather information requirements to build a beginner information database. 70% of the respondents exceed the speed limit, and 62% have made sudden acceleration and brake, which means speed reminder, speed limit information, and pedestrian information should be put into the driving assistant information database. Driving at night is the worst environment in various scenarios, which shows that design night visualization is essential for navigation. Furthermore, the beginner driver often has the driving state "It is difficult to control the specified speed," far exceeding other options. Therefore, speed reminders are essen- tial in the beginner information database and design phase to display speed information in real-time on the interface and avoid distracting the driver. In addition, the respondents have a great demand for driving assistance and orientation visualization information.

Limitations There are several limitations in this section. First of all, we did not design a separate survey for the skilled group for behavior analysis. The driving situation of the skilled drivers is only derived from the analysis of the interview. This could lead to some bias in the results. Second, the study canceled the user observation part before the interview according to Japan's anti-epidemic control regulations. We initially planned to observe the user's behavior patterns when using the existing HUD system or navigation system on the interviewee's vehicle and interview the user's real-time psychological activities and information needs. Therefore, the user can only recall the driving scene in the interview to describe the problems and information needs during driving. To a certain extent, it affects the emotional needs of the interviewer. Third, because the AR technology as such is not available in vehicle' HUD yet, it is difficult to find participants without expert knowledge, but experience in AR-HUD [23].

As results, this research completed the behavioral part of the mental model, constructed the user mental model, and summarized the information database of the three modes. However, how the information is displayed on the interface and how much information should be presented to the driver in a certain driving task still need to be explored.

Chapter 5

AR-HUD Interface Information Structure



The study in this chapter focuses on classifying these information needs into information priorities based on different driving scenarios. This chapter designs the information structure in two steps: first ***classifying the road environment and the common driving scenarios***, and then ***building the information priority*** of the interface based on the common situations.

5.1 AR-HUD interface information structure

5.1.1 Information structure of AR-HUD interface

Information structure is the fundamental part of the visual and display design of the automobile HMI interface. Firstly, HMI in automobiles needs to face various dangerous driving situations [31]. As a result, there is a large amount of interface information required. Secondly, the information provided by the system must ensure that it does not interfere with the standard driving task of the driver and cause additional driving distractions [32].

Hicks Law is commonly used to determine how the information is organized in the user interface in the HMI design. The Hick-Hyman law describes a linear increase in reaction time (RT) as a function of the information entropy of response selection, which is computed as the binary logarithm of several response alternatives[33]. Hicks law formula defines this principle as Figure 2 shown: RT = a + b log2 (n).

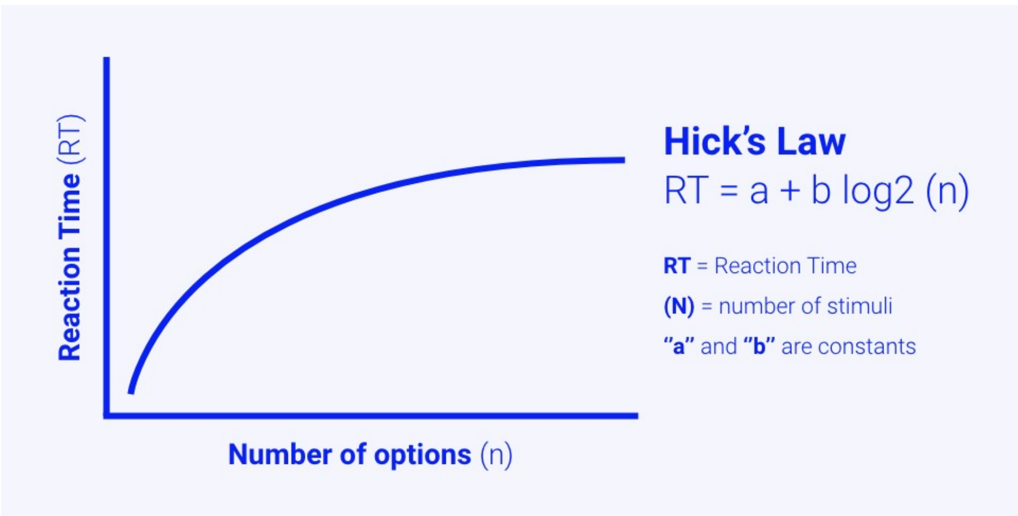


FIGURE 5.1: Hick's Law Graph.
"RT" is the reaction time. "(n)" is the number of stimuli (choices).
"a" and "b" are constants, depending on the task and condition.

As a result, when designing the AR-HUD human-computer interaction interface, the layout of the interface and amount of information should be reasonable. Generally, the visual information of the automobile HMI interface can be divided into two parts: context information and status information.

(1) Context information

When providing information, it is necessary to ensure that the driver's vision does not deviate when browsing various types of information. When relying on head-up display technology and enhanced display technology, the information related to the current driving situation and the various information that the driver is operating can be directly projected into the front driving field of vision. Provide driving assistance and reminders. Precisely, all kinds of the necessary information in the driving process closely related to the main driving task, such as safety warnings, navigation, etc., can be placed in the driver's primary field of vision in the front windshield. Those not directly re- lated or even unrelated information, such as adjusting the volume, is generally arranged in the driver's secondary driving field of vision to give the driver a certain visual stimulation without causing the driver to be distracted while driving.

(2) Status information

Status information generally refers to various driving data output by the vehicle during driving, various information outside the vehicle, and various driving entertainment information. They are usually large in number and involve multiple aspects. This type of information is generally displayed in a fixed area to avoid interference with the driver's driving vision. First, arrange the information that has a more significant impact on driving, such as vehicle speed and rotation speed in the main area. Second, users can customize the display of various information according to their own needs. By presenting the information that users most need to pay attention to the driver's information acquisition efficiency can be improved. The integration of the environment and the interface will not be destroyed as much as possible, which is more suitable for the interface AR-HUD interface design.

5.2 Priority classification of AR-HUD interface information

According to the user mental model derived in Chapter 4, we find out that users' expectations and needs for the AR-HUD interface are as follows.
(1) Real-time information on the various status of the car.
(2) Real-time understanding of navigation information to make driving decisions.
(3) To be reminded of potential hazards in the driving environment in time.

However, there is a limit to the amount of information displayed on a single interface. If too much information is displayed at once, it can cause confusion and distraction to the driver's decision-making. At the same time, it can easily lead to driving errors and even traffic accidents.

Considering these requirements, the information structure of the AR-HUD needs to do the following.
(1) prioritize the information that affects the driver's driving decisions by placing it at the highest level.
(2) Improve cognitive efficiency and reduce the cognitive burden on the user. Information needs to be summarized and streamlined. Prevent the user from being overloaded with too much information at once.

The real-time driving information must be prioritized to ensure that the user spends as little time as possible keeping track of driving conditions and navigation information while driving. To ensure that key information is highlighted in the interface to improve the user's cognitive efficiency. In this section, the information is layered into three levels, as shown in the figure 5.2. The top layer priority group indicates that the information significantly impacts users' driving behavior, needs to be understood in time and gives feedback. The second layer secondary group indicates that the information impacts user behavior. The user needs to know it in time, but it does not require them to give feedback. The bottom layer basic group indicates that the information has little impact on users' driving behavior, and users can ignore this information.

Based on this model, we used card sorting experiments to classify the information requirements database obtained in chapter 4 into three groups according to different driving scenarios.

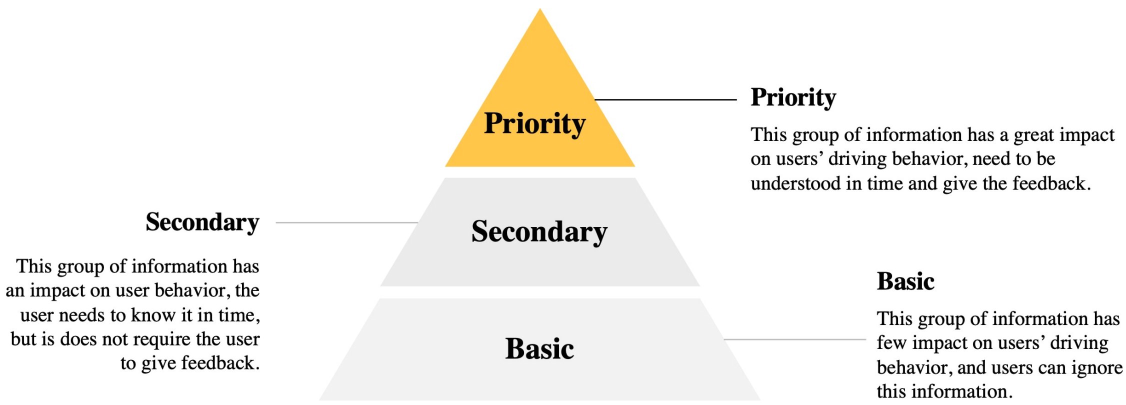


FIGURE 5.2: Priority classification model

5.3 Card sorting experiments

Card sorting is an established method for understanding users' mental models of information structure. It is used frequently in software development, evaluation and human-computer interaction design, to understand the clustering of information and relationships between information from the users' perspective [34].

In this study, the card sorting method can be used to grasp the changes in user requirements for the interface in different driving scenarios, which allows the information architecture of the AR-HUD interface to be constructed on this basis. The processing of the results of the card sorting method usually uses cluster analysis to define different values [24] for the information classification results in each driving scenario, thereby structuring and integrating this information based on the values of the ratings.

5.3.1 Road environment condition

Card sorting is an established method for understanding users' mental models of information structure. It is used frequently in software development, evaluation and human-computer interaction design, to understand the clustering of information and relationships between information from the users' perspective [35].

Driving in different road environments such as highways and urban roads, the driver's information requirements are also affected by the surrounding environment, which affects the related driving operations. As a result, card analysis experiments for information stratification need to be conducted based on different road environment conditions. There were four different road environment conditions used in the experiment: urban road, Highway, residential and countryside road.

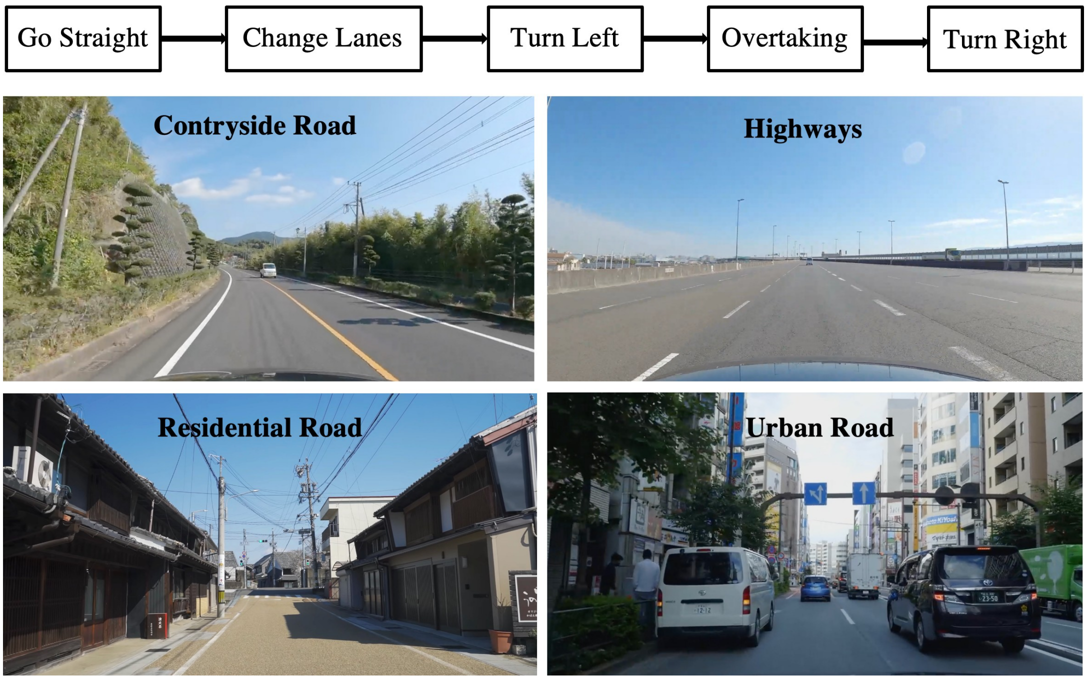


FIGURE 5.3: Four driving environments and navigation commands

Urban road that are Urban will generally be characterized by low to moderate posted speeds, frequent entrances, and moderate to heavy residential or commercial development. Curbed sections with closed drainage will generally be prevalent, although open drainage sections may be interspersed. Intersections, sidewalks, and on-street parking are often characteristic of Urban roadways.

Highway that are two or more lanes in each intersection. They have double solid lines to separate high-speed traffic. It was driving on the Highway with long distances between cars, high speeds, straightforward information about road conditions and single driving operations.

Residential road in residential areas with narrow roads, difficult to see turn-offs, and pedestrian bicyclists and cars on the same lane.

Countryside road that are few traffic values and often lack pavements should be mindful of pedestrians, cyclists and riders passing either side of the car while driving on the road.

Depending on the characteristics of each road environment, different traffic conditions and driving situations can also occur. This experiment sets the same navigation commands to compare the variability of information priority in each environment.

5.3.2 Participants

Participants conducting card sorting experiments need to meet the criteria of the target users of the design. According to the definitions of beginners and skilled drivers, 60 participants were recruited for the experiments, with 30 in each group.

5.3.3 Design cards

When designing the cards, the appropriate number of cards will ensure the accuracy of the experiment. When the number of cards is less than 30, the experimental results cannot fully reflect the correlation between the information of each card. When the number of information is greater than 100, it is easy to cause stress to the subjects and affect the accuracy of the experimental results [36]. In this experiment, the 36 items from the beginner mode and the 30 information from the skilled driver mode derived in Chapter 4 were used as the card base for classification.

5.3.4 Experimental procedure

This experiment is in the form of a closed classification. We defined the number of groups and names of the card categories in advance and laid out the experimental interface according to the four driving environments. As shown in the figure 5.4, according to the situation of the navigation instructions, the

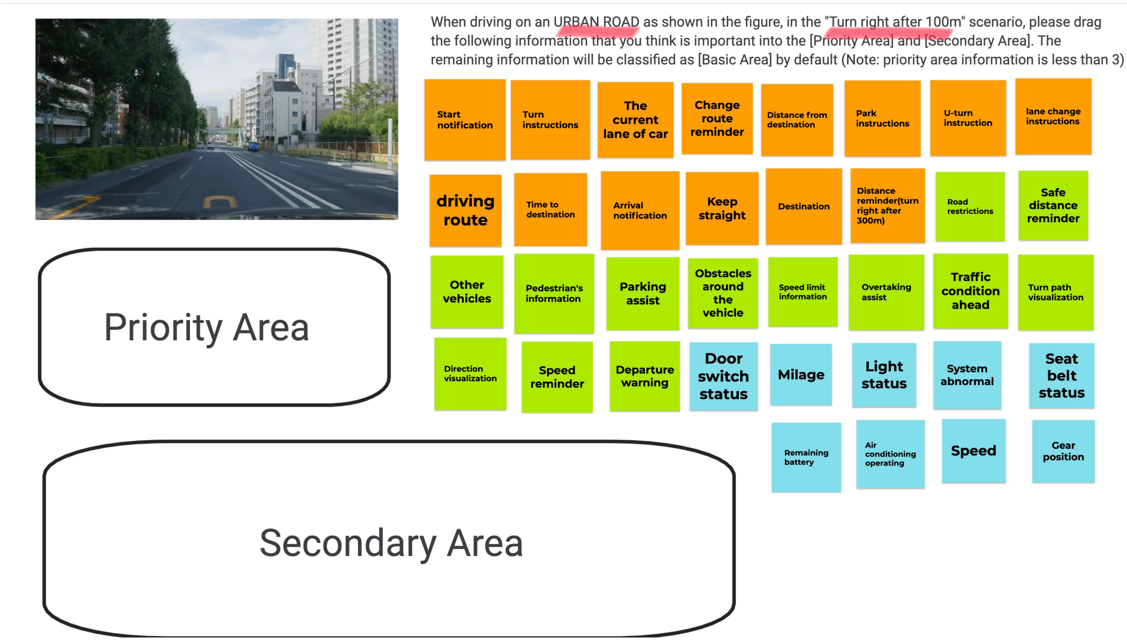


FIGURE 5.4: Jamboard interface for card sorting experiments[1]

participants were asked to divide the cards into two groups: priority group and secondary group (see figure 5.2) using Google jam-board. Also mentioned that the remaining information would be classified as a basic group, and only three or fewer cards can be selected to be placed in the priority area. The participants' own judgment determines the number of cards in each area. In the end, explain the reason for grouping. We interacted with the participants in real-time and recorded the whole experiment on screen.

5.3.5 Cluster Analysis

The experimental data of each group were evaluated using the cluster analysis. The analysis procedure is shown in Figure 5.5.

The first step is to create a matrix with the same number of rows and columns as the number of cards to perform cluster analysis. For example, for

[1]Google Jamboard is a digital whiteboard that allows for remote or in-person collaboration on a shared space.

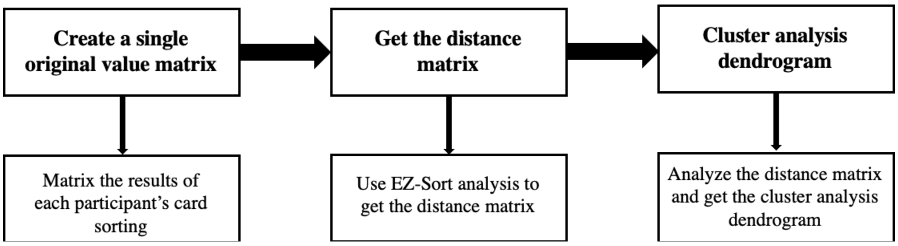


FIGURE 5.5: Flow chart of cluster analysis method[1]

the beginner group, the matrix chart of 36 x 36 and the 36 cards are set as horizontal and vertical coordinates. Used the matrix chart to record the results of the above classification of the participant's selected cards, assign a value of 1 to the position of the matrix icon with coordinates (m, n) if card M and card N are placed in the same group. While card M and card N are not in the same group, they are assigned a value of 0 at the location of the matrix icon coordinate (m, n). A single-trial original value matrix is constructed for each participant using this method.

The single-participant original value matrix for each test subject was loaded into the card classification cluster analysis software EZSort after the first phase was completed, and cluster analysis was used to create the distance matrix. EZSort software is used to analyze the resulting distance matrix [37]. EZSort is a software tool that makes both the card sorting exercise and the interpretation of the resulting trees simpler. The EZCalc package could be used to manage card sort data generated by USort as well as conduct cluster analysis. EZCale provides tree diagrams that allow users to adjust the cluster thresholds automatically.

Finally, analyze the distance matrix to get the cluster analysis deprogram for each group in various environments and driving conditions.

[1]Helen L. Petrie, A Web Based Tool for HCI-Orientated Massive Asynchronous Linear Card Sorting.

5.4 Results

5.4.1 Participants

In the beginner group, 30 participants (18 male and 12 female) aged between 20 and 29 years old (mean = 23.5 years, standard deviation = 4.41) took part in this experiment. Participants are all undergraduate and graduate students from different departments of the University of Tsukuba. In the skilled driver group, 30 participants (16 male and 14 female) aged between 27 and 42 years old (mean = 33.9 years, standard deviation = 4.5) took part in this experiment. All of the 60 participants have a Japanese driving license. Characteristics of the participants are summarized in table 5.1.

TABLE 5.1: Characteristics of participants in two groups

	Beginner group	Skilled driver group
N	30	30
Age	23.5 (4.41)	33.9 (4.5)
Gender(%male)	60%	53.3%
Years of driving	1.08	11.3
Driving frequency		
do not use it much	10%	0%
monthly	20%	0%
1-2 times a week	13.4%	6.7%
3-4 times a week	10%	10%
daily	46.6%	83.3%

5.4.2 Beginner Group

The cluster analysis tree diagram illustrating the cluster analysis between each card contents in terms of information priority grouping is obtained in this experiment, as shown in Figure 5.6. The top orange section contains the essential information, the middle blue section has the basic information, and the bottom light yellow section contains the second group. When drivers make a left turn choice in an urban road setting, the most important information they want is speed, distance, and turn direction indication.

Based on the cluster analysis findings, it is possible to describe the grouping structure and hierarchical linkages between the data included in the AR-HUD interface. The information classification structure for the beginning group is shown in 5.8 and figure 5.9.

5.4.3 Skilled driver Group

We also construct the skilled driver's AR-HUD information architecture using the 30 information needs collected in Chapter 4 based on the cluster analysis findings and our evaluation of the card information of the 30 participants. It depicts the grouping structure and hierarchical relationship between the information needs in each environment, as shown in the figure 5.6.

5.5 Summary

This chapter used card sorting experiments and cluster analysis to classify information into three groups based on the amount of information required for each user group while driving. The target user group's mental model of the AR-HUD interface information structure is collected and analyzed. In addition, the information structure was constructed using four common road types in Japan as the environmental background. The information structure and priority categorization of the resultant AR-HUD interface offers a significant foundation for later design development. It is helpful for the following chapter's interface layout design and visual elements design sections.

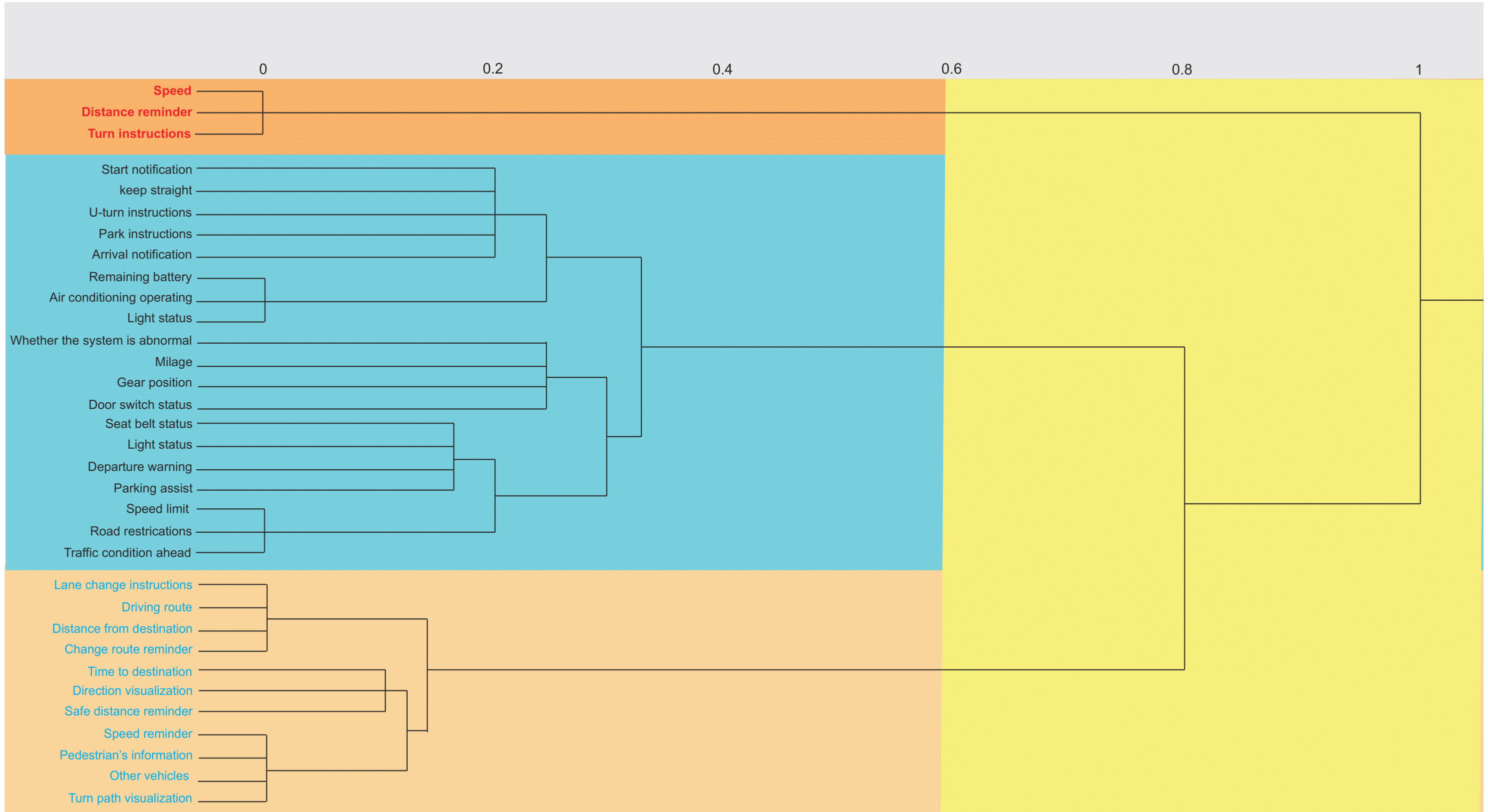


FIGURE 5.6: Information prioritization card sort EZSort cluster analysis tree diagram (turn left in Urban Road)

Environments	***Driving conditions***	***Information structure***	
		Priority group	Secondary group
Urban	Go straight	Speed, time to destination, distance reminder	Speed limit, nearby convenience store, traffic condition ahead
	Change lanes	Lane change instructions, speed, other vehicles	Speed, speed limit, change route reminder
	Turn left	Turn instructions, speed, distance reminder	Pedestrian's information, other vehicles, turn path visualization
	Overtaking	Speed	Safe distance reminder, speed reminder
	Turn right	Turn instructions, speed	Distance reminder, direction visualization
	On-street parking	Obstacle reminder, speed, other vehicles	Traffic condition ahead, driving route
	Pedestrian bicyclists nearby	Warning, safe distance reminder	Speed, lane change instruction, speed reminder
Countryside	Go straight	Speed, traffic condition ahead, distance reminder,	Vehicle service, nearby convenience store
	Change lanes	Lane change instructions, speed	Speed limit, other vehicles, distance reminder
	Turn left	Turn instructions, speed, distance reminder,	Distance reminder, pedestrian's information
	Overtaking	Speed	Distance reminder, speed reminder
	Turn right	Direction visualization, speed	Turn instructions, distance reminder
	Pedestrian bicyclists nearby	Warning	Speed, safe distance reminder
Highway	Go straight	Speed, distance reminder	Speed limit, vehicle service
	Change lanes	Speed, lane change instructions	Speed limit, change route reminder
	Overtaking	Speed, other vehicle	driving route, speed reminder
	Convergence	Other vehicle, speed	Speed limit, other vehicles, safe distance reminder
	ETC	Driving route, speed, speed limit	lane change instructions
Residential	Go straight	Speed, distance reminder, warning	Other vehicle, speed limit,
	Turn left	Turn instruction, direction visualization	Speed, distance reminder,
	Turn right	Turn instruction, direction visualization	Speed, distance reminder, other vehicle
	Pedestrian bicyclists nearby	Warning, safe distance reminder	Speed, lane change instruction
	On-street parking	Warning, other vehicles	Speed, lane change instruction, safe distance reminder

FIGURE 5.7: The AR-HUD interface information architecture for the skilled driver group based on four environments conditions

Environments	*Driving conditions*	*Information structure*	
		Priority group	Secondary group
Urban	Go straight	Speed, departure warning, distance reminder	Speed limit, pedestrian's information, other vehicles, driving route, safe distance reminder, traffic condition ahead
	Change lanes	Lane change instructions, speed, other vehicles	Speed, speed limit, change route reminder, safe distance reminder, distance reminder, driving route, turn path visualization
	Turn left	Turn instructions, speed, distance reminder	Lane change instructions, driving route, distance from destination, change route reminder, time to destination, direction visualization, safe distance reminder, speed reminder, pedestrian's information, other vehicles, turn path visualization
	Overtaking	Other vehicles, speed, lane change instructions	Distance reminder, driving route, change lane reminder, safe distance reminder, speed reminder
	Turn right	Change route reminder, turn instructions, speed	Distance reminder, lane change instructions, driving route, other vehicle, pedestrian's information, direction visualization
	On-street parking	Obstacle reminder, driving route, other vehicles	Speed, lane change instruction, driving route
	Pedestrian bicyclists nearby	Warning, safe distance reminder, other vehicles	Speed, lane change instruction, driving route, speed reminder
Countryside	Go straight	Speed, departure warning, traffic condition ahead	Speed limit, other vehicles, driving route, safe distance reminder, distance reminder
	Change lanes	Lane change instructions, speed, change route reminder	Speed, speed limit, other vehicles, safe distance reminder, distance reminder, driving route, turn path visualization
	Turn left	Turn instructions, speed, pedestrian's information	Distance reminder, lane change instructions, driving route, distance from destination, change route reminder, time to destination, direction visualization, safe distance reminder, speed reminder,

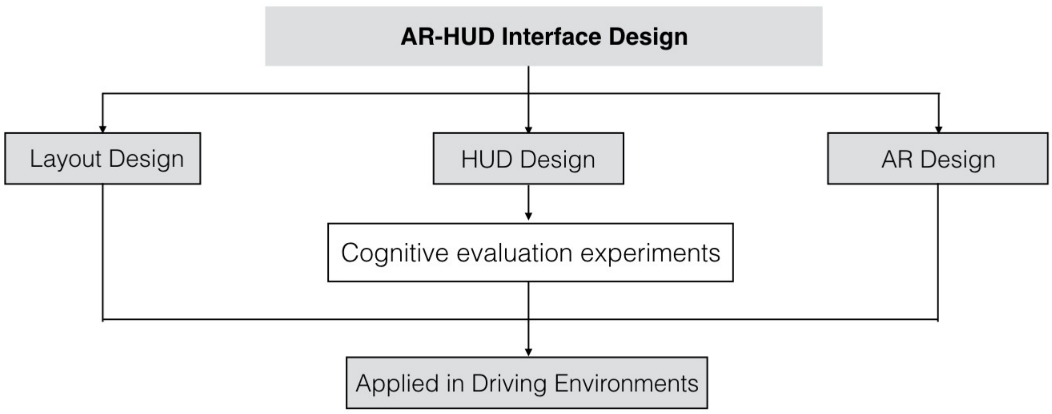
FIGURE 5.8: The AR-HUD interface information architecture for the beginner group based on four environments conditions

			other vehicles, turn path visualization
	Overtaking	Other vehicles, speed, lane change instructions	Distance reminder, driving route, change lane reminder, safe distance reminder, speed reminder
	Turn right	Change route reminder, direction visualization, speed	Turn instructions, distance reminder, lane change instructions, driving route, other vehicle, pedestrian's information, direction visualization
	Pedestrian bicyclists nearby	Warning, safe distance reminder, other vehicles	Speed, lane change instruction, driving route, speed reminder
Highway	Go straight	Speed, departure warning, distance reminder	Speed limit, other vehicles, driving route, safe distance reminder, distance reminder
	Change lanes	Speed, lane change instructions, change route reminder	Speed limit, other vehicles, driving route, safe distance reminder, distance reminder
	Overtaking	Distance reminder, speed, other vehicle	driving route, change lane reminder, safe distance reminder, speed reminder
	Convergence	Other vehicle, driving route, speed	Speed limit, other vehicles, safe distance reminder,
	ETC	driving route, speed, speed limit	lane change instructions, driving route, other vehicle
Residential	Go straight	Speed, distance reminder, warning	Pedestrian's information, other vehicle, speed limit, road restrications
	Turn left	Turn instruction, direction visualization, pedestrian's information	Speed, distance reminder, other vehicle, road restrications
	Turn right	Turn instruction, direction visualization, pedestrian's information	Speed, distance reminder, other vehicle, road restrications
	Pedestrian bicyclists nearby	Warning, safe distance reminder, other vehicles	Speed, lane change instruction, driving route, speed reminder
	On-street parking	Warning, safe distance reminder, other vehicles	Speed, lane change instruction, safe distance reminder

FIGURE 5.9: The AR-HUD interface information architecture for the beginner group based on four environments conditions)

Chapter 6

AR-HUD Interface Design



This chapter presents ***the process of designing visual elements and layout.*** The design elements are also ***verified and evaluated through cognitive assessment experiments.***

6.1 Introduction

Starting from the design background, design objectives and design directions presented in Chapter 2, using the information requirements of the target users' mental models presented in Chapter 3 as the database, and based on the information architecture and information priority classification framework of the AR-HUD interface constructed in Chapter 4, this chapter designed the interface layout and visual elements of the AR-HUD, and made actual effect drawings for different environments and user groups, also evaluates the readability and rationality of the design in the end.

6.2 AR-HUD interface Design Principles

AR-based displays have been hailed as a better means to deliver information to drivers while still maintaining lower levels of mental workload[6]. When comparing general driving performance via HUD to a traditional head-down display (HDD) (i.e. a visual display mounted in the center of a vehicles dash), clear advantages emerge. Combined with HUD, it can project computer-generated virtual objects directly onto the front windshield to provide an imaginary-reality combination of augmented reality scenes.

The design of the interface should meet the principles of human-computer interaction design on the one hand, while meeting the requirements of improving driver distraction and cognitive load in the driving process on the other hand. For the AR-HUD interface design requirements and principles, we summarize the following points as design objectives for the design activi- ties in this section:

(1) To strictly control the content and quantity of information displayed at the same time, according to the priority structure of information in Chapter 5, the

information directly related to safe driving is displayed in priority, minimizing the amount of information projected onto the front windshield.
(2) The visual symbols of the interface need to be simple and easy to understand, with appropriate size and proportion, and simple semantics to avoid ambiguity. Make the design of the interface conform to the driver's psychological perception and prevent causing more cognitive load to the driver.
(3) Regarding the impact of changes in the driving environment on visibility (see section 4.5.4), the color and dynamics of the visual symbols of the interface need to be considered to provide an effective warning impact.

6.3 AR-HUD interface layout design

Interface layout design is to group and arrange the information that has been clustered, to make the same group of information in a specific module reasonably distributed in the interface. The modular construction of information means that similar information is laid out in the interface, making the interface's information regular.

According to the user's mental model, it is known that the user's expectation of the interface layout is mainly focused on clarity and convenience for quick browsing. So when designing the interface layout, we should fully consider the cognitive load and avoid giving users too much information at one time, resulting in information overload. Cognitive economic theory shows that a partitioned modular information interface can effectively reduce the occupation of users' attention resources and improve their cognitive efficiency and accuracy of information.

In this study, the display information of the AR-HUD assisted driving system mainly includes two parts: status information and contextual information.

The status information refers to the basic driving information and warning information required by the driver during the driving process, which will not change with the driving process and should be displayed in a fixed area of the interface and should avoid interfering with the driver's vision in front.

As the lower area is more compatible with the visual flow and properties of the human eye-viewing, we have laid out the basic driving information and various warning information which drivers need to know in the fixed position of the right lower area. Moreover, pedestrian warnings, forward vehicle warnings, curve warnings, and other priority information related to the real-time context of driving priority information (based on the information structure of Chapter 5) will change with the driving environment and road conditions. As a result, augmented reality display should be used to appear in the right context to avoid driver splitting energy and vision deflection. The contextual information that affects users' driving decisions is integrated with the driving context of the front windshield to provide driving assistance and warnings to the driver. Depending on the user's attention to different information types and the priority and quantity of information, the AR-HUD interface layout is shown in the figure 6.1.

The human eye visual field study shows that when the eyes are kept looking straight ahead, and neither the eyes nor the head is turned, the binocular visual field is 120rˇ, but the human visual field will be reduced in the motion state. The relationship between vehicle speed and visual field is: when the vehicle speed is 40 km/h, the binocular visual field is 100rˇ; when the vehicle speed is 75 km/h, the binocular visual field decreases to 65rˇ, and when the vehicle speed increases to 100 km/h, the binocular visual field decreases to 40rˇ [38]. Therefore, to ensure that the driver can fully perceive the AR-HUD system, the system is positioned within a 40rˇ field of view centered on the point of gaze.

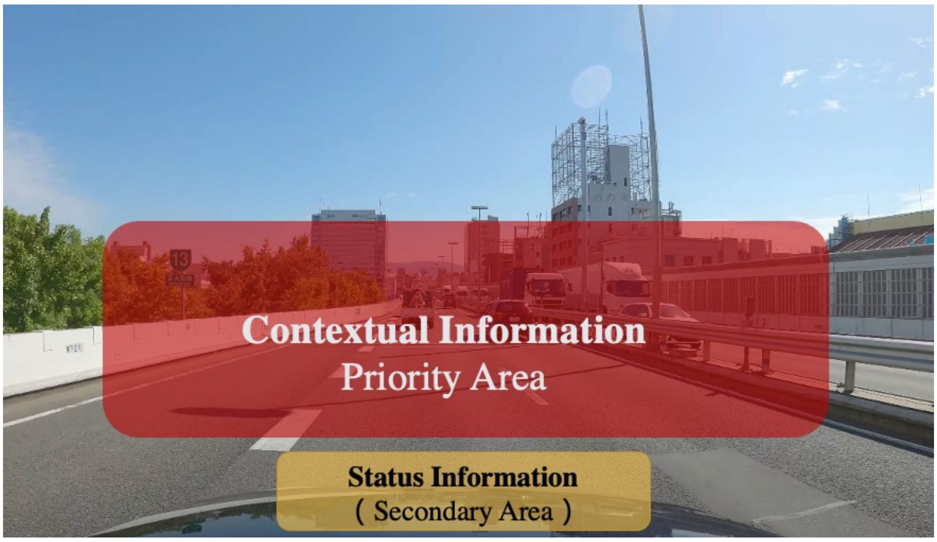


FIGURE 6.1: AR-HUD interface layout design

6.4 AR-HUD interface visual element design and evaluation

6.4.1 Visual Design Principles

Visual communication is the combination of visual organization and perception, and its goal is to represent the content and function of a product in the best form for user experience. In this study, the research aims to minimize user attention resources while communicating timely information related to driving decisions. Since the AR-HUD system's interface information content is closely connected to the driving environment and the user's driving behav- ior. In the design process, we need to consider the size, display mode and the color tendency of the visual elements of the interface comprehensively. AR- HUD interface design should be carried out with attention to the readability and legibility of the elements. Considering the particular characteristics of the panoramic AR-HUD, the conceptual design of this human-machine interface follows these principles:

1 Visual elements are simple, intuitive and easily recognizable

The simple icons and graphics can be helpful to shorten the user's cognitive time and improve cognitive efficiency. Besides, only when the visibility of the interface graphics is sufficiently high can users accurately understand the meaning of the information displayed in the interface by glancing at it. HUD display devices have a high light transmission rate, generally at 60%-80% [39]. Based on this feature, the HUD is not suitable for displaying complex graphics, which will be detrimental to the user's recognition.

2 Reasonable color selection

In addition to graphic patterns, color is one of the main elements of human-machine interface composition. As an important way to convey information, especially in the design of the in-vehicle interface, several colors have traditional meanings. The warning information mostly uses red and yellow with strong visual impact and good visibility as the warning color. For example, red represents a warning, stop, no passing; green represents operation normal; yellow has the role of reminding but less than the degree of warning. Besides, the traffic indication information also mostly uses the color scheme of the white picture on blue background. Because of the features of HUD displays, colors with less variance would become difficult to distinguish in the HUD interface. Using contrasting colors will make the interface more legible and suitable for HUD devices display.

3 Low information load

Some studies have shown that HUD interfaces are easier to cause information overload, especially with too much text, which can easily lead to attention diversion and visual capture consequences [16]. Using icons or a combination of simple words and icons to convey information where possible can reduce the information load of the interface and make it easier to understand. It is also important to avoid conveying too much information to the user at once, especially for beginners. They tend to be nervous about driving and can only focus on one thing. With too much information, beginners cannot decide which one is the most important information to influence their decisions, leading to wrong driving behavior.

6.4.2 Design of HUD visual elements

During the interface's visual design, easy-to-understand graphics and text should be used. The system should be designed to bring the driver's attention to the necessary information while not interfering with the actual driving environment and creating additional driving distractions.

For the visual elements of the AR-HUD interface, it is essential to create a simple, reliable and technological visual sense for the users, besides clear and easy to understand and clear semantics.

In order to achieve the project objectives and conform to the user's mental model, the main reference for the color design is the existing traffic signs that users are very familiar within their lives. The colors and forms were refined and extracted to reduce the cognitive cost for users. At the same time, for the feature of the AR-HUD display device, high color contrast color is selected, as shown in the figure 6.2. We extracted the original colors from the common traffic signs in Japan as a reference for the HUD design. Furthermore, considering the brightness standard of the HUD display, the hue and saturation in the HSB mode (hues, saturation, brightness) of the original colors were adjusted to the highest. Each color conveys a different semantic meaning and level of danger.

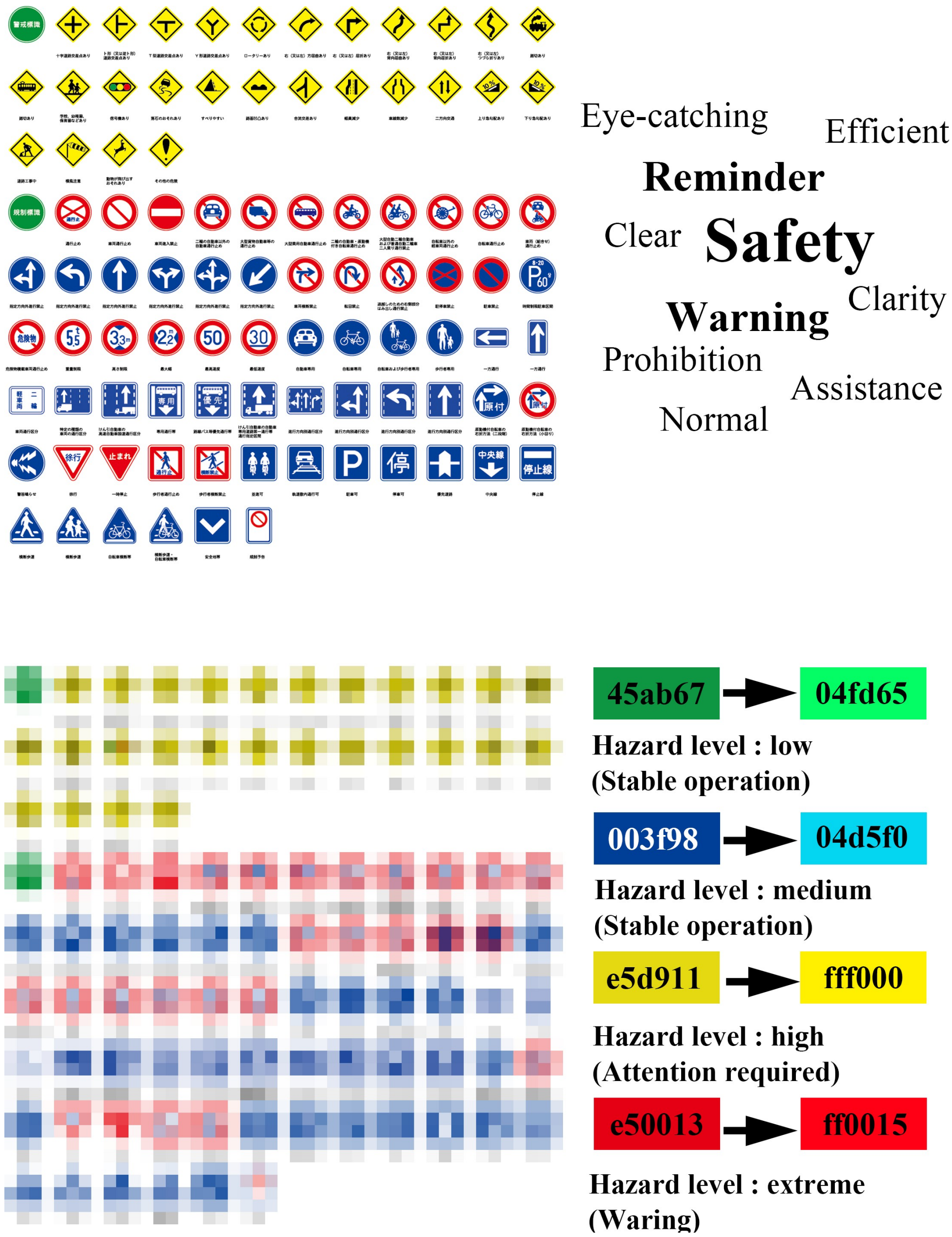


FIGURE 6.2: Color extraction for AR-HUD visual elements design

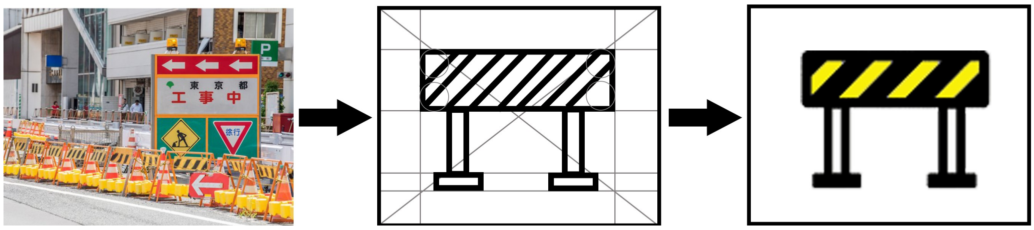


FIGURE 6.3: HUD visual elements refinement process

We also refined the elements based on the traffic signs that users are already familiar with when designing the icons. In terms of details, we use the emotional model of the user's mental model to design a pleasant and straightforward effect with a sense of technology. For example, rounded corners are added to make the graphics more affable. For example, the design of the road repair logo (see figure 6.3) starts by extracting the visual elements from real-life road repair panels and logos, then fine-tuning the features to make it more consistent with the requirements of AR-HUD interface design.

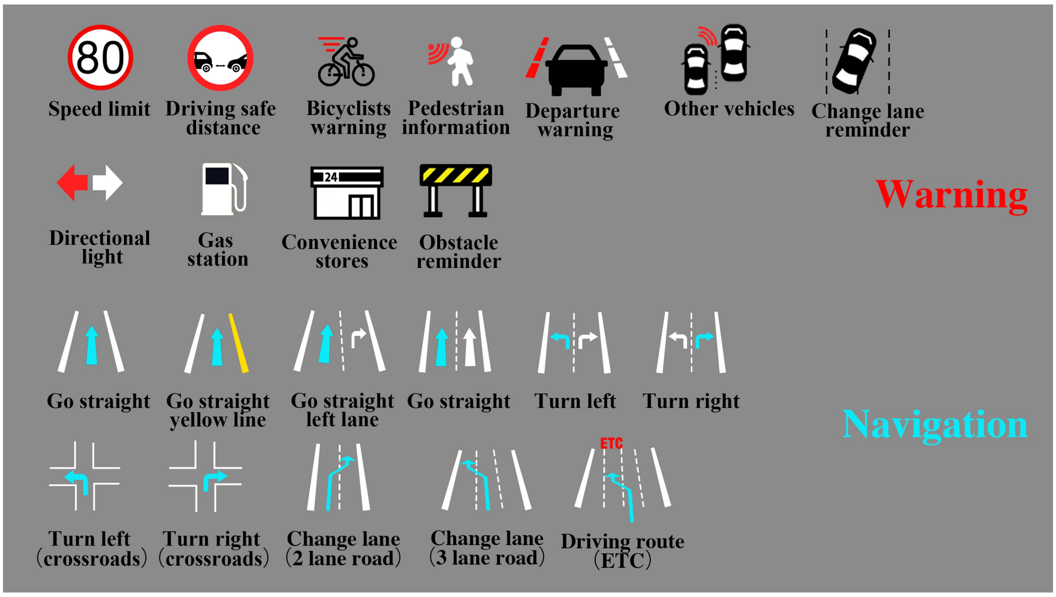
Based on the information structure resulting from Chapter 5, the information that needs to be graphically presented is summarized in the table 6.1.

6.5 HUD information elements cognitive evaluation experiment

6.5.1 Participants

Two groups of 40 participants were recruited based on the beginner and skilled driver groups defined in Chapter 3. Participants in the beginner group (aged 2029, 12 females, 8 males) and the skilled group (aged 2845, 11 females, 9 males) were asked to select a scale to assess the visual elements' consistency

TABLE 6.1: Summary of HUD information icons



with their corresponding semantics. The task was to evaluate two characteristics of the icons: (1) their effectiveness in the conveyance of meaning and (2) visual attractiveness. All participants were screened using the ISHIHARA test [1] and had normal vision.

6.5.2 Stimulus

The stimuli were two icon Categories that we have designed in chapter 6.4: warning and navigation (see table 6.1). The stimuli were displayed on a 27-inch LCD monitor running on Retina iMac. The participants were asked to use the mouse to select their options. Each of the icons was normalized to 450 x 450 pixels and individually presented on a uniform background rendered as middle gray. The order in which the 22 icons (table 6.1) were presented was randomized throughout the experiment.

[1] The Ishihara test is a color perception test for red-green color deficiencies, making numbers out of dots that are a different color than the dots surrounding them.

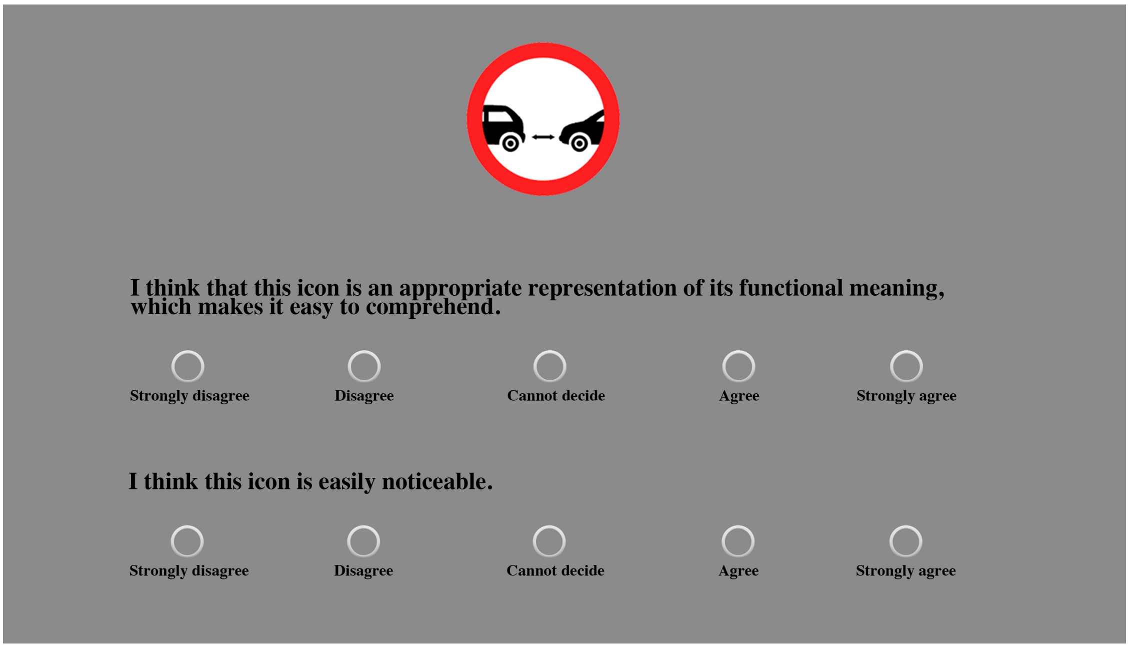


FIGURE 6.4: Interface of the HUD element evaluation test

6.5.3 Procedure

Two groups were given a questionnaire based on a Likert-type scale aimed at quantifying two characteristics related to icon quality: (1) their effectiveness in the conveyance of meaning and (2) visual attractiveness. The participants were asked to select a scale to evaluate the consistency of the visual elements with their corresponding semantics: (1) I think that this icon is an appropriate representation of its functional meaning, which makes it easy to comprehend. (2) I think this icon is easily noticeable (see figure 6.4). Each response was assigned a numerical value (1-5) to measure effectiveness in conveying meaning and visual attractiveness.

The participants performed the evaluation individually in a silent room. The order in which the icons were presented was randomized. No time limit was set for the evaluations.

TABLE 6.2: Descriptive statistics of corresponding semantics of 2 scales

Category	***HUD elements***	***Mean (2)***	***SD (2)***
Warning	Speed limit	4.9743 (4.8205)	0.1601 (0.3887)
	Driving safe distance	4.4613 (4.5897)	0.5050 (0.4983)
	Bicyclist's warning	4.8461 (4.9487)	0.3655 (0.2234)
	Pedestrian information	4.4871 (4.7435)	0.5559 (0.4423)
	Departure warning	4.4615 (4.6666)	0.7555 (0.6212)
	Other vehicles	4.3846 (4.1282)	0.6330 (0.8006)
	Change lane reminder	4.1538 (4.0000)	0.5399 (0.6882)
	Directional light	4.8205 (3.8717)	0.3887 (0.6950)
	Gas station	4.7692 (4.1794)	0.4268 (0.9423)
	Convenience stores	4.8974 (4.0256)	0.3073 (0.9315)
	Obstacle reminder	4.9487 (4.9743)	0.2234 (0.1601)
Navigation	Go straight	4.9487 (4.1794)	0.2234 (0.9698)
	Go straight yellow line	4.8974 (4.8384)	0.3073 (0.7555)
	Go straight left lane	4.8974 (4.5128)	0.3073 (0.6833)
	Go straight two lanes	4.7948 (4.7179)	0.4090 (0.4558)
	Turn left	4.8974 (4.7692)	0.3073 (0.4268)
	Turn right	4.8974 (4.7948)	0.3073 (0.4090)
	Turn left (crossroad)	4.7948 (4.8974)	0.4090 (0.4090)
	Turn right (crossroad)	4.8974 (4.7948)	0.3073 (0.3073)
	Change lane (2 lane road)	4.8974 (4.8974)	0.3073 (0.3073)
	Change lane (3 lane road)	4.8461 (4.6923)	0.3655 (0.4675)
	Driving route (ETC)	4.8717 (4.7179)	0.3386 (0.4558)

6.5.4 Results and discussion

Table 6.1 shows the descriptive statistics of the semantic scales for all the tested icons. On average, all the tested icons were rated around the score of 4 (of 1-5 scale) for all the subjective design features. These results indicated that all the tested icons are easy to comprehend and noticeable.

The mean effectiveness and attractiveness scores were compared with beginner and skilled groups of the same icons using an independent-samples t-test analysis. The results revealed no significant difference in effectiveness between beginner (M = 4.62, SD = 0.30) and skilled driver (M = 4.58, SD = 0.29); p = .07. Besides, there is no significant difference in attractiveness was observed between beginner (M = 4.61, SD = 0.69) and skilled driver (M = 4.62, SD = 0.66); p = .09. According to the experimental results, these 22 visual elements were designed to satisfy the target users' perceptions and could be used for subsequent design tasks regardless of the user group.

6.6 AR-HUD design applied in driving environment

6.6.1 HUD interface modules

The overall design of the interface is based on the predefined user mental model, information architecture, information prioritization, interface layout and visual elements design criteria. The base color of the modules in the HUD section is translucent to ensure that the actual environment is not obscured and that key information is highlighted. In terms of information layout, the priority group and the second group of information are placed on the HUD interface according to the information structure in Chapter 5, priority informa- tion is highlighted in real-time, the auxiliary information is weakly displayed, while the most important is projected into the real road environment in the form of AR. Aiming to reduce the user's driving cognitive burden and the time spent on information extraction.

The layout in the HUD section is composed of four modules in a side-by-side manner (see figure 6.5). According to the information structure of the priority group and the secondary group obtained in chapter 5, it is known that speed, navigation, and speed limit information belong to the priority group in each driving condition. Therefore, the module layout of HUD is from left to right with four information modules: navigation information, real-time speed, warning message, and speed limit.

As shown in the figure 6.5, The most critical current speed information is placed in the center and occupies a large position, making the information visible and easy to glance at while driving. The warning message module is changed in real time according to the driving situation to assist the user to drive safely. The warning message included departure warning, other vehi- cles, obstacle reminder, pedestrian information, bicyclists warning etc.

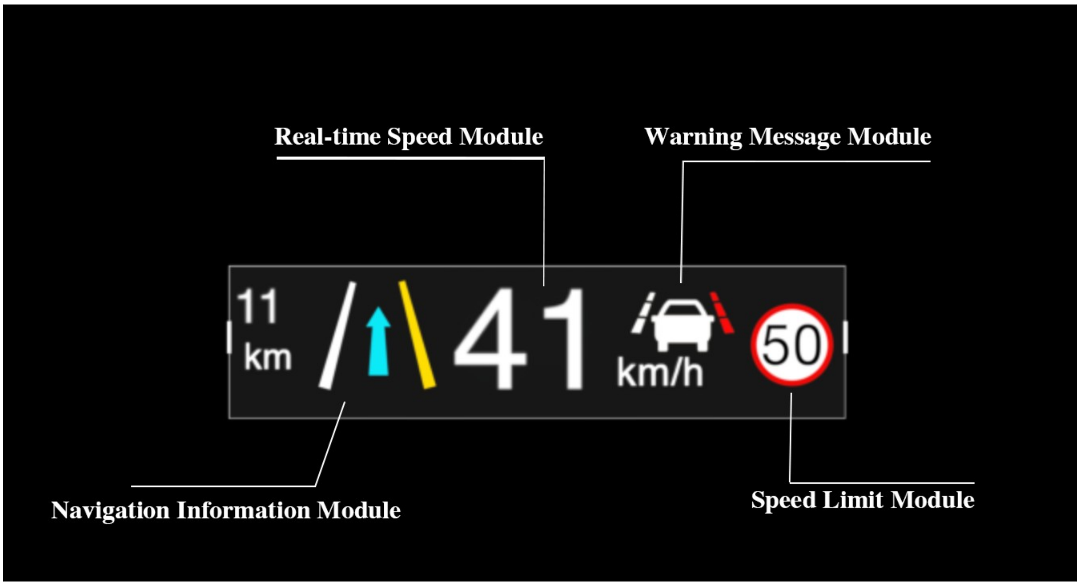


FIGURE 6.5: HUD information display interface layout

FIGURE 6.6: HUD information interface applied in driving environment

6.6.2 AR information elements design

According to the module layout of the HUD in the previous subsection, the effect of the HUD application in the real environment is shown in the figure 6.6. The central area of the AR-HUD interface mainly displays the car driving decision information combined with real road scenes, including indicating the car driving route with arrows, marking the pedestrians and dangerous vehicles on the road to help users drive safely.

Based on the layout design of the overall AR-HUD in Figure 6.1 in Section 6.3, the design of the status information display interface (HUD part) was completed in the previous subsection, and this section starts with the design of the contextual information display interface (AR part).

According to the information structure in Chapter 5, the most important information among the priority information in each driving situation:

- Beginner group: pedestrian warning, bicyclists nearby warning, safe distance, turn instructions, directional visualization, dangerous vehicle warning;
- Skilled driver group: pedestrian warning, bicyclists nearby warning, directional visualization.

(1) Pedestrian nearby recognition information When the driving system detects a pedestrian ahead within the driving hazard range, it projects the specific location of the pedestrian ahead in the actual driving view. At the same time, the navigation indication changes from blue to yellow to improve the driver's hazard foresight and provide sufficient hazard response time for the driver. The status information display (HUD) screen will also show the pedestrian warning icon, as shown in the figure 6.7.

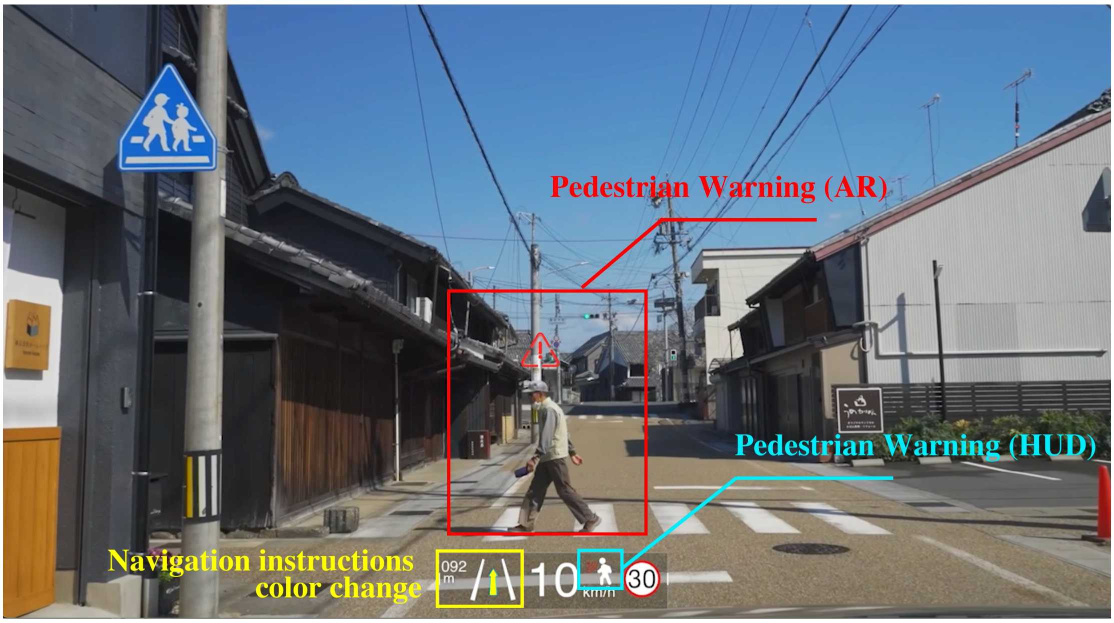


FIGURE 6.7: AR-HUD pedestrian nearby recognition interface

(2) Bicyclists nearby recognition information When the system detects a bicyclist is going to cross the road, or on the driveway, it will project the specific location of the bicyclist in the actual driving view with real-time tracking. At the same time, a bicyclist warning icon appears in the warning information module of the status information display interface (HUD), as shown in the figure 6.8.

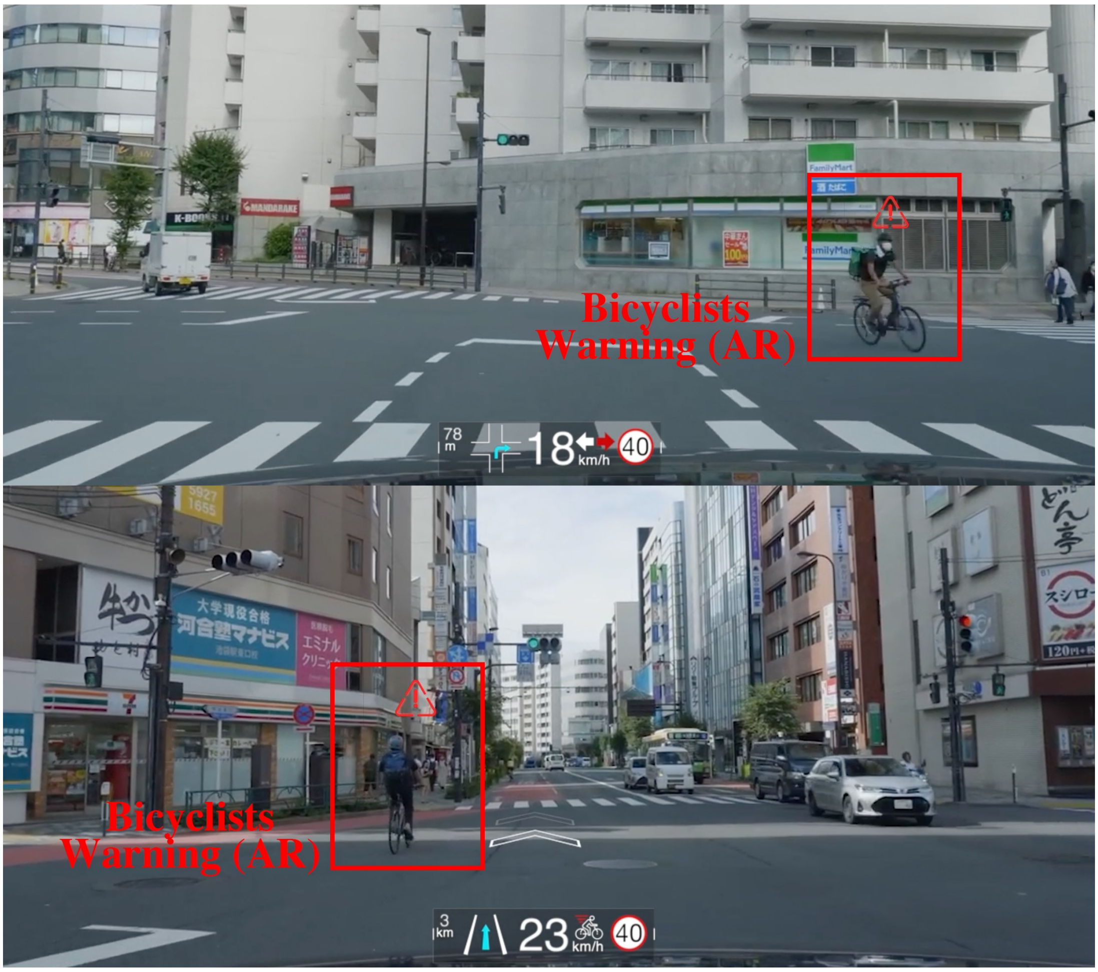


FIGURE 6.8: AR-HUD bicyclist nearby recognition interface

(3) Safe distance information The system detects information such as the distance and speed of the vehicle ahead and determines whether it is in the safe distance. When the vehicle ahead is within a non-safe distance, an AR warning sign requiring the user to slow down will be projected in the actual driving view. The warning will not disappear until it is within a safe distance from the vehicle in front. At the same time, the navigation instructions change from blue to yellow for preventing tailgating accidents. The status information display interface module also shows the driving safety distance icon, as shown in the figure 6.9.

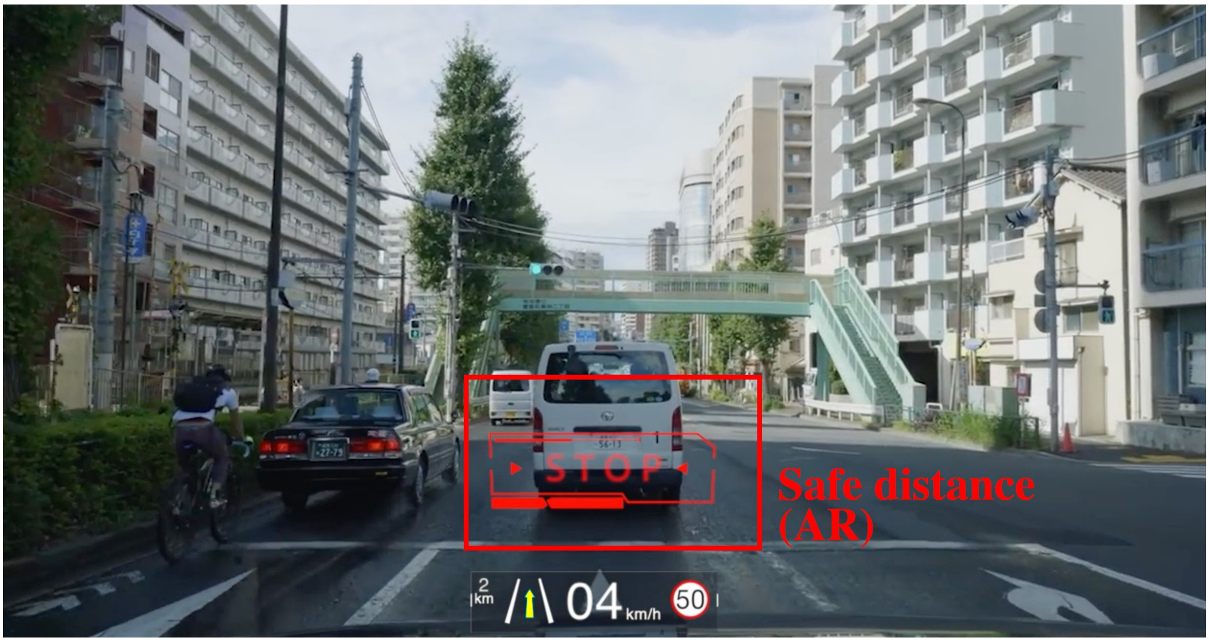


FIGURE 6.9: AR-HUD safe distance information interface

(4) Direction visualization When driving on complex and unconventional intersections or intersections that are difficult to find on narrow roads. In addition to displaying navigation guidance information on the HUD, it also displays visual direction AR in advance to provide users with more accurate navigation information to avoid missed intersections. As shown in the figure 6.10, at such unfamiliar intersections, it is easy to be misguided by the HUD's navigation instructions and turn left early to go the wrong way. The visual direction can guide the driver to read the information quickly and accurately to avoid driving mistakes.

FIGURE 6.10: AR-HUD direction visualization interface

(5) Dangerous vehicle warning When detecting vehicles around that may cause the user to drive in a risky situation, such as a car suddenly appearing from a blind corner, a car parked on the roadside. It will project the specific location and trajectory of the vehicle in the actual driving view and project AR signs that will require the user to slow down according to the driving situation. At the same time, the warning information module in the status display HUD interface will also display a warning icon to pay attention to the vehicle, as shown in figure 6.11.

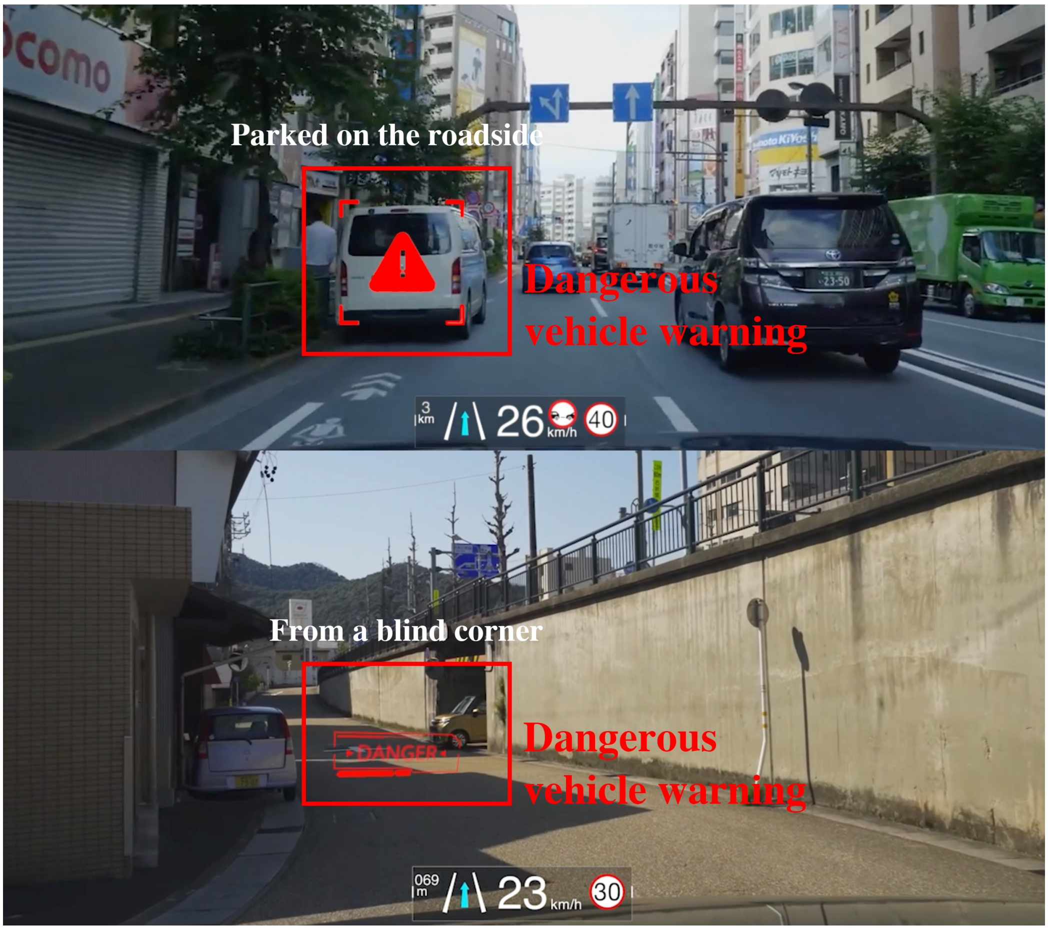


FIGURE 6.11: AR-HUD dangerous vehicle warning interface

6.7 Summary

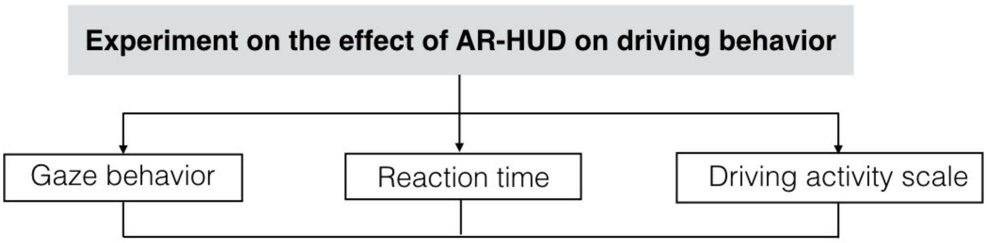
This section designs the interface layout based on the information structure derived in Chapter 5 and the user mental model concluded in Chapter 3. The HUD interface is divided into a navigation information module, a real-time speed module, a hazard alert module, and a speed limit module.

Real-life traffic signs inspire the interface's visual elements to improve the user's comprehension of the semantics and reduce the user's cognitive load. Moreover, an evaluation test of 22 visual elements of the HUD was conducted after planning the color system of the interface based on the information priority derived in Chapter 5. The results show that all 22 visual elements can express the semantics well and satisfy the cognitive requirements of the target users, which can be used in the subsequent interface design.

The AR elements were designed and applied to the real driving environment in the final stage. Due to the dynamic nature of AR and the environment's impact on its semantic expression. As a result, we do not evaluate the AR elements in this section.

Chapter 7

Experiment on the effect of AR-HUD on driving behavior



In this chapter, an experiment on the impact of the AR-HUD system on driving behavior was conducted using eye-tracking. The typical road videos were used as the stimulus materials. The experimental participants' gaze behavior, operation reaction time, change of heartbeat, and the effect of the road environment on the operation were compared in two HUD systems.

7.1 Experimental studies

7.1.1 Experimental purpose

The AR-HUD customized driving system is proposed to convey an effective and non-redundant amount of information for different target user groups to help drivers reduce cognitive load and ensure driving safety and user experience. To verify the system's effectiveness, the objectives of this experiment were obtained.

1 Compare the driver's gaze behavior in different hazardous driving situations under two types of HUD (our AR-HUD and the existing HUD system in the market) and analyze the AR-HUD system's effect on driver attention resource allocation and distraction.

2 Compare the reaction time of drivers in different hazardous driving situations between our AR-HUD and existing HUD systems in the market, and analyze the effect of the AR-HUD system on drivers' awareness and cognitive load in hazardous situations.

3 Compare whether there is a difference between beginner and skilled drivers on the above two points.

7.1.2 Experimental hypothesis

For the effect of the AR-HUD system on the driving behavior of beginner and skilled drivers under different dangerous driving conditions, the main hypotheses for our study were as follows:

Hypothesis 1 (H1). AR-HUD can effectively improve the driver's hazard perception time and decision time in different dangerous driving situations.

Hypothesis 2 (H2). AR-HUD can effectively improve the bad habit of beginner drivers who do not pay attention to their surroundings. In terms of gaze interval, it is more focused on the area covered by the AR-HUD system than the comparison group.

7.1.3 Experimental variables

In this experiment, the variables to be dealt with are divided into four categories: independent, dependent, external disturbance, and mediating variables.

(1) Independent variables In this experiment, two kinds of assisted systems, AR-HUD and HUD, were used to simulate driving as the eliciting conditions, and the participants' eye-movement variations, heartbeats, and situational response behaviors were recorded.

(2) Dependent variables Gaze behavior in the area of interest (area of hazard occurrence): to assess the allocation of subjects' attentions resources when a hazardous situation occurs, analyze the experimenter's hot spot map, sight trajectory map, and data on the coordinates of the gaze point, the duration of the gaze point, and the start and end of the gaze point.

Reaction time: The participant's reaction time when driving decisions needs to be made.

(3) External disturbance variables and mediating variables The external disturbance variables mainly included the participants' gender, age, and familiarity with the road; the mediating variables mainly included the participants' personal character, acceptance of AR-HUD and other intrinsic factors.

We should minimize the possible influence of the external disturbance variables and mediating variables on the results during the experiment.

7.2 Experimental apparatus

7.2.1 Eye-tracking device

Selective attention is the mechanism by which our brain selects and focuses on a few important scene regions for cognitive and visual processing [40]. The human eye moves 34 times per second on average, pausing to sample information from those important scene regions [41]. Understanding eye movements have been central to research in attention and visual processing in the brain, including focus areas such as visual search, scene perception, usability.

Depending on the hardware structure, the line-of-sight tracking systems can be divided into desktop and head-mounted. The advantages of the for- mer, which can acquire eye-movement data in a completely natural state, are genuine user psychological response, simple operation and easy recording of eye-movement data. The second type of eye-tracking device is represented by Eye-link eye-tracking device from research, which is based on the scene camera worn by the user's head for eye-tracking, and this type of eye-tracking device tracks a wider range of vision than the desktop type. However, these devices are expensive; also, the movement of the head device will lead to errors in the position of the coordinates for eye-tracking.

In this experiment, we choose Tobii 4C as the eye-tracking device to collect the users' gazing data due to its affordable price, suitable sampling rate, and reasonable accuracy. As shown in the figure 7.1, the eye-tracking device consists of three illuminates and one camera, where the illuminates create the

FIGURE 7.1: Tobii eye-tracking device used in the experiment

pattern of near-infrared light on the viewer's eyes, and the camera captures high-resolution images of the driver's eyes and the patterns.

7.2.2 Heart Rate Monitor

The physiological evaluation of experimental participants was performed using a heart rate monitor experiment. Heart rate is the measurement of how many cardiac cycles are performed by the heart in the span of one minute. Considering the influence of the large age span of skilled drivers in this study, the XOSS armband heart rate range from 38 to 110 beats per minute [42]. The estimated formula of health rate is 208 - 0.7 * Age. The monitor uses Blue- tooth smart technology to provide a live and accurate heart rate to compatible mobile training apps to capture real-time heartbeat data.

FIGURE 7.2: XOSS heartbeat device

FIGURE 7.3: Xiaomi Mi 360 Smart Home Security Camera (left side) Cameras record driving behavior in real time (right side)

7.2.3 Surveillance Camera

The Xiaomi 360 Smart Home Security Camera records the participants' behavioral changes in the experiment, such as turning the steering wheel and hitting the pointing light. Considering the ethical aspects of the study, the camera only captured the steering wheel rotation and the screen portion, ensuring that no participant's face appeared within the camera. Also, if the participant feels uncomfortable, he/she can turn off the camera at any time.

7.2.4 Experimental stimulus materials

This experiment was conducted using the dynamic video method, with dynamic traffic videos in typical hazardous driving situations as the stimulus material. Hazardous driving situations can be classified according to the cause as intersections, pedestrians, non-motorized vehicles, other vehicles, weather, road environment, highways, special roads, and other major categories [43]. The hazardous driving situations selected for this experiment need to satisfy the following points to verify the influence of AR-HUD on driving behavior.

(1) Be able to be frequently encountered in daily driving.

(2) The AR-HUD driver assistance system can provide effective warning information.

(3) The driver's ability to perceive and react to the hazardous situation can be clearly distinguished.

They were combining the dangerous driving situations described in the five principles for developing driver hazard perception tests proposed by Mark in 2011 [44], the five most typical dangerous driving situations were extracted, including pedestrian & bicyclist conflict, slowing down of the vehicle in front, vehicle intersection turning, vehicle lane change, and two vehicles in parallel. Five road environments containing the above driving situations were selected as the experimental videos. The video processing software Adobe After Effects processed five dynamic traffic videos to superimpose the AR-HUD information contained in the system to the front of the field of view in both beginner and skilled driver versions. The experiment video's detailed explanation is shown below.

(1) Highway Hanshin Expressway, center lane of three lanes, 60-80m distance between vehicles, 80km per hour.

Driving Directions:

1. Go straight at the Kansai International Airport Interchange and continue on to the Kansai International Airport Bridge Route 481.(4.1km)
2. Construction on the left side. switch to the left lane after passing
3. Merging into ECT stations
4. At Rinku JCT, use the left lane and follow the sign for Hanshin Expressway No.4 for Osaka Kobe(550m)
5. There are trucks merging behind. change lane to the right overtaking lane
6. Change lanes to the left lane
7. Take Hanshin Expressway Route 4 wangan Line Route 4(3.1km)

FIGURE 7.4: Experimental stimulus environment materials - Comparison of Highway [1]

(2) Residential Road Gifu City to Kawaramachi, center lane of three lanes, 10-20m distance between vehicles, 30km/h.

Driving Directions

- Go straight at Kanda-machi 5 (intersection) and continue on Nagarabashi-dori. (500m)
- Complicated intersections.
- Turn left onto Kawaramachi Street. (140m)
- Pedestrians pass by and vehicles stop for a while.
- Turn right onto Kawaramachi Street. (20m)
- Pedestrians are standing on the roadside need to pay attention.
- Go straight on Kawaramachi Street. (800m)
- Trucks are merging behind, change lane to the right overtaking lane.
- A car appears at a blind corner
- Turn right and head for Nagarabashi Street 256. (500m)

FIGURE 7.5: Experimental stimulus environment materials - Comparison of Residential road [2]

(3) Countryside Road Vengenwa-cho to Kaiwendake, Single lane, 2040m distance between vehicles, 50km/h.

Driving Directions

- Turn left at Kaimon Jumachi, Ibusuki City (intersection) onto Prefecture Road No. 28. (1.0km)
- Follow Prefecture Road 28 in a northwesterly direction. (2.5km)
- Take Prefecture Road No. 28 in a northerly direction to Route 226. (28m)
- Turn left at Ibusuki-Iwamoto (intersection) onto Route 226 (Kagoshima). (2.4km)
- Stay in the left lane and continue on Route 226. (61m)
- Go straight at the south entrance of Sangyo Road (intersection) and continue to Sangyo Road/ Prefecture Road 219. (450m)
- Enter a gas station to refuel.
- Take Industrial Road/Provincial Road 217 in the north direction to Taniyama Road/National Road 225. (140m)
- Take Industrial Road/Route 225 in a northwesterly direction. (6km)

FIGURE 7.6: Experimental stimulus environment materials - Comparison of Countryside road [3]

(4) Urban Road Metropolitan Expressway Kumano-cho JCT to Higashi-Ikebukuro Exit, left of lane of two lanes, 15-20m distance between vehicles, 50km/h.

Driving Directions

- Take Metropolitan Expressway Route 5 Ikebukuro Route 5 in a south-westerly direction. (500m)
- Exit Higashi-Ikebukuro. (550m)
- Turn diagonally to the left. (22m)
- Proceed northwest. (280m).
- Turn right onto Kasuga Street / Route 254 (190m).
- There are bicyclists cross to road suddenly need to pay attention.
- Turn left at Higashi-Ikebukuro 3-chrome (intersection) onto Kasuga Street / Route 254. (90m)
- Turn diagonally to the left (140m).
- Go straight on the Metropolitan Road 435 (38m)
- Turn left onto Meiji-Dori / Metropolitan Road 305. (220m)
- Turn right onto Sunshine Street (400m)

FIGURE 7.7: Experimental stimulus environment materials - Comparison of Urban road [4]

(5) Urban Road with traffic jam Shinjuku to Shibuya Exit, left of lane of two lanes, 5-10m distance between vehicles, 50km/h.

Driving Directions

- Proceed in a southerly direction on Meiji-Dori/Toei Road 305 (800m)
- Pass the Mini Stop Sendagaya 3-chome store (400 meters ahead on the left).
- There are cars parked on the roadside.
- There are cyclists on the left side of the road.
- Turn right at Shibuya-Bashi (intersection) onto Komazawa-Dori. (150m)
- An emergency brake for a car in front.
- Turn left at Ebisu 1-chome (intersection) and enter Ebisu-Dori. (120m)

FIGURE 7.8: Experimental stimulus environment materials - Comparison of Urban road with traffic jam

7.2.5 Pre-experiment Survey

A pre-experiment survey was used to record participants' basic information, including age, gender, driving experience, and driving. In this experiment it allows us to know which user group the participants belongs to and facilitates the use of stimulus materials for the corresponding group. An English and Japanese version (Appendix A12) of the survey was prepared and administered using Goggle Forms.

7.2.6 Driving Activity Load Index

Mental workload is a variable difficult to assess in comparison with other variables. The DALI (Driving Activity Load Index) is a tool set up to assess the subjective mental workload due to a driving task [11]. It is inspired by the NASA-TLX and comprises six sub-scales, and seven points scale ranging from 1 = 'low' to 7 = 'high' is proposed for each dimension. An English and Japanese version (Appendix A9) of the survey was prepared and administered using Goggle Forms.

(1) Effort of Attention Evaluate the attention required by the activity.

(2) Visual Demand Evaluate the visual demand necessary for the activity.

(3) Auditory Demand Evaluate the auditory demand necessary for the activity.

(4) Temporal demand Evaluate the specific constraint owing to timing demand when running the activity.

(5) Interference Evaluate the possible disturbance when running the driving activity simultaneously.

(6) Situational Stress Evaluate the level of constrains/stress while conducting the activity such as fatigue, insecure feeling.

For this experiment, the factor auditory demand has been removed due to not being relevant.

7.2.7 Characterization index

In the process of driving, more than 90% of the information that the driver has is obtained by visual perception [45]. The visual characteristics of the driving process directly affect the accuracy and breadth of access to information, so the driver's visual features and driving behavior have a direct and close relationship. The gaze behavior of the human eye is an essential part of the driver's visual search process. The higher the proportion of information in an area of interest, the higher the number of gaze points generated.

Consequently, by evaluating gaze indicators such as gaze time, gaze frequency, and gaze time percentage of interest areas while driving, we may get a better understanding of the driver's attention to interest areas, their information density, and the driver's cognitive load.

In this experiment, the number of gazes, the average gaze time and the percentage of gaze time were selected as indicators of drivers' gaze behavior. The number of gazes refers to the number of times the driver's gaze point rests on a certain area of interest. In general, the higher the number of gazes, as the number of information obtained, the more frequently the driver observes the area, and indicator reflects a certain extent the driver's interest in the area.

However, in the visual search process, the gaze is only related to the number of information to be processed and has no relationship with the depth of information. Therefore, this experiment analyzed the gaze duration index to verify whether the AR-HUD assisted driving system can effectively improve driver perception of hazardous driving situations. The gaze time in the re- gion of interest indicates the time required to process information related to the dangerous driving situation, which reflects the difficulty of information processing and the speed of information processing by the driver.

AR-HUD can improve drivers' awareness of hazardous situations and reduce cognitive load by projecting various types of warning information onto the forward view and integrating it with the real driving environment. The response behavior of drivers in dangerous driving conditions was selected as the main characterization index to verify its effectiveness.

The driver's stress response behavior during driving mainly refers to avoid hazards such as steering wheel and signal lights through brain analysis when the vehicle acquires relevant signals during driving.

As shown in the Figure 7.9, in this experiment the data characterization index is divided into two judging parts, (1) the number of gaze, the area of gaze and the duration of gaze from the visual characteristic behaviors are an- alyzed; (2) Hazard perception time and decision time were analyzed in terms of reaction time.

Driving behavior	***Characterization index***
Visual characteristic behavior	Number of gazes, gaze time, gaze area
Reaction time	Perception time, decision-making time

FIGURE 7.9: Experimental characterization index

7.3 Experimental setup

The experimental setup is shown in Figure 7.10. Eye tracker was recorded the trajectory of the participants' visual movements in real time. At the same time, the steering wheel rotation and signal presses during the experiment are also recorded as reaction time. The security camera on the right side records the participant's movements and posture during the driving process.

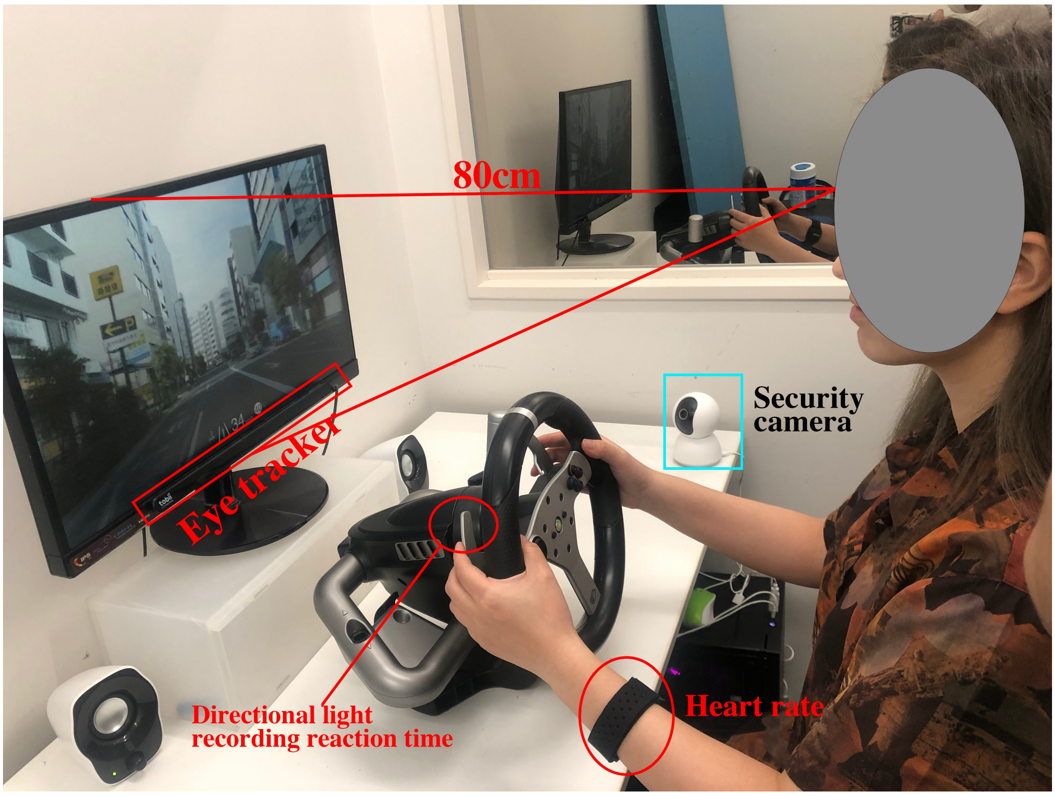


FIGURE 7.10: Setup of AR-HUD's effect on driving behavior experiment

7.4 Experimental procedure

The procedure of the experiment was be divided into three major parts, shown in the figure 7.11.

To begin, we explained the concept of AR-HUD and how it differs from a traditional HUD. The experimental procedures and goal of the experiment were described to participants through a printed document. After signing the agreement form, participants were asked to complete a pre-experiment survey to determine which user group they should be assigned.

During the preparation session, participants wore heart rates on their small arms. After confirming that the heart rate was working properly, participants were asked to adjust the seat height to ensure that the eye height was at a 30-degree angle to the eye tracker to accurately capture the visual motion trajectory. Since individual differences highly influence eye trackers results, participants were required to perform eye tracker personal preference adjustment, eye movement and head movement assessment to prevent sight capture errors. After the preparation was complete, participants were calmed by watching a 5-minute video of the landscape. Notably, the 5-minute relaxation period was conducted to obtain participants' resting heart rates (as a baseline).

Following that, we informed the participants that the experiment would begin with both hands on the steering wheel and driving behaviors based on the HUD or AR-HUD navigation in the movie. Although participants could not control the vehicle, their reaction time would be measured by rotating the steering wheel and pushing the directional lights. After watching the driving videos, participants completed a DALI (Driving Activity Strain Index) test to assess mental load. Each video lasted approximately three minutes.

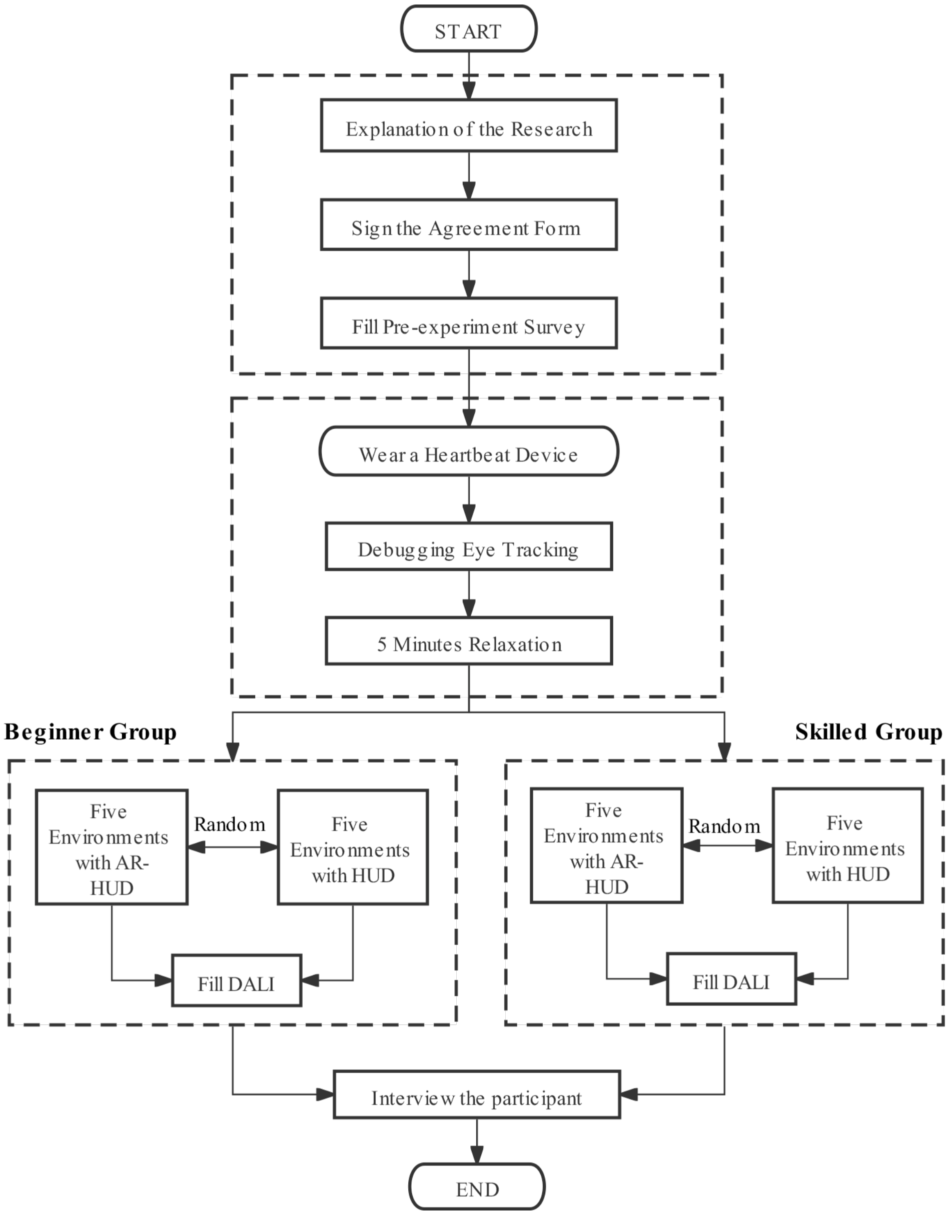


FIGURE 7.11: Procedure of AR-HUD's effect on driving behavior

Considering COVID-19 protocol in university, all participants have checked their health conditions including body temperature measurement and symp- toms assessment. Additionally, all participants were required to wear a mask during the entire process. Moreover, all apparatus were strictly disinfected before they were used.

7.5 Data analysis and data visualization

Licensed SPSS 26.0 was used for data input and data analysis. The following main aspects conducted the statistical analysis of the experimental data.

Data Visualization Box plots and folding line charts were used to visualize the distribution of data and analyze the average level, range of variation, and dispersion of each indicator. Stacked bar chart was used to compare the seven-points feedback between questions.

Paired samples t-test and one-way ANOVA test A paired-samples t-test was used to determine confirm the difference in the reaction time and psychological characteristics of the participants owing to the use of the in-vehicle AR-HUD system. Also, ANOVA was used to test whether there was a significant difference in driving behavior across environments. In addition, the relationship between the reaction time and mental load was analyzed through a correlation and regression analysis, and we conducted ANOVA to confirm the difference between the driving conditions and experimental groups.

7.6 Results

7.6.1 Participants

A total of thirty experimental participants took part in the experiment, including fifteen each in the beginner group and the skilled driver group, aged between 20 and 58 years. All participants had a driver's license, normal visual acuity (including corrected), color vision, and were eligible to test the eye-tracking device for the experiment. The detailed information of the beginner and skilled driver groups is shown in Table 7.1.

TABLE 7.1: The mean and standard deviation of basic information for beginner and skilled driver groups

	Beginner group	Skilled driver group
N	15	15
Age	24.5 (3.31)	42.7 (4.8)
Gender(male)	8 (7)	8 (7)
Years of driving	1.02	18.2
Driving frequency		
do not use it much	21.2%	0%
monthly	13.3%	0%
1-2 times a week	13.3%	20%
3-4 times a week	26.6%	20%
daily	26.6%	60%
Total driving mileage (km)	560	58728

7.6.2 Division of attention area during driving

During the experiment, the hot spot map that comes with the eye-tracking device was used to record in real-time the driving process of both groups of users as well as the field of view and the traffic scenes noticed during the driving process (see Figure 7.12).

FIGURE 7.12: Hot spot distribution for skilled drivers on residential roads with AR-HUD

The experimental video footage was analyzed frame by frame and counted the different types of targets that drivers gazed at during the car-following process. According to the characteristics and commonality of these targets, we obtained two major categories and five different types of gaze targets, divided into static and dynamic targets: (1) Static Objectives including road targets, HUD targets, traffic signs and other targets; (2) Dynamic Objectives including vehicle targets, AR targets.

In this study, the total gaze area of the driver is divided into eight small regions, which are located in eight different directions of the total gaze area, as shown in the figure 7.13. A, B, C, D, E, F, G, and H generally represent one of eight distinct staring areas. The A area indicates the far frontage road, which is more than 200 meters away from the driver; the B, C, and D areas signify the medium distance frontage road, which is 20-200 meters away from the driver; the E, F, and G areas represent the near frontage road, which is less than 20 meters away from the driver; and the H area denotes the HUD area. In each area, the target things that the driver can look at in that area are indicated.

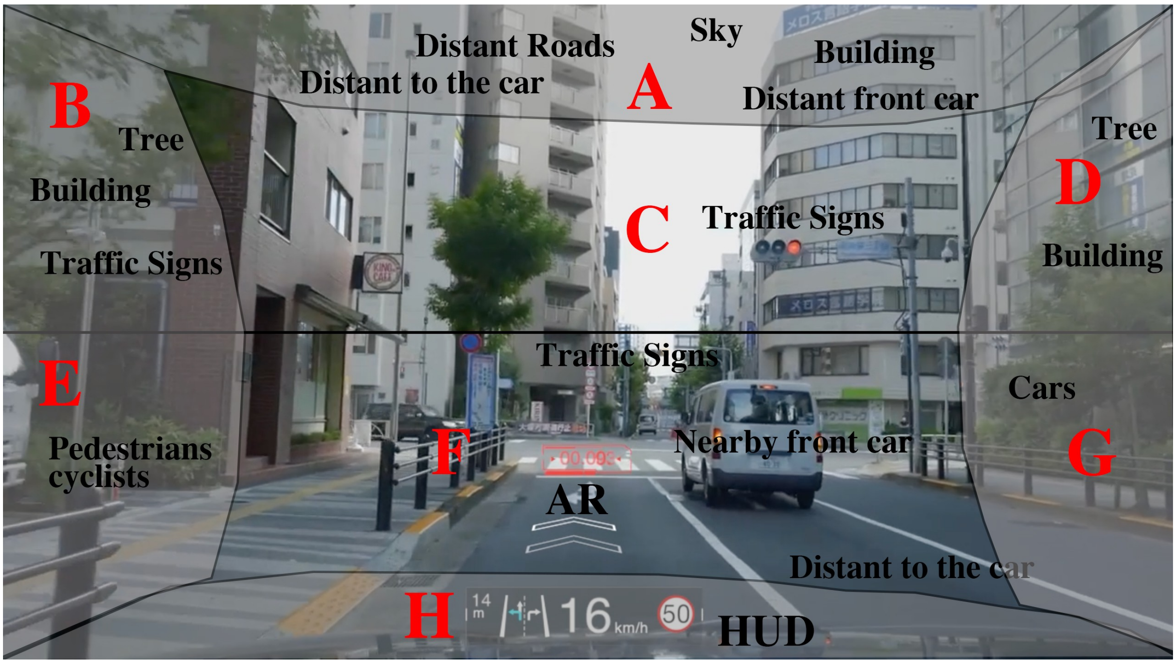


FIGURE 7.13: The division of gaze area

7.6.3 Sweep time and gaze time

The gaze characteristics of the driving user are evaluated in terms of sweep time, gaze duration, and gaze frequency per gaze area.

When the participant's eye gaze is above 100ms at a certain gaze point, it is the gaze time, and if the gaze is below 100ms at a certain gaze point, it is the occurrence of eye-hopping movement, which we define as the sweep time.

Sweep time and gaze time in Countryside Road As shown in the Figure 7.14, sweep time was much greater than gaze time for both beginners and skilled drivers in the countryside, an environment with simple traffic conditions and low hazards. The proportion of sweep time of beginner drivers in 0-100ms to total eye movement time (65.3%) was much lower than that of skilled drivers (91.2%). In contrast, the proportion of gaze time to total eye movement time above 100 ms for beginner drivers (34.7%) was four times higher than for skilled drivers (8.8%).

According to the results from the independent sample t-test, there is a significant difference between gaze time in beginner driver (M = .34, SD = .05) and skilled driver (M = .07, SD = .02), F = 7.021, p = .013 < 0.05. In addition, there is a significant difference between sweep time in beginner driver (M = .65, SD = .53) and skilled driver (M = .92, SD = .02), F = 7.170, p = .012 < 0.05 (Table 7.2). Analyzing the actual eye movement in Figure 7.14 shows that beginners lacked confidence in their driving control and preferred to focus their gaze on the spot in front of them. On the other hand, skilled drivers make more sweeping movements due to their familiarity in this environment and their ability to process information effectively.

		Levene's Test Equally of Variances		t-test for Equality of Means				
		F	Sig.	t	df	Sig. (2 – tailed)	Mean Difference	Std. Error Difference
Gaze	Equal variances assumed	7.021	.013	17.921	28	.000	.26553	.01482
	Equal variances not assumed			17.921	18.144	.000	.26553	.01482
Sweep	Equal variances assumed	7.170	.012	-17.857	28	.000	-.26467	.01482
	Equal variances not assumed			-17.857	18.165	.000	-.26467	.01482

TABLE 7.2: Independent sample test for sweep time and gaze time of two groups in countryside road

FIGURE 7.14: Distribution of gaze time and sweep time for two user groups - Countryside Road
(The sight hot-spot map picture on the right side for beginner, the bottom Hot spot picture on the right side for skilled driver)

Sweep time and gaze time in Residential Road In residential roads, there are pedestrians walking in the lane and sudden appearance of cars at blind corner on narrow roads. Compared to countryside roads, the driving situa- tion is more complicated but only medium risk level due to the slow speed of the cars. As shown in the Figure 7.15, the change in sweep time (from 65.3% to 64.4%) and gaze time (34.7% to 35.6%) for beginner drivers was minimal compared to countryside roads. In contrast, the sweep time of skilled drivers increased almost 3 times compared to countryside roads (8.8% to 21.4%).

According to the results from the independent sample t-test, there is no significant difference between gaze time in beginner driver (M = .34, SD = .05) and skilled driver (M = .22, SD = .02), F = 3.946, p = .057 > 0.05. In addition, there is no significant difference between sweep time in beginner driver (M = .65, SD = .04) and skilled driver (M = .81, SD = .05), F = 1.096, p = .304 > 0.05 (Table 7.3).

Figure 7.15 also illustrates that the beginner's sight hotspot map shows that beginners stay focused on the road ahead and rarely look at their surroundings when driving on residential roads. While skilled drivers frequently watch the HUD part of the road to prevent missing critical intersections while driving.

		Levene's Test Equally of Variances		t-test for Equality of Means				
		F	Sig.	t	df	Sig. (2 – tailed)	Mean Difference	Std. Error Difference
Gaze	Equal variances assumed	3.946	.057	8.098	28	.000	.11780	.01455
	Equal variances not assumed			8.098	19.980	.000	.11780	.01455
Sweep	Equal variances assumed	1.096	.304	-8.523	28	.000	-.16467	.01932
	Equal variances not assumed			-8.523	26.627	.000	-.16467	.01932

TABLE 7.3: Independent sample test for sweep time and gaze time of two groups in residential road

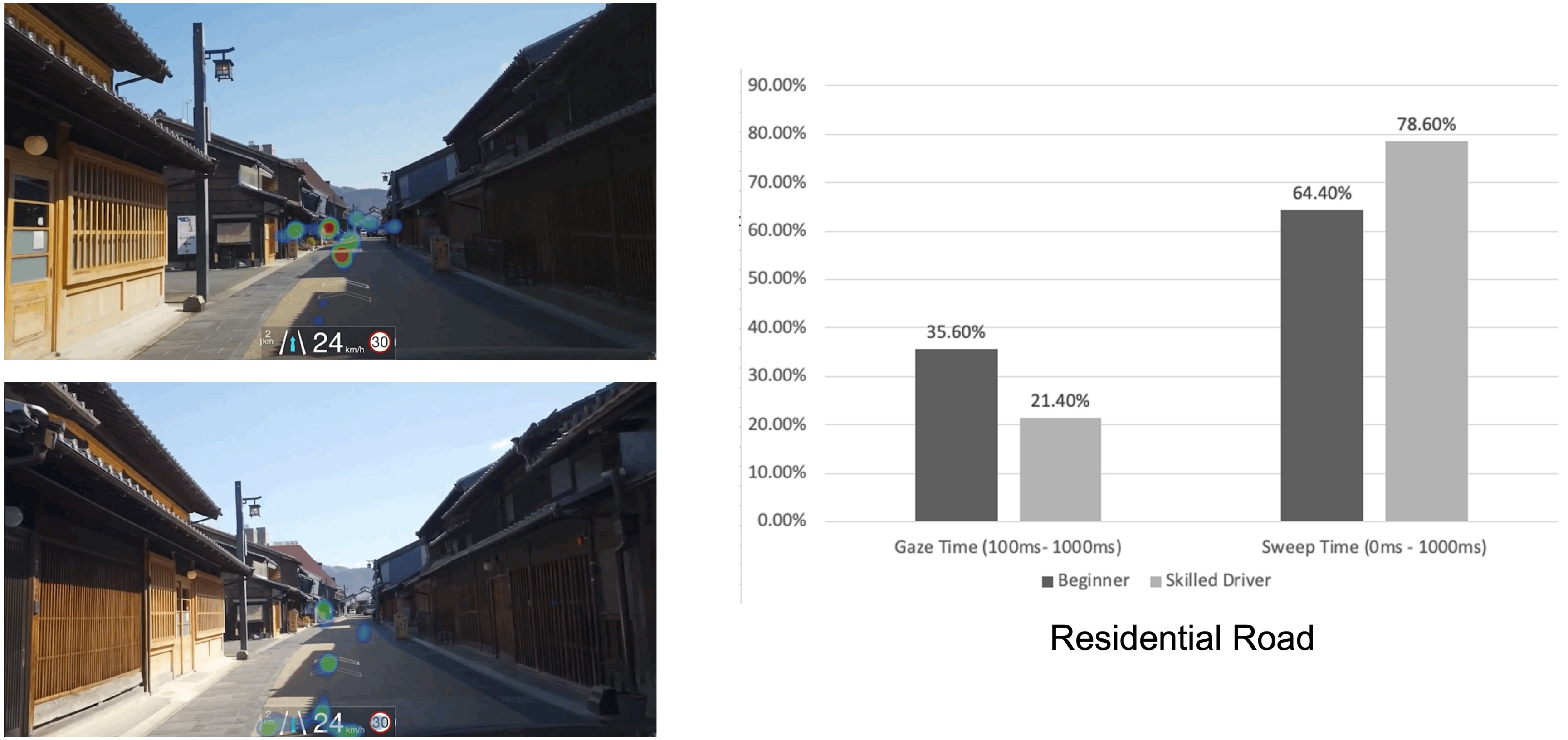


FIGURE 7.15: Distribution of gaze time and sweep time for two user groups - Residential Road
(The sight hot-spot map picture on the left side for beginner, the bottom Hot spot picture on the left side for skilled driver)

Sweep time and gaze time in Highway Road For the highway driving environment, the beginner gaze time increased from 64.4% in residential areas to 72.4%. Due to the high speed, beginner easily nervous and has always stared at the front afraid to move their sight. However, skilled driver may be used to the speed of the highway, the gaze time from 78.6% in residential areas to 52%.

According to the results from the independent sample t-test, there is no significant difference between gaze time in beginner driver ($M = .72$, $SD = .02$) and skilled driver ($M = .52$, $SD = .04$), $F = .808$, $p = .376 > 0.05$. In addition, there is no significant difference between sweep time in beginner driver ($M = .27$, $SD = .029$) and skilled driver ($M = .27$, $SD = .04$), $F = .687$, $p = .414 > 0.05$ (Table 7.4).

As shown in Figure 7.16, maps of the sight hot-spots show that both groups were focused on the road ahead while driving on the highway. While looking ahead, the skilled drivers continually checked the HUD screen to confirm navigation and speed information. Beginner drivers appeared more apprehensive, looking straight ahead and not daring to move their sight.

		Levene's Test Equally of Variances		**t-test for Equality of Means**				
		F	Sig.	t	df	Sig. (2 – tailed)	Mean Difference	Std. Error Difference
Gaze	Equal variances assumed	.808	.376	15.627	28	.000	.20067	.01284
	Equal variances not assumed			15.627	25.501	.000	.20067	.01284
Sweep	Equal variances assumed	.687	.414	-15.522	28	.000	-.20000	.01289
	Equal variances not assumed			-15.522	25.631	.000	-.20000	.01289

TABLE 7.4: Independent sample test for sweep time and gaze time of two groups in highway road

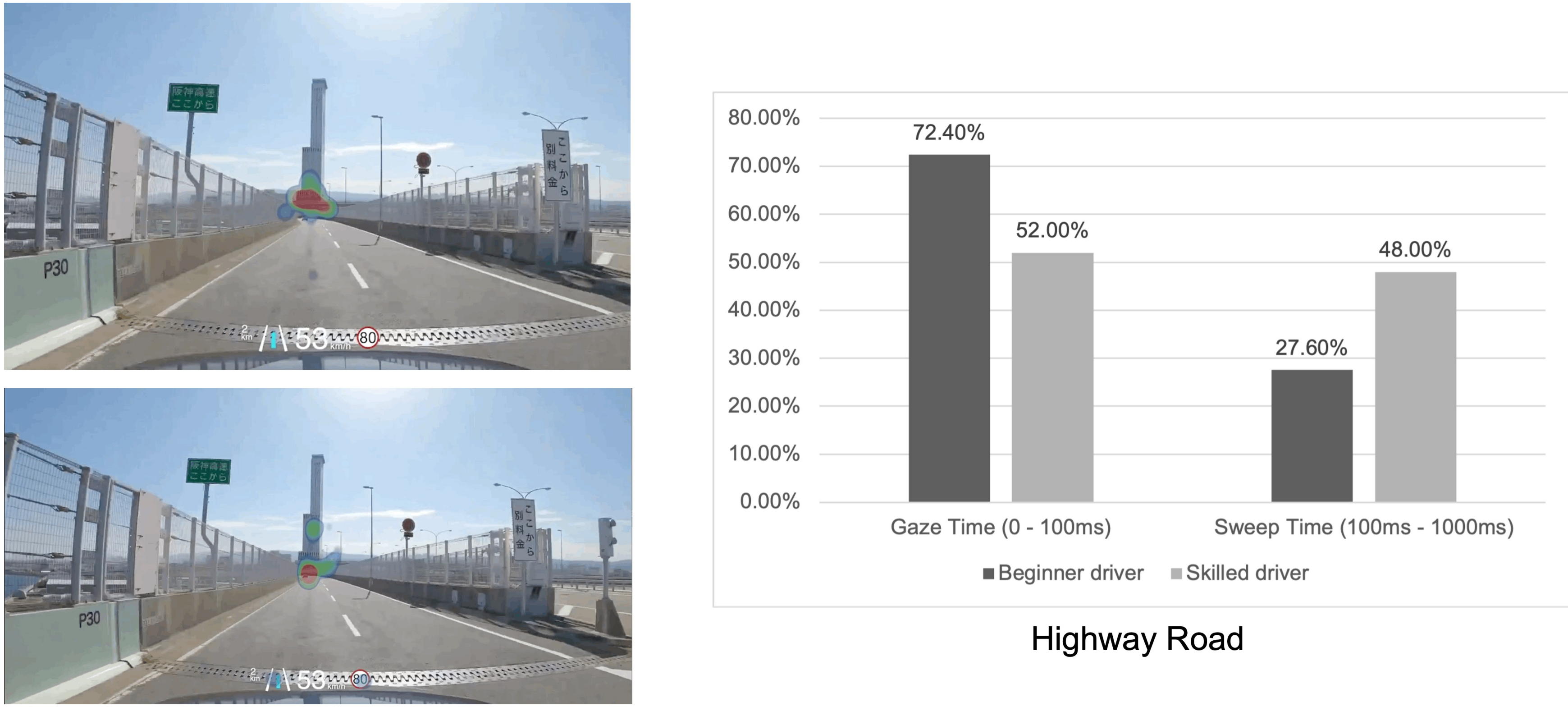


FIGURE 7.16: Distribution of gaze time and sweep time for two user groups - Highway Road
(The sight hot-spot map picture on the left side for beginner, the bottom Hot spot picture on the left side for skilled driver)

Sweep time and gaze time in two Urban Road environments On both urban roadways, beginner drivers' gaze time and sweep time are relatively constant. While the skilled driver's gaze time reduced dramatically (37.5% to 57.7%). This is a high-risk scenario due to the urban traffic jam, with cyclists crossing the road, parked cars, and sudden emergency stops of the vehicle ahead of them. To anticipating potential risks in this high risk situation, skilled driver reduced gaze time and increased sweep time.

As shown in the Figure 7.17 and Figure 7.18, the sweep time for both groups of drivers was much greater under urban traffic conditions. On urban roads, beginner accounted for a smaller proportion of gaze time than on other routes, and gaze time and sweep time were roughly equal. Due to the complexity of urban road traffic, beginners need to be constantly aware of changes in their surroundings when making driving judgments.

According to the results from the independent sample t-test, there is a significant difference between gaze time in beginner driver (M = .52, SD = .01) and skilled driver (M = .62, SD = .04), F = 7.829, p = .009 < 0.05. In addition, there is a significant difference between sweep time in beginner driver (M = .47, SD = .01) and skilled driver (M = .38, SD = .04), F = 7.829, p = .009 < 0.05 (Table 7.5).

		Levene's Test Equally of Variances		t-test for Equality of Means				
		F	Sig.	t	df	Sig. (2 – tailed)	Mean Difference	Std. Error Difference
Gaze	Equal variances assumed	7.829	.009	-9.222	28	.000	-.10800	.01171
	Equal variances not assumed			-9.222	17.872	.000	-.10800	.01171
Sweep	Equal variances assumed	7.829	.009	9.222	28	.000	.10800	.01171
	Equal variances not assumed			9.222	17.872	.000	.10800	.01171

TABLE 7.5: Independent sample test for sweep time and gaze time of two groups in urban road

		Levene's Test Equally of Variances		t-test for Equality of Means				
		F	Sig.	t	df	Sig. (2 – tailed)	Mean Difference	Std. Error Difference
Gaze	Equal variances assumed	3.460	.073	13.078	28	.000	.08033	.00614
	Equal variances not assumed			13.078	17.962	.000	.08033	.00614
Sweep	Equal variances assumed	.047	.829	-13.253	28	.000	-.09133	.00689
	Equal variances not assumed			-13.253	24.075	.000	-.09133	.00689

TABLE 7.6: Independent sample test for sweep time and gaze time of two groups in urban road with traffic jams

However, there is no significant difference between gaze time in beginner driver (M = .50, SD = .01) and skilled driver (M = .42, SD = .02), F = 3.460, p = .073 > 0.05. In addition, there is no significant difference between sweep time in beginner driver (M = .49, SD = .01) and skilled driver (M = .49, SD = .02), F = .047, p = .829 > 0.05 (Table 7.6).

By comparing the sight hot-spot maps of the two driver groups (Figure 7.17 and Figure 7.18), it can be seen that the beginner group's sweeping behav- ior was already significantly greater than in other environments. Moreover, the skilled driver group's sweeping range and frequency were significantly greater than the beginner group's. Due to their expertise, the skilled group looked to drive more relaxed and focused on places around them that may have unexpected situations.

FIGURE 7.17: Distribution of gaze time and sweep time for two user groups - Urban Road

(The sight hot-spot map picture on the right side for beginner, the bottom Hot spot picture on the right side for skilled driver)

FIGURE 7.18: Distribution of gaze time and sweep time for two user groups - Urban Road with traffic jam
(The top sight hot-spot map picture on the left side for beginner, the bottom Hot spot picture on the left side for skilled driver)

7.6.4 Distribution of Sighting Area

In this subsection, we compared the average number of driver gaze at the H-area see table 7.13 and F-area while driving in both AR-HUD and HUD states, and analyze whether there is any significant difference in each environments.

Statistics of the average number of gazes in the H area Table 7.7 summarizes the average number of gaze periods on the H-zone in the five environments for the two driving groups. The statistical results show that in the beginner and skilled driving groups, participants on average of gaze at the H-zone less frequently than in the HUD group while driving on roads equipped with an AR-HUD.

A three-way ANOVA was conducted to determine whether there is a three-way interaction between environments, driver groups and HUD type. As shown in Table 7.8, there was a statistically significant three-way interaction between environments, driver groups and HUD type; $F(4, 280) = 261.078$, $p = .000 < .05$.

A paired-samples t-test was used to determine if there was a significant difference between driving with AR-HUD and HUD. Since the samples for the t-test were from the normal or near-normal totals, a K-S test was required for the gaze data. The results of the study indicate that the data from the four groups are normally distributed and can be submitted to the t-test.

TABLE 7.7: Statistics of the average number of gazes in the H area

		Countryside	Highway	Residential	Urban	Urban 2	Mean	SD
Beginner	AR-HUD	2.11	2.54	5.21	5.67	6.27	4.36	1.9014
	HUD	3.21	5.34	6.43	7.85	7.34	6.034	1.8450
Skilled	AR-HUD	2.53	3.21	4.21	6.3	7.21	4.692	2.0018
	HUD	3.7	4.1	7.2	7.34	8.2	6.108	2.0563

TABLE 7.8: Three-way ANOVA results in the H area

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1094.329[a]	19	57.596	1955.478	.000
Intercept	8442.589	1	8442.589	286638.277	.000
group	3.765	1	3.765	127.842	.000
type	177.578	1	177.578	6029.017	.000
environment	856.020	4	214.005	7265.779	.001
group * type	.812	1	.812	27.577	.001
group * environment	10.459	4	2.615	88.776	.708
type * environment	14.936	4	3.734	126.778	.041
group * type * environment	30.759	4	7.690	261.078	**.000**
Error	8.247	280	.029		

a. R Squared = .993 (Adjusted R Squared = .992)

The results of the paired sample t-test for mean gaze duration are shown in Table 7.9. For the beginner group, there was no significant average difference between driving with AR-HUD (M = 4.36, SD = 1.90) and HUD ((M = 6.03, SD = 1.84) t = -1.24, p = .224 > .05. However, compare the effect of AR-HUD (M = 4.69, SD = 2.00) and HUD ((M = 6.11, SD = 2.06) on the average number of gazes in the H area, there was a significant difference, t = 3.867, p = .019 < .05.

TABLE 7.9: Paired-sample t-test for average number of gazes in H area

	Paired Differences					t	df	Sig (2 – tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Beginner	-0.232	0.362	0.165	-0.682	0.218	-1.24	4	0.224
Skilled	1.038	0.654	0.287	0.291	1.845	3.867	4	0.019

As illustrated in the Figure 7.19, skilled drivers are usually more interested in the H area. As shown in Table 7.7, the average value of gaze is significantly greater in each environment for the skilled group. In addition, the gaze value of the skilled group became significantly smaller when driving with AR-HUD.

FIGURE 7.19: sight hot-spot map in the H area

Statistics of the average number of gazes in the F area In section 7.6.2, we have introduced that divided the total gaze area into eight small areas, which are located in eight different directions of the total gaze area, as shown in the Figure 7.13. Since the F-area is the most critical area to focus on when driving, the AR-HUD is intended to encourage the driver to gaze at it more often and with greater interest, hence decreasing distractions.

Figure 7.20 summarizes the average number of gaze periods on the F-zone in the five environments for the two driving groups. The statistical results show that the average number of gazes was much higher for both groups driv- ing with the AR-HUD than HUD only.

		Countryside	*Highway*	*Residential*	*Urban*	*Urban 2*	*Mean*	*SD*
Beginner	AR-HUD	7.32	9.11	8.21	6.32	7.54	7.7	1.0395
	HUD	4.43	7.3	7.45	6.21	5.2	6.118	1.3107
Skilled	AR-HUD	6.24	9.31	6.34	7.27	8.45	7.522	1.3381
	HUD	6.12	9.08	6.28	6.1	7.2	6.956	1.4588

FIGURE 7.20: Statistics of the average number of gazes in the F area

A three-way ANOVA was conducted to determine whether there is a three-way interaction between environments, driver groups and HUD type. As shown in Table 7.10, there was a statistically significant three-way interaction between environments, driver groups and HUD type; $F(4, 280) = 776.668$, $p = .000 < .05$.

TABLE 7.10: Three-way ANOVA results in the F area

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	496.353[a]	19	26.124	2582.564	.000
Intercept	14900.036	1	14900.036	1472994.02	.000
group	8.420	1	8.420	832.410	.000
type	82.436	1	82.436	8149.462	.000
environment	254.503	4	63.626	6289.931	.002
group * type	22.065	1	22.065	2181.294	.000
group * environment	77.723	4	19.431	1920.891	.000
type * environment	19.431	4	4.945	488.895	.000
group * type * environment	31.425	4	7.856	776.668	**.000**
Error	2.832	280	.010		

a. R Squared = .994 (Adjusted R Squared = .994)

A paired-samples t-test was used to determine if there was a significant difference between driving with AR-HUD and HUD. Since the samples for the t-test were from the normal or near-normal totals, a K-S test was required for the gaze data. The results of the study indicate that the data from the four groups are normally distributed and can be submitted to the t-test.

The results of the paired sample t-test for mean gaze duration are shown in Table 7.11. For the beginner group, there was a significant average difference between driving with AR-HUD ($M = 7.70$, $SD = 1.03$) and HUD (($M = 6.12$, $SD = 1.31$) $t = -4.78$, $p = .009 < .05$. However, compare the effect of AR-HUD ($M = 7.52$, $SD = 1.34$) and HUD (($M = 6.96$, $SD = 1.46$) on the average number of gazes in the H area, there was no significant difference, $t = -1.669$, $p = .170 > .05$.

As illustrated in the below of Figure 7.20, beginner drivers are usually more interested in the F area. The gaze value of the skilled group became significantly greater when driving with AR-HUD in each environment

TABLE 7.11: Paired-sample t-test for average number of gazes in F area

	Paired Differences					t	df	Sig (2 – tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Beginner	-3.460	1.618	.723	-5.469	-1.450	-4.780	4	**.009**
Skilled	-.804	1.077	.482	-2.142	.533	-1.669	4	.170

7.6.5 Heart rate

Statistics of heart rate in beginner group Figure 7.21 shows heart rate (HR) relative to the baseline of participants from beginner group, in percentage. The average variance of HR of the participants in countryside road with Audi HUD as the smallest, while the average variance was the biggest when driving in the urban road with AR-HUD.

An one-way within subject ANOVA was conducted to compare the effect of environment on variance of HR with AR-HUD in percentage in countryside road ($M = 6.00$, ($SD = 4.55$), residential road ($M = 5.40$, $SD = 5.01$), highway road ($M = 7.27$, $SD = 5.77$), urban road ($M = 5.93$, $SD = 4.94$) and urban road with traffic jams ($M = 7.53$, $SD = 4.31$) conditions. As Table 7.12 shown, the results suggested that no significant effect of the environment was found, $F(3.370, 47.174) = .772$, $p = .529 > .05$.

TABLE 7.12: Tests of within subjects effects for heat-rate in five environments (Beginner group)

Source		Type III Sum od Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Environments	Sphericity Assumed	.005	4	.001	.772	.548	.052
	Greenhouse - Geisser	.005	3.370	.002	.772	**.529**	.052
	Huynh-Feldt	.005	4.000	.001	.772	.548	.052
	Lower - bound	.005	1.000	.005	.772	.394	.052
Error (E)	Sphericity Assumed	.093	56	.002			
	Greenhouse - Geisser	.093	47.174	.002			
	Huynh-Feldt	.093	56.000	.002			
	Lower - bound	.093	14.000	.007			

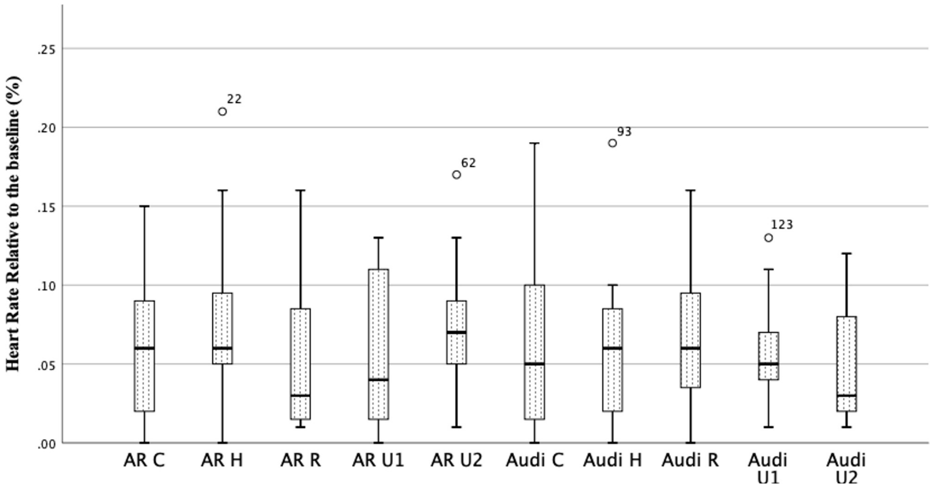


FIGURE 7.21: The distribution of heart rate relative to the baseline in % during driving in each stimulus environment by beginner group. (AR C) Countryside road with AR displays. (AR H) Highway road with AR displays. (AR R) Residential road with AR displays. (AR U1) Urban road with AR displays. (AR U2) Urban road with traffic jams and AR displays. (Audi C) Countryside road with Audi HUD. (Audi H) Highway road with Audi HUD. (Audi R) Residential road with Audi HUD. (Audi U1) Urban road with Audi HUD. (Audi U2) Urban road with traffic jams and Audi HUD.

Statistics of heart rate in skilled group However, as Figure 7.22 shows, the data from the skilled driver group shows that the average variance was the biggest when driving in the urban two roads with AR-HUD. The highest heart rates were in the driving environment with the AR-HUD, while the lowest heart rates were distributed in the driving environment with the Audi HUD in both groups.

An one-way within subject ANOVA was conducted to compare the effect of environment on variance of HR with AR-HUD in percentage in country-side road ($M = 6.07$, ($SD = 3.99$), residential road ($M = 4.00$, $SD = 3.57$), highway road ($M = 6.00$, $SD = 5.85$), urban road ($M = 5.20$, $SD = 6.84$) and urban road with traffic jams ($M = 6.53$, $SD = 6.30$) conditions. As Table 7.13 shown, the results suggested that no significant effect of the environment was found, $F(2.620, 36.677) = .1.130$, $p = .345 > .05$.

TABLE 7.13: Tests of within subjects effects for heat-rate in five environments (Skilled group)

Source		Type III Sum od Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Environments	Sphericity Assumed	.006	4	.001	1.130	.352	.075
	Greenhouse - Geisser	.006	2.620	.002	1.130	**.345**	.075
	Huynh-Feldt	.006	3.277	.002	1.130	.349	.075
	Lower - bound	.006	1.000	.006	1.130	.306	.075
Error (E)	Sphericity Assumed	.074	56	.001			
	Greenhouse - Geisser	.074	36.677	.002			
	Huynh-Feldt	.074	45.882	.002			
	Lower - bound	.074	14.000	.005			

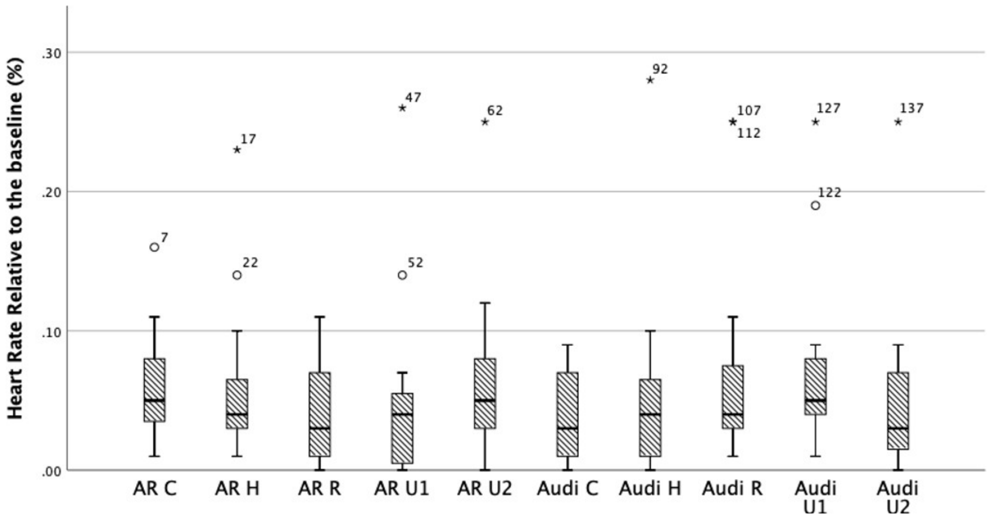


FIGURE 7.22: The distribution of heart rate relative to the baseline in % during driving in each stimulus environment by skilled driver group. (AR C) Countryside road with AR displays. (AR H) Highway road with AR displays. (AR R) Residential road with AR displays. (AR U1) Urban road with AR displays. (AR U2) Urban road with traffic jams and AR displays. (Audi C) Countryside road with Audi HUD. (Audi H) Highway road with Audi HUD. (Audi R) Residential road with Audi HUD. (Audi U1) Urban road with Audi HUD. (Audi U2) Urban road with traffic jams and Audi HUD.

7.6.6 Mental Workload

The DALI was used to measure the psychological workload during driving. The participant was required to respond to each question on a seven-point Likert scale ranging from 1 (low) to 7 (high). Two dimensions of effort of attention and visual demand were extracted.

Statistics of effort of attention Figure 7.23 shows the effort of attention (EOA) score from beginner group. In countryside road environment with AR-HUD ranked the lowest ($M = 4.13$, $SD = 1.59$), while the average EOA score in residential environment with Audi HUD weighted the most ($M = 5.20$, $SD = 1.26$). However, in the skilled driver group, there had highest EOA in Urban road with AR-HUD ($M = 5.73$, $SD = 0.79$) and lowest EOA in countryside road with AR-HUD ($M = 3.40$, $SD = 1.80$) (see Figure 7.24).

A Friedman's test was conducted with the beginner group to compare the Environmental impact on the variance of EOA with AR-HUD. There was a significant effect of environments, $\chi^2(4) = 12.84, p = .012 < .05$.

Post-hoc tests using Wicoxon test were carried out between environments trials, which are shown in Table 7.15. There were significant differences between Urban road with traffic jams and Residential road ($z = -2.412, p = .007 < 0.01$) and two Urban road ($z = -2.699, p = .021 < 0.05$). However, no significant differences were found in the skilled group,$\chi^2(4) = 32.49, p = .37 > 0.05$.

TABLE 7.14: Descriptive statistics of attention effort in five environments

Environments	**AR-HUD**		**HUD**	
	Beginner	Skilled Driver	Beginner	Skilled Driver
Countryside	4.33 ± 1.18	3.40 ± 1.80	4.00 ± 1.51	3.47 ± 1.46
Residential	4.87 ± 1.50	5.47 ± 1.13	5.20 ± 1.26	5.20 ± 1.52
Highway	4.80 ± 1.57	3.80 ± 1.89	4.67 ± 1.50	3.67 ± 1.95
Urban 1	4.87 ± 1.25	5.73 ± 0.79	4.60 ± 1.68	5.20 ± 1.42
Urban 2	4.13 ± 1.59	4.53 ± 1.77	4.73 ± 1.34	4.53 ± 1.46

Note: Date are presented as mean ± standard deviation.

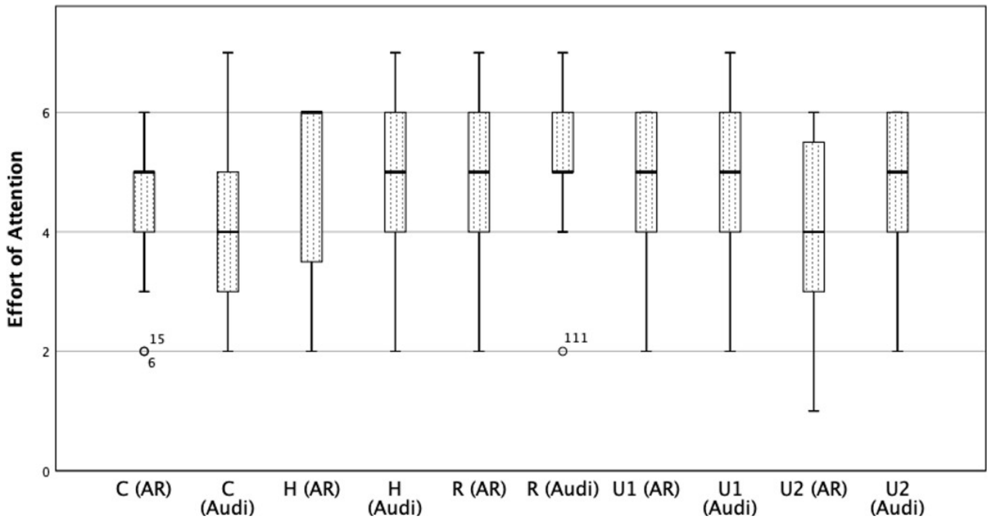


FIGURE 7.23: Distribution of attention effort in each environment by beginner group. (C) Countryside road. (H) Highway road. (R) Residential road. (U1) Urban road. (U2) Urban road with traffic jams.

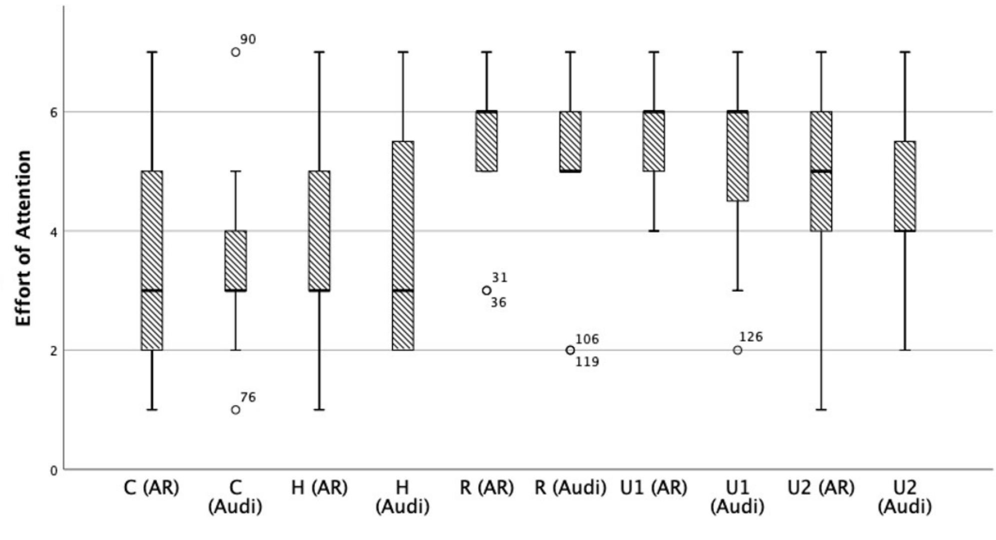


FIGURE 7.24: Distribution of attention effort in each environment by skilled driver group. (C) Countryside road. (H) Highway road. (R) Residential road. (U1) Urban road. (U2) Urban road with traffic jams.

TABLE 7.15: The results of post-hoc comparisons of effort of attention and visual demand in five environments. (C) Countryside road. (H) Highway road. (R) Residential road. (U1) Urban road. (U2) Urban road with traffic jams.

Environments	**Effort of Attention**[1]		**Visual Demand**[2]	
	z-Value	*p*-Value	z-Value	*p*-Value
H-C	-1.507	.221	-1.552	.121
R-C	-3.166	.214	-2.184	.029*
U1-C	-3.222	.085	-3.076	.002**
U2-C	-2.850	.597	-2.722	.006**
R-H	-2.689	.615	-1.862	.063
U1-H	-3.127	.831	-2.971	.003**
U2-H	-1.768	.142	-2.089	.037*
U1-R	-.9540	.886	-1.767	.077
U2-R	-2.412	.007**	-.774	.439
U2-U1	-2.699	.021**	-2.724	.006**

*p < 0.05, ** p < 0.01
[1] For beginner driver [2] For skilled driver

Statistics of Visual Demand Figure 7.25 shows the visual demand (VD) score from beginner group. In countryside road with HUD ranked the lowest (M = 4.47, SD = 1.46), while the average VD score in residential environment with AR-HUD weighted the most (M = 5.33, SD = 1.40). However, in the skilled driver group, there had highest VD in Urban road with AR-HUD (M = 6.13, SD = 0.990) and lowest EOA in countryside road with AR-HUD (M = 3.60, SD = 1.96) (see Figure 7.26). Notably, the result is consistent with the VOA value evaluation of the driving environment.

A Friedman's test was conducted with the beginner group to compare the Environmental impact on the variance of VD with AR-HUD. There was no significant effect of environments, $\chi^2(4) = 8.195, p = .085 > .05$.

However, there were significant statistically differences found in the skilled group, $\chi^2(4) = 22.732, p = .000 < .01$.

Post-hoc tests using Wicoxon test were carried out between environments trials, which are shown in Table 7.15. There were significant differences between Residential road and Countryside road (z = -2.184, p = .029 < 0.05), Urban road and Countryside road (z = -3.076, p = .002 < 0.01), Urban road with traffic jams and Countryside road (z = -2.722, p = .006 < 0.01), Urban road and Highway road (z = -2.971, p = .003 < 0.01), Urban road with traffic jams and Highway road (z = -2.089, p = .037 < 0.05), two Urban road (z = -2.724, p = .006 < 0.01).

TABLE 7.16: Descriptive statistics of visual demand in five environments

Environments	**AR-HUD**		**HUD**	
	Beginner	Skilled Driver	Beginner	Skilled Driver
Countryside	4.67 ± 1.45	3.60 ± 1.95	4.47 ± 1.46	3.87 ± 1.50
Residential	5.33 ± 1.40	5.33 ± 1.44	4.43 ± 1.45	5.33 ± 1.63
Highway	5.07 ± 1.22	4.07 ± 1.79	4.73 ± 1.16	3.74 ± 1.87
Urban 1	5.00 ± 1.31	6.13 ± .990	5.00 ± 1.25	5.13 ± 1.69
Urban 2	5.20 ± 1.10	4.93 ± 1.79	4.80 ± 1.32	4.93 ± 1.33

Note: Date are presented as mean ± standard deviation.

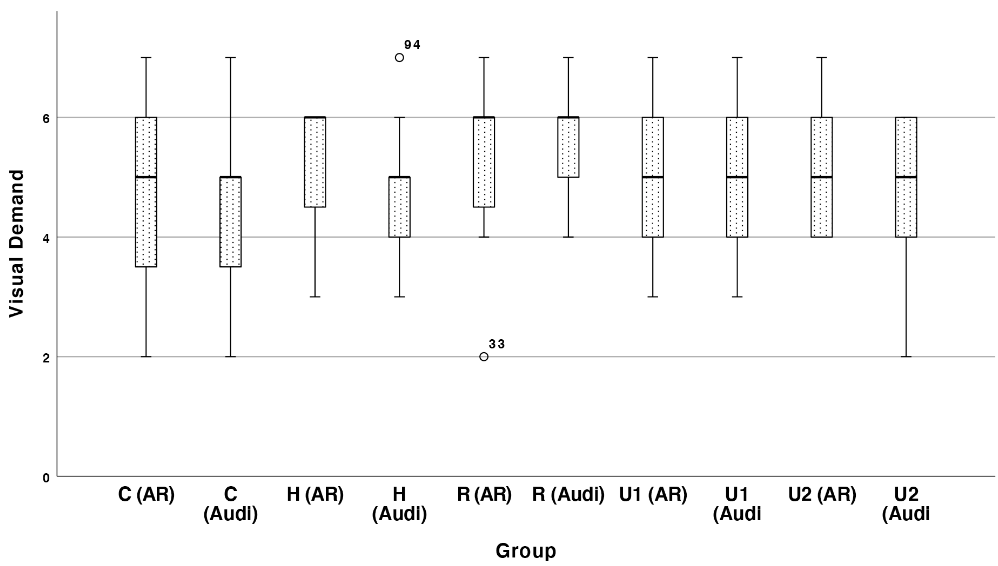


FIGURE 7.25: Distribution of visual demand in each environment by beginner group. (C) Countryside road. (H) Highway road. (R) Residential road. (U1) Urban road. (U2) Urban road with traffic jams.

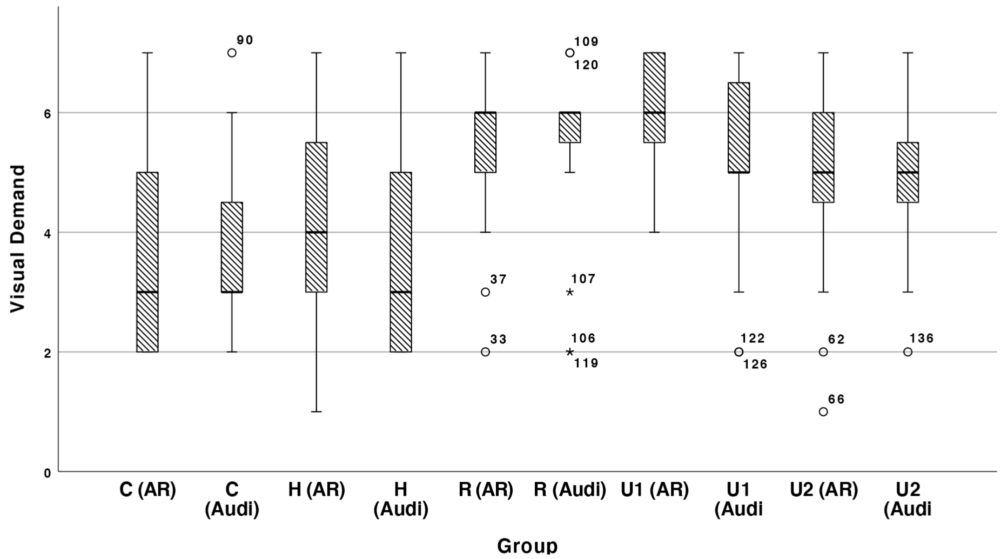


FIGURE 7.26: Distribution of visual demand in each environment by skilled driver group. (C) Countryside road. (H) Highway road. (R) Residential road. (U1) Urban road. (U2) Urban road with traffic jams.

7.7 Discussion

We conducted this experimental study to determine the effectiveness of using an in-vehicle AR-HUD system on drivers' eye movements and psychological characteristics. In addition, we tried to confirm the difference in effectiveness between each environment and driver group. For this purpose, we measured the sweep time of the area of interest, the mean gaze time and collected DALI scores for the beginner and skilled groups.

7.7.1 Effects of AR-HUD on Driver Behaviors

By analyzing the average number of gaze in two area, using AR-HUD can effectively reduce the skilled driver's attention to the H area and reduce the number of times of looking down at the HUD ($t = 3.867, p = .019 < .05$). Meanwhile, the AR-HUD system can significantly improve beginner drivers attention to dangerous areas of interest (F area) and avoid distractions causing driving errors ($t = -4.78, p = .009 < .05$).

7.7.2 Relationship between Driving Experience and Driver behaviors

The Sweep time and Gaze time results showed that sweeping movements and fewer gaze movements dominated participants' visual search. However, the percentages of both sweep and gaze are constantly changing in environments with different hazard levels and are influenced by driving experience. By assessing the danger in their surroundings, skilled drivers can change the proportion of sweeping to gazing. On the other hand, beginner drivers prefer to keep focusing on a central point and are afraid of moving their gaze due to their lack of confidence in their driving.

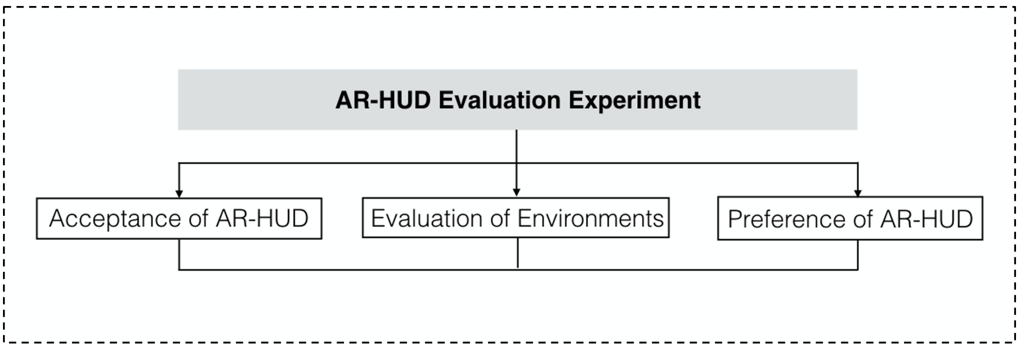
When driving in low-risk conditions (countryside road), the sweep time is significantly longer than the gaze time for both driver groups. Even still, beginner drivers had four times more gaze than skilled drivers. This results in beginner drivers taking longer to process information and make the driving decision when confronted with dangerous conditions. In comparison, the skilled drivers had more sweeping movements because of their familiarity with this environment.

In contrast, beginners continued to stare ahead and ignore observing their surroundings when driving on the same low-risk residential roads. However, skilled drivers considered the risk factors of having pedestrians and vehicles in the same lane and thus increased the percentage of gazing ahead. When driving on medium-risk high-speed roads, both skilled and beginner drivers focused on staring ahead because of the high speed. Additionally, it is worth noting that on high-risk urban roads, beginner's gaze time proportion was less than other roads. Due to the complexity of urban road traffic, beginners were no longer staring ahead and started to sweep the surrounding environment to prevent dangerous situations. However, as a beginner with less experience, too much sweeping can easily lead to driving mistakes due to distractions when dangerous situations occur.

The results showed that skilled drivers adjusted the gaze and sweep proportions based on actual road conditions. When driving in an environment where hazardous conditions may occur, they reduce gaze time and sweep time to warn of potential hazards. The sweep time and gaze time of begin- ner drivers are relatively stable, maintaining a certain amount of gaze time regardless of high or low risk. Beginner driver appear to be nervous in driving environments and keep looking at central point for large percentage of the time. For beginners' driver behavior characteristics, this provides a new direction for provide dynamic elements that adapt to changing contextual traffic situations to better regulate a driver's traffic behaviors.

Chapter 8

AR-HUD evaluation experiment



This chapter summarized the findings of an AR-HUD design cognitive effect evaluation experiment designed to ascertain AR-HUD adoption by beginner and skilled drivers, including its performance in various driving environments.

8.1 Experimental purpose

The design objectives of this study include accurately conveying driving information to the user and improving cognitive efficiency by reducing cognitive load. In the previous chapter we focused on analyzing the effects of AR-HUD in terms of physiological and behavioral responses.

In this chapter, the purpose of the experiments is to understand the acceptance of AR-HUD by beginner and skilled groups and its evaluation in different driving environments using subjective questionnaire assessment.

8.2 Experimental procedure

Since the experiments in the previous chapter use a computer screen for driving simulation, there is a significant gap with the actual driving field of view, which can bias the evaluation of the subjective evaluation test. For this reason, the experiments in this chapter were conducted by sitting in a car model to simulate a real driving scenario. Participants in the experiment are those who have participated in the previous experiment. The detailed information of the beginner and skilled driver groups is shown in Table 7.1.

The procedure of this experiment was divided into 3 steps.

First, explain the experiment to the participants sitting in the car and adjusting the seats. The dimensions of the car model and the participants' seating position are shown in the figure 8.1. A full-scale model of a domestic sedan-type vehicle was installed in a silent Room as a driving simulator. A screen is placed on the wall in front of the simulation to show the driving environment. The projector for showing the running images was an EPSON EH TW. The screen was placed on the wall in front of the mock-up to present the running images. EPSON EH TW 400 was used as the projector to present the running images. The angle of the screen seen by the collaborator depends on the height of the collaborator. As the angle at which the participants looked at the screen during the experiment varied with their height, it was calculated assuming a height of 170 cm.

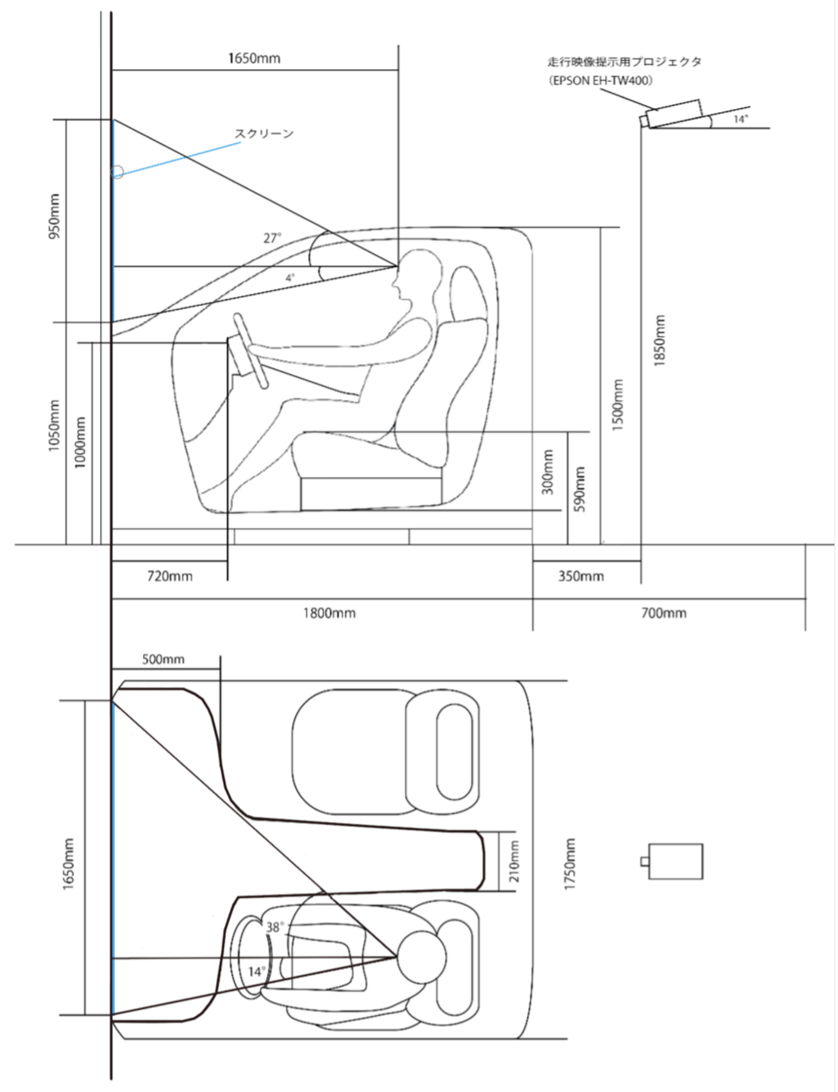


FIGURE 8.1: Experimental environment

In the second step, participants were asked to keep their eyes on the direction of driving, refrain from looking away while the video was shown, and keep their hands on the steering wheel while the video was ended. After viewing a driving video, the participants were asked to fill out two surveys: (1)

measure the acceptability and annoyance of AR-HUD (Acceptability and Annoyance of AR-HUD), and SART (Situation Awareness Rating Technique), a survey that assesses situation awareness. The time required for each environment is about 5 minutes.

Once the experiment was over, participants were asked several open questions. The expert gave positive and negative feedback concerning the AR-HUD concepts and was asked whether they had any suggestions for improvements. Furthermore, they were asked whether a combination of contact analog and static content is meaningful for an AR-HUD and how this could be realized.

FIGURE 8.2: Experimenting in the car model

8.3 Result

8.3.1 Acceptability and annoyance of AR-HUD

The subjective assessment of AR-HUD concepts for the categories effective (Q1-Q6), interference (Q8-Q10), reliability (Q11-Q14) was obtained using a self-designed questionnaire that consisted of 14 questions. The items use a 7-points Likert scale. Specific questions include the following

Q1 This AR-HUD display makes driving information easier to read by the driver?

Q2 The information provided by the system is easy to read and alerting.

Q3 AR-HUD projects navigation information directly onto the road environment to make it more intuitive and easier to understand

Q4 The system displays the information I need exactly while driving.

Q5 I could perceive the displayed AR-HUD content well under the experimental

Q6 The system displays the right amount of information that is neither missing nor redundant.

Q7 The system's information obscures the real driving environment.

Q8 In my opinion AR-HUD covered too much of the real environment. Q9 In this driving scenario and display conditions, the AR-HUD would interfere with driving

Q10 AR-HUD displays information that distracts the driver's attention.

Q11 Compared to HUD and traditional driving, using AR-HUD system is a much more relaxing during driving.

Q12 The navigation effect of AR-HUD is more obvious and comfortable than HUD.

Q13 Have complete trust in the AR-HUD system and have a dependence on it while driving.

Q14 In this driving scenario and display conditions, the AR-HUD can help driver drive more easily and safely.

As shown in Table 8.1, the residential roads were rated as the best in the effectiveness question group (Q1-Q6), scoring above 90 points. Meanwhile, on the horizontal axis, countryside roads were rated the lowest. In comparing the ratings for each environment, skilled drivers and beginners gave similar ratings to the AR-HUD. This indicates that AR-HUD can be helpful for different driving experiences.

Analysis of variance (ANOVA) was conducted to verify whether there was significant variability between group and question scores. As shown in the Table, there was a significant effect in the comparison of environments for Q3"AR-HUD projects navigation information directly onto the road environment to make it more intuitive and easier to understand", $F = 7.174$, $p = .027 < .05$. In addition, the SNK analysis was continued and there were signifi- cant differences between countryside roads, residential roads and urban roads. Also, in the comparison of beginner and skilled groups, there was a significant difference for Q4 "The system displays the information I need exactly while driving", $F = 6.637$, $p = .033 < .05$.

TABLE 8.1: Total Sum Value and Mean value of basic information for beginner and skilled driver groups. (ARC) Countryside road with AR displays. (ARH) Highway road with AR displays. (ARR) Residential road with AR displays. (ARU1) Urban road with AR displays. (ARU2)Urban road with traffic jams and AR displays. (B) Beginner driver. (S) Skilled driver.

	ARC		ARH		ARR		ARU1		ARU2		Average
	B	S	B	S	B	S	B	S	B	S	
Q1	86	80	87	87	93	92	93	86	85	84	87.3
Q2	78	71	85	86	96	89	95	80	86	82	84.8
Q3	82	81	81	78	97	89	92	89	87	84	86
Q4	79	65	84	86	92	79	92	71	87	77	81.2
Q5	85	76	91	90	94	91	93	83	89	85	87.7
Q6	69	74	66	76	66	68	76	67	86	78	72.6
Q7	32	26	29	24	41	27	31	30	40	30	31
Q8	32	24	28	25	35	33	31	36	37	28	30.9
Q9	30	23	27	23	41	29	34	31	36	35	30.9
Q10	41	34	43	48	41	47	53	59	51	41	45.8
Q11	80	77	84	84	81	78	84	78	76	67	78.9
Q12	81	76	83	83	90	83	88	84	80	78	82.6
Q13	55	50	54	62	62	54	73	62	51	65	58.8
Q14	79	75	85	80	86	86	86	88	83	84	83.2

TABLE 8.2: Analysis of variance table of Acceptability and annoyance of AR-HUD

	Group		Environment	
Tested Factor	F-Value	P-Value	F-Value	P-Value
Q1	1.308	0.286	3.351	0.109
Q2	1.973	0.198	2.556	0.166
Q3	0.934	0.362	7.174	0.027
Q4	6.637	0.033	0.65	0.651
Q5	2.957	0.124	2.012	0.231
Q6	0	1	2.276	0.196
Q7	6.987	0.03	0.691	0.629
Q8	1.482	0.258	1.276	0.39
Q9	2.581	0.147	2.162	0.21
Q10	0	1	3.583	0.097
Q11	1.811	0.215	3.174	0.119
Q12	2.025	0.193	3.016	0.129
Q13	0.007	0.936	1.248	0.398
Q14	0.203	0.664	6.663	0.031

TABLE 8.3: Student-Newman-Keuls statistical methods in each environments for Q3. (H) Highway road. (C) Countryside road. (U2) Urban road with traffic jams. (U1) Urban road. (R) Residential road.

	Environment	N	Subset for alpha = 0.05	
			1	2
Student-Newman-Keuls[a]	H	2	79.5000	
	C	2	81.5000	
	U2	2	85.5000	85.5000
	U1	2	90.5000	90.5000
	R	2		93.0000
	Sig.		.053	.120

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 2.000.

8.3.2 SART Situation Awareness Rating Technique

The SART approach [12] is a post-trial subjective rating technique. SART uses the following ten dimensions to measure operator SA: Q1. Instability of Situation, Q2. The complexity of the Situation, Q3. Variability of Situation, Q4. Arousal, Q5. The concentration of Attention, Q6. Division of Attention, Q7. Spare Mental Capacity, Q8. Information Quantity, Q9. Familiarity with the Situation.

SART is administered post-trial and involves the participant rating each dimension on a seven-point rating scale (1=Low, 7=High) base-don their performance of the task under analysis. The ratings are then combined to calculate a measure of participant SA.

As shown in Table 8.4, the beginner group had higher evaluation scores than the skilled group for each scale in all environmental groups. They drove with more stress and information reading time from the environment than the skilled group due to less driving experience.

TABLE 8.4: Total Sum Value of SART. (ARC) Countryside road with AR displays. (ARH) Highway road with AR displays. (ARR) Residential road with AR displays. (ARU1) Urban road with AR displays. (ARU2)Urban road with traffic jams and AR displays. (B) Beginner driver. (S) Skilled driver.

	ARC		ARH		ARR		ARU1		ARU2		Average
	B	S	B	S	B	S	B	S	B	S	
Instability of Situation	33	31	56	27	69	60	70	65	68	63	54.2
Complexity of Situation	25	25	49	43	79	64	71	66	73	62	55.7
Variability of Situation	31	31	52	43	77	70	71	70	76	63	58.4
Arousal	41	54	69	60	75	80	75	78	71	69	67.2
Concentration of Attention	61	62	65	64	71	80	68	80	69	85	70.5
Division of Attention	67	65	51	59	68	66	67	72	63	77	65.5
Spare Mental Capacity	92	90	75	89	67	75	67	71	60	72	75.8
Information Quantity	88	82	76	83	87	84	90	77	85	84	83.6
Familiarity with Situation	73	90	77	93	77	83	69	76	73	84	79.5

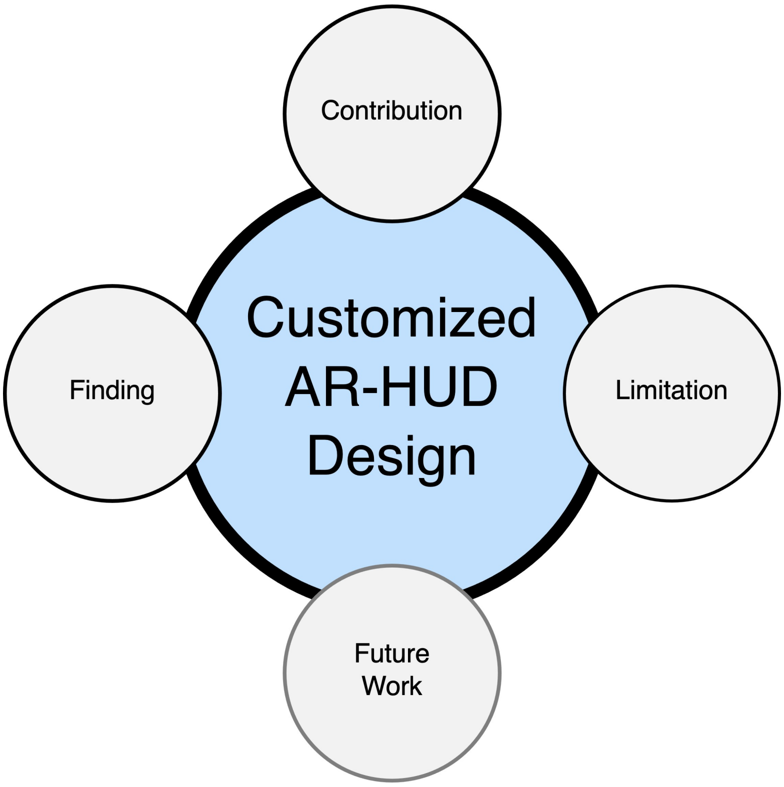
An one-way within subjects ANOVA was conducted with two user groups to compare situation awareness in each environment. As shown in table 8.5, there was a significant differences in the comparison of environments for com- plexity of situation (F = 19.525, p = .003 < .05), variability of situation (F = 22.787, p = .002 < 0.05), arousal (F = 10.344, p = .012 <0.05). Besides, there was a significant differences between skilled driver and beginner driver for famil- iarity with situation, F = 11.836, p = .009 <0.05.

TABLE 8.5: Analysis of variance table of SART

	Group		Environment	
Tested Factor	F-Value	P-Value	F-Value	P-Value
Instability of Situation	0.845	0.385	5.455	0.046
Complexity of Situation	0.337	0.577	19.525	0.003
Variability of Situation	0.258	0.625	22.787	0.002
Arousal	0.06	0.812	10.344	0.012
Concentration of Attention	2.201	0.176	2.034	0.228
Division of Attention	1.081	0.329	2.543	0.167
Spare Mental Capacity	1.089	0.327	5.127	0.051
Information Quantity	1.34	0.28	0.439	0.777
Familiarity with Situation	11.836	0.009	0.563	0.701

Chapter 9

Conclusions



The chapter presents the ***conclusions*** and ***future work*** of this research. This chapter summarized ***the study's findings and discussed the study's significance*** to the automobile industry. Additionally, it explains ***the study's shortcomings*** and gives a perspective for future research.

9.1 Finding of the study

The combination of augmented reality technology and usual display technology is an important development direction of the future vehicle information system, which has a crucial role in the development of future automated driving sight, navigation.

This study applied AR-HUD technology to in-vehicle navigation system and designs a custom AR-HUD interface based on the driving behavior and information needs of skilled and beginner drivers. The design interface of the system is studied to construct information organization guidelines and visual design strategies for the in-vehicle AR-HUD interface.

To verify the effectiveness of the proposed custom AR-HUD interface in the target group, this study uses the AR-HUD interface to assist driving behavior as an entry point to verify that the AR-HUD interface can improve the driving behavior of drivers and reduce the information recognition load.

Their main research work is as follows:

1. Research and analyze the driving situations and behaviors of target users through qualitative research methods of questionnaires and interview methods, deeply explore the information needs of users, and conduct information structure layering based on the user's mental model to avoid the problem of too much or too little information during the driving process.

2. Complete the information module construction (HUD) as well as the status module (AR) design of AR-HUD interface based on the interface design principles of the system, and propose a comprehensive interface design. Also, the route design and interaction design are based on four common road conditions in Japan. Finally, the visual elements were tested for cognitive evaluation to ensure that users can quickly understand the semantics of the HUD.

3. A combination of descriptive statistics, box-line plots, and non-parametric

tests were used to analyze the effects of the in-vehicle AR-HUD system on the driver's eye-movement behavior and responsiveness during driving. And the effectiveness of the AR-HUD interface was evaluated by establishing an AR-HUD interface evaluation index system based on driver driving behavior using hierarchical analysis. The results of the study show that in terms of eye-movement behavior, AR-HUD can significantly reduce the attention time of drivers looking down at the H area, and at the same time can improve the attention of beginner to the danger interest area when driving in the urban road. In terms of reaction time, the AR-HUD interface can significantly reduce the participants' perception time of hazardous driving situations.

9.2 The contributions of the study

This study proposes an AR-HUD custom interface design concept from the needs of two user groups, beginner and skilled driver, and investigates the effects of the AR-HUD system on driver driving behavior using eye-tracking. The experimental results demonstrate that the system can effectively guide beginners to focus on danger areas and reduce the information cognitive load of beginner.

This study contains the following significant contributions to the field of automotive interface design:

1. In terms of data collecting for AR-HUD

There is still a gap in the development of standards and guidelines for defining the information needs of AR-HUD in the existing literature and published concept descriptions by automobile manufacturers. By studying and summarizing beginner and skilled driver behavior and information demands, this study advances a database of information for three distinct driving experience modes, which serves as a reference for manufacturers when creating

AR-HUDs.

Additionally, the information base was stratified according to the three modes using clustering collection analysis. We designed an AR-HUD database structure based on five driving environments in Japan, prioritizing the information that should be presented under each navigation direction. Multiple data collections were obtained in intended to assist in the development of fu- ture AR-HUD-enabled navigation systems.

2. In terms of user interface design

To beginning, the AR element design was developed by including visible 3D horizontal dynamic directional arrows that were not previously accessi- ble in major manufactures' previous AR-HUD designs. The visual arrow also rated better than other AR features in the post-Experiment visual evaluation interview. This serves as a design reference for future development of AR-HUDs.

Second, since the majority of researchers in the same field have backgrounds in engineering or computing, they disregard the fact that, while HUD ele- ments were designed for the experiments and not tested for semantic associ- ation evaluation, the experimenter's level of understanding of HUD elements also influences the experimental results. This research addresses this gap by ensuring that each HUD element is readable and semantically accurate, and providing a validation methodology for both HUD design and development and AR-HUD.

3. The influence of AR-HUD on the gaze's field of interest

We studied variations in driver gaze time and environment in various areas using a positional split of the driving field of view. The behaviors of the beginners and skilled drivers experimental groups were examined, and the resulting disparities in AR-HUD efficacy are instructive for manufacturers building HUD systems.

The data from this research gives manufacturers with provides a new idea for future in-vehicle information systems that need to meet the demands of complex driving tasks while ensuring driving safety and cognitive speed.

9.3 Further research

While such extensive experimental research was conducted in this study, due to the experimental equipment conditions, the experimental schedule, and the epidemic's influence, the experimental results still have numerous shortcomings, and future research on the subject should focus on the following aspects.

1. Due to the limitations of the experimental equipment, this study relied on dynamic video to assess the effect of the AR-HUD interface on the driving behavior of the target users. Because participants were not able to drive the car on the actual road, their driving load condition would be affected. As studies have shown that AR-HUDs applied in 3D modeled driving simulation environments tend to make participants feel like they are playing a game rather than actually driving [23]. Field tests on actual roads should be conducted in future studies and experimental sample data should be increased to obtain more objective and accurate data.

On the other hand, highly automated driving has become more feasible with the rise of advanced driving assistant systems. However, one of the most pressing research questions in highly automated driving is how to aid drivers to make safe transitions between manual and automated control. Since the AR-HUD can be effectively used to increase attention in hazardous areas, future research could also consider how the AR-HUD can be applied to take over systems.

2. The eye-movement data collected in this experiment were only evaluated for gaze area and sweep gaze percentage. However, the assessment of the

driver's cognitive load and emotions such as arousal is not sufficient. Measurement of pupil size is commonly used as an index of cognitive load and arousal[46]. Pupil size data are recorded using eye tracking devices that provide an output containing pupil size at various points in time. To create a more thorough physiological assessment system, behavioral analyses such as sight capture trajectories, blinking, and pupil diameter should be added to future studies.

3. The effect of age was not explored in this study due to the large span of age distribution in the small sample. However, the age distribution of the skilled driver group cannot be dismissed. Compared to the beginner group, which is mostly between the ages of 20 and 30, the skilled driver group spans 30 to 60, thus showing more behavioral diversity when it comes to driving assistance with AR-HUD. Age will be investigated as a vital aspect of future studies in today's aging society. Several studies have shown that higher levels of physical, cognitive, or visual impairment among older drivers are associated with increased risk of crash involvement and tend to have significant impairments in their visual function, which could interfere with driving $p = .000 < .01$.

Future research should focus on designing AR-HUD visual elements that are easy to understand for the elderly, and an information base that meets the elderly driving navigation needs and enabling AR-HUD to assist the elderly in driving safely.

Furthermore, the study was designed with the concept that the AR-HUD system has three modes: beginner mode, normal mode, and skilled mode. However, the normal mode was not designed because the purpose of the study was mainly around the variability of the beginner and the skilled. The normal mode corresponds to the largest group of car users and needs to be analyzed in future studies.

9.4 Closing Remarks

The author hopes that the result of this study will help to develop standards or guidelines for AR-HUD information structure and according Customized information database to design the in-vehicle HMI system.

Appendix

A.1 1. Agreement Form

A.2 2. Research Instructions

A.3 3. Survey

A.1 Agreement Form

【資料 3.1】同意書（日本語版）

同　意　書

筑波大学芸術系長　殿

私は、「自動車用カスタマイズ AR-HUD インターフェース設計：ユーザーのメンタルモデルに基づいた運転情報の研究」の研究について、その目的、方法、その成果及び危険性とその対処法について充分な説明を受けました。また、本研究への協力に同意しなくても何ら不利益を受けないことも確認した上で、研究への協力を同意します。

ただし、この同意は、あくまでも私自身の自由意思によるものであり、不利益を受けず随時撤回できるものであることを確認します。

令和　　年　　月　　日

氏　名＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿（自署）

「自動車用カスタマイズ AR-HUD インターフェース設計：ユーザーのメンタルモデルに基づいた運転情報の研究」の研究について、書面及び口頭により令和　年　月　日に説明を行い、上記のとおり同意を得ました。

研究責任者　所属　芸術系
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A.1 Agreement Form in English

【資料 3.2】同意書（英語版）

Agreement Form

To Director of Art and Design, University of Tsukuba,

I agree that I have received an adequate explanation about the objective, methodology, results, risks, and coping methods about the study: In-Vehicle Customized AR-HUD Design to Provide Driving Safety Information Based on User Mental Model. Also, I agree to become a participant after understanding that I will not suffer any disadvantages if I decide not to cooperate in this research.

Nevertheless, this agreement is based upon my own free will, and I understand that it can be withdrawn at any time without suffering any disadvantages.

Date（YYYY/MM/DD）:

________/____/____

NAME: ________________________________

（Signature or Seal）

I received the aforementioned agreement after giving a textual and verbal explanation about the study: In-Vehicle Customized AR-HUD Design to Provide Driving Safety Information Based on User Mental Model on _____/____/____.

Researcher	Department	Comprehensive Human Sciences Kansei, Behavioral, and Brain Sciences	
	Name	ZHANG HAN	㊞
	Contact	s1930391@s.tsukuba.ac.jp	
Instructor	Department	Art and Design	
	Name	LEE Seung Hee	㊞
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A.1 Consent form used in the experiment

【資料　2.1】研究についての説明（日本語版）

研究についての説明

① 研究の説明

ア. 拡張現実の技術を応用した車載ヘッドアップディスプレイ（AR-HUD）の情報表示を対象として，ドライバにとって好ましい表示位置、表示サイズ、およびそれらの走行環境依存性について検討します。

イ. 実験前に、年齢・性別・運転経験などについての基本情報を調べる事前調査書を回答してもらいます。

ウ. 実験中の生態反応情報を記録するために、心拍を計測する装置を装着していただきます。

エ. 本実験は AR-HUD と HUD の比較評価、AR-HUD の位置サイズの調整、運転環境の評価の 3 つの実験に分かれています。実施に所要される時間は，個人差はありますが，70～90 分程度となります。

オ. AR-HUD と HUD の比較評価は、運転していることを想定しやすいように、実験中はハンドルに手を添えます。10 回の走行映像を観てもらいます。毎回の走行映像を視聴後に認知負荷を測る DALI（Driving activity load index）テストを行います。各動画の所要時間は約 3 分です。

カ. 運転環境の評価実験は、ドライビングシミュレーター内の運転席に着座してもらいます。5 つの異なる運転環境の AR-HUD 走行映像を提示します。走行映像提示中は進行方向を注視してよそ見を控えること、実験中はハンドルに手を添えてもらいます。走行映像視聴後に AR-HUD の受容性と煩わしさ度を測る（Acceptability and annoyance of AR-HUD）と状況認識の評価 SART(Situation Awareness Rating Technique)の調査を行います。各運転環境の所要時間は約 5 分です。

キ. 最後に、AR-HUD の位置サイズの調整を行います。動画編集ソフト Adobe Premiere Pro を使い、マウスのドラッグ操作で AR と HUD 表示の位置と大きさを画素単位で好ましい条件に自由に調整します。AR と HUD 表示が先行車と重畳しにくい位置で，かつ表示を視認しやすい位置と大きさに調整することができます。各環境の AR- HUD を調整した後に AR 要素の評価調査（Evaluation of AR elements）テストを行います。各運転環境の所要時間は約 5 分です。

ク. その後、実験についての意見を聞きます。

ケ. 休憩を取りたい、実験をやめたいという場合は、いつでも実験を中止することができますので研究分担者にお声をかけてください。

② 倫理的配慮に関すること

ア. 実験への同意の有無および得られた結果に関わらず、研究協力者が不利益を被ることはありません。

③ 本人の自由意思による同意であること

ア. 研究協力者は、実験に協力しない自由があります。

④ 同意後も不利益を受けず随時撤回できること

ア. 研究協力者は実験実施中でも実験協力の同意を撤回することができます。それによって、研究協力者が不利益を被ることはありません。

⑤ 同意しない場合でも不利益を受けないこと

ア. 研究協力者は実験協力に同意しない場合でも、研究協力者が特に不利益を被ることはありません。

⑥ 新型コロナウイルスの感染拡大を防止すること

「筑波大学の新型コロナウイルス感染症（COVID-19）対策行動方針」を定め適切な対応を行います。3 つの密を満たす場所を避け、24 時間換気システムを用いた部屋で行い

A.1 Consent form used in the experiment

【資料　2.2】研究についての説明（英語版）

Research Instructions

① About the research

a. The purpose of this research is to investigate the preferred display position and size for drivers and their dependence on the driving environment for the information display of an in-vehicle augmented reality head-up display (AR-HUD).
b. Before the experiment, you will be asked to fill the will be asked to fill out a pre-survey about their age, gender, driving experience.
c. You will be asked to wear a wear a device that measures heartbeat to record your emotional changes during the experiment.
d. This experiment is divided into three parts: Comparative evaluation of AR-HUD and HUD, Adjustment of the position size of AR-HUD, and Evaluation of the driving environments. The time required to conduct this experiment will vary depending on the individual but will be approximately 70 to 90 minutes.
e. For the Comparative evaluation of AR-HUD and HUD, you will be asked to imagine that you are driving and watch 10 driving videos. After watching the driving videos, a DALI (Driving activity load index) test will be conducted to measure the cognitive load. The duration of each video is about 3 minutes.
f. For the Evaluation of the driving environments. You will be seated in the driving simulator, and five AR-HUD driving videos will be presented. You will be asked to keep your eyes on the direction of driving and refrain from looking away while the video is being shown, and to keep your hands on the steering wheel during the experiment. After viewing a driving video, you will ask to fill 2 surveys: (1) measure the acceptability and annoyance of AR-HUD (Acceptability and Annoyance of AR-HUD), and SART (Situation Awareness Rating Technique), a survey that assess situation awareness. The time required for each environment is about 5 minutes.
g. For the Adjustment of the position size of AR-HUD, you can freely adjust the position and size of AR and HUD display in pixel units by dragging the mouse using the video editing software Adobe Premiere Pro. The AR and HUD displays were adjusted to a position where they would not overlap with the vehicle ahead and where the display would be easily visible. After adjusting the AR-HUD for each environment, you will be asked to fill the Evaluation of AR elements test. The time required for each environment is about 5 minutes.
h. Once the experiment is over, we will talk about the experience.
i. Feel free to ask, at any time, if you would like to take a rest, or stop the experiment.

② Ethical considerations

a. You will not suffer any disadvantages from the results obtained in the experiment and whether you agree to participate in the experiment.

③ Agreeing to participate is completely voluntary

a. You are free to decide whether you want to participate or not without suffering any negative consequences.

④ Cancellation of the agreement will not cause any penalties

a. You can stop the experiment and cancel your participation at any time without any negative consequences.

⑤ If you decide not to participate, there are no penalties

a. You can decide not to participate without any negative consequences.

A.2 Acceptability and annoyance of AR-HUD

Acceptability and annoyance of AR-HUD

Use the 7-point Likert scale to answer the following questions

*必須

1。 This AR-HUD display makes driving information easier to read by the driver. 運転情報を読みやすくするAR-HUDディスプレイ。*

1 つだけマークしてください。

	1	2	3	4	5	6	7	
Very Strongly Disgree	◯	◯	◯	◯	◯	◯	◯	Very Strongly Agree

2。 The information provided by the system is easy to read and alerting. システムが提供する情報は見やすく、注意喚起もしやすい。*

1 つだけマークしてください。

	1	2	3	4	5	6	7	
Very Strongly Disgree	◯	◯	◯	◯	◯	◯	◯	Very Strongly Agree

3。 AR-HUD projects navigation information directly onto the road environment to make it more intuitive and easier to understand. Ar-HUD はナビゲーション情報を道路環境に直接投影することで、より直感的で分かりやすい情報を提供する。*

1 つだけマークしてください。

	1	2	3	4	5	6	7	
Very Strongly Disgree	◯	◯	◯	◯	◯	◯	◯	Very Strongly Agree

4。 The system displays the information I need exactly while driving. 運転中に必要な情報を的確に表示してくれる。*

1 つだけマークしてください。

	1	2	3	4	5	6	7	
Very Strongly Disgree								Very Strongly Agree

5。 I could perceive the displayed AR-HUD content well under the experimental conditions. 今回の環境では、表示されたAR -HUDの内容をしっかりと認識することができました。*

1 つだけマークしてください。

	1	2	3	4	5	6	7	
Very Strongly Disgree								Very Strongly Agree

6。 The system displays the right amount of information that is neither missing nor redundant. 欠落も冗長もない適量の情報が表示される。*

1 つだけマークしてください。

	1	2	3	4	5	6	7	
Very Strongly Disgree								Very Strongly Agree

7。 The system's information obscures the real driving environment. システムの情報が実際の運転環境を覆い隠してしまう。*

1 つだけマークしてください。

	1	2	3	4	5	6	7	
Very Strongly Disgree								Very Strongly Agree

8。 In my opinion AR-HUD covered too much of the real environment. このAR-HUDコンセプトは実際の環境をカバーしすぎていると考えた。*

1 つだけマークしてください。

	1	2	3	4	5	6	7	
Very Strongly Disgree	◯	◯	◯	◯	◯	◯	◯	Very Strongly Agree

9。 In this driving scenario and display conditions, the AR-HUD would interfere with driving. この運転シナリオと表示条件では、AR-HUD が運転の妨げになる。*

1 つだけマークしてください。

	1	2	3	4	5	6	7	
Very Strongly Disgree	◯	◯	◯	◯	◯	◯	◯	Very Strongly Agree

10。 AR-HUD displays information that distracts the driver's attention. AR-HUD はドライバーの注意をそらすような情報を表示する。*

1 つだけマークしてください。

	1	2	3	4	5	6	7	
Very Strongly Disgree	◯	◯	◯	◯	◯	◯	◯	Very Strongly Agree

11。 Compared to HUD and traditional driving, using AR-HUD system is a much more relaxing during driving. HUDや従来の運転に比べて、AR-HUDシステムを使用することで、よりリラックスして運転することができます。*

1 つだけマークしてください。

	1	2	3	4	5	6	7	
Very Strongly Disgree	◯	◯	◯	◯	◯	◯	◯	Very Strongly Agree

12。 The navigation effect of AR-HUD is more obvious and comfortable than HUD. AR-HUDのナビゲーション効果は、HUDよりもわかりやすく、快適だ。*

1 つだけマークしてください。

	1	2	3	4	5	6	7	
Very Strongly Disgree	◯	◯	◯	◯	◯	◯	◯	Very Strongly Agree

13。 Have complete trust in the AR-HUD system and have a dependence on it while driving. AR-HUDシステムを完全に信頼し、運転中はそれに依存します。。 *

1 つだけマークしてください。

	1	2	3	4	5	6	7	
Very Strongly Disgree	◯	◯	◯	◯	◯	◯	◯	Very Strongly Agree

14。 In this driving scenario and display conditions, the AR-HUD can help driver drive more easily and safely. AR-HUDは、このような運転シーンや表示条件において、ドライバーがより簡単に、より安全に運転できるようサポートする。 *

1 つだけマークしてください。

	1	2	3	4	5	6	7	
Very Strongly Disgree	◯	◯	◯	◯	◯	◯	◯	Very Strongly Agree

15。 Number Env *

A.2 Driving Activity Load Index

10/7/21, 10:46 AM Driving Activity Load Index

Driving Activity Load Index

Watch the HUD video, imagine you are driving, and answer the following questions. HUD動画を見て、自分が運転している姿を想像し、以下の質問に答えてください。

*必須

16. Effort of Attention *

Evaluate the attention required by the activity 運転に必要な注意力を評価する

1 つだけマークしてください。

	1	2	3	4	5	6	7	
Low	◯	◯	◯	◯	◯	◯	◯	High

17. Visual Demand *

Evaluate the visual demand necessary for the activity 運転に必要な視覚的要求を評価する

1 つだけマークしてください。

	1	2	3	4	5	6	7	
Low	◯	◯	◯	◯	◯	◯	◯	High

18. Auditory Demand *

Evaluate the auditory demand necessary for the activity 運転に必要な聴覚的要求を評価する

1 つだけマークしてください。

	1	2	3	4	5	6	7	
Low	◯	◯	◯	◯	◯	◯	◯	High

19. Temporal demand *

Evaluate the specific constraint owing to timing demand when running the activity 行動の反応時間（例：方向HUD が現れたときに考えて行動するまでの時間）長い（High）、短い（Low）

1 つだけマークしてください。

	1	2	3	4	5	6	7	
Low	◯	◯	◯	◯	◯	◯	◯	High

20. Interference 干渉 *

Evaluate the possible disturbance when running the driving activity simultaneously 運転操作に影響を及ぼす要因 多い（High）、少ない（Low）

1 つだけマークしてください。

	1	2	3	4	5	6	7	
Low	◯	◯	◯	◯	◯	◯	◯	High

21. Situational Stress 状況に応じたストレス *

Evaluate the level of constrains/stress while conducting the activity such as fatigue, insecure feeling. 運転している時のストレスのレベルを評価する

1 つだけマークしてください。

	1	2	3	4	5	6	7	
Low	◯	◯	◯	◯	◯	◯	◯	High

A.2 Evaluation of AR elements for beginner group

Evaluation of AR elements B

Use the 7-point Likert scale to answer the following questions

*必須

22. Number *

Countryside Road

23. I found it easy to recognize and interpreted the displayed navigation hints. 表示されたナビゲーションのヒントを認識し、理解するのは簡単だと思いました。 *

1 つだけマークしてください。

	1	2	3	4	5	6	7	
Very Strongly Disgree	◯	◯	◯	◯	◯	◯	◯	Very Strongly Agree

A.2 Evaluation of AR elements for skilled driver group

Evaluation of AR elements S

Use the 7-point Likert scale to answer the following questions

*必須

24。 Number *

Countryside Road

25。 I found it easy to recognize and interpreted the displayed navigation hints. 表示されたナビゲーションのヒントを認識し、理解するのは簡単だと思いました。 *

1 つだけマークしてください。

	1	2	3	4	5	6	7	
Very Strongly Disgree	◯	◯	◯	◯	◯	◯	◯	Very Strongly Agree

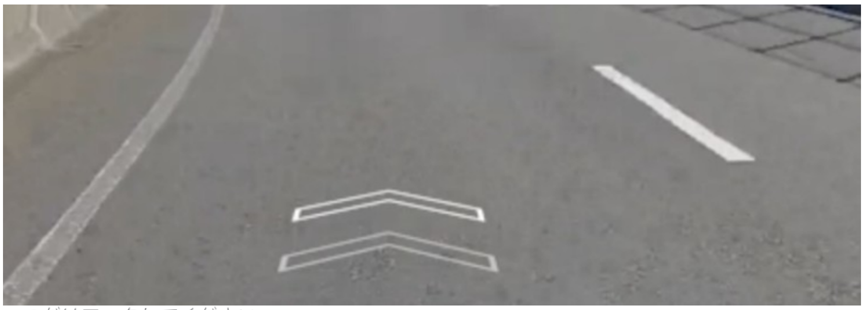
26. I don't think this AR is very useful in this driving environments. この運転環境では、このAR はあまり役に立たないと思いました。*

1 つだけマークしてください。

	1	2	3	4	5	6	7	
Very Strongly Disgree								Very Strongly Agree

Highway Road

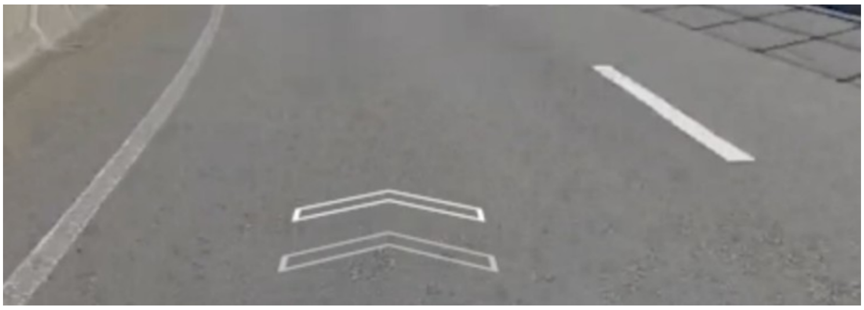
27. I found it easy to recognize and interpreted the displayed navigation hints. 表示されたナビゲーションのヒントを認識し、理解するのは簡単だと思いました。*



1 つだけマークしてください。

	1	2	3	4	5	6	7	
Very Strongly Disgree								Very Strongly Agree

28. I don't think this AR is very useful in this driving environments. この運転環境では、このAR はあまり役に立たないと思いました。*



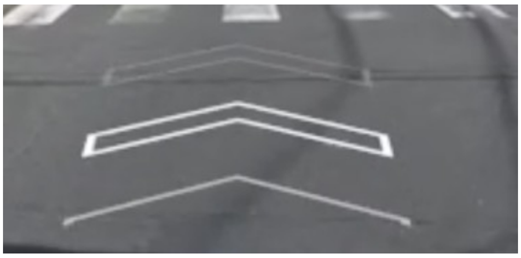
1 つだけマークしてください。

	1	2	3	4	5	6	7	
Very Strongly Disgree								Very Strongly Agree

Residential road

29. I found it easy to recognize and interpreted the displayed navigation hints. 表示されたナビゲーションのヒントを認識し、理解するのは簡単だと思いました。*

Arrows

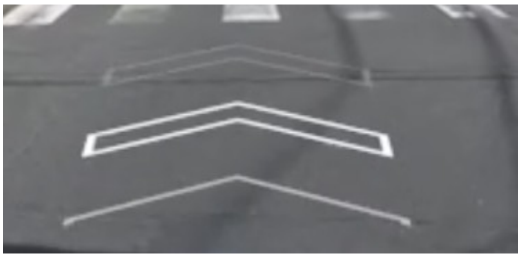


1 つだけマークしてください。

	1	2	3	4	5	6	7	
Very Strongly Disgree								Very Strongly Agree

30. I don't think this AR is very useful in this driving environments. この運転環境では、このAR はあまり役に立たないと思いました。*

Arrows



1 つだけマークしてください。

	1	2	3	4	5	6	7	
Very Strongly Disgree								Very Strongly Agree

31. I found it easy to recognize and interpreted the displayed navigation hints. 表示されたナビゲーションのヒントを認識し、理解するのは簡単だと思いました。*

Guidance arrows for complex turnouts 複雑なフォークでのガイダンスアロー

1 つだけマークしてください。

	1	2	3	4	5	6	7	
Very Strongly Disgree								Very Strongly Agree

32。 I don't think this AR is very useful in this driving environments. この運転環境では、このAR はあまり役に立たないと思いました。*

Guidance arrows for complex turnouts 複雑なフォークでのガイダンスアロー

1 つだけマークしてください。

	1	2	3	4	5	6	7	
Very Strongly Disgree	◯	◯	◯	◯	◯	◯	◯	Very Strongly Agree

33。 I found it easy to recognize and interpreted the displayed navigation hints. 表示されたナビゲーションのヒントを認識し、理解するのは簡単だと思いました。*

1 つだけマークしてください。

	1	2	3	4	5	6	7	
Very Strongly Disgree	◯	◯	◯	◯	◯	◯	◯	Very Strongly Agree

34 。 I don't think this AR is very useful in this driving environments. この運転環境では、このAR はあまり役に立たないと思いました。*

1 つだけマークしてください。

	1	2	3	4	5	6	7	
Very Strongly Disgree								Very Strongly Agree

Urban Road

35。 I found it easy to recognize and interpreted the displayed navigation hints. 表示されたナビゲーションのヒントを認識し、理解するのは簡単だと思いました。
*

1 つだけマークしてください。

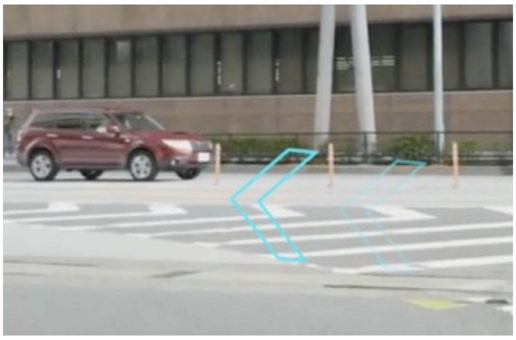
	1	2	3	4	5	6	7	
Very Strongly Disgree								Very Strongly Agree

36。 I don't think this AR is very useful in this driving environments. この運転環境では、このAR はあまり役に立たないと思いました。*

1 つだけマークしてください。

	1	2	3	4	5	6	7	
Very Strongly Disgree								Very Strongly Agree

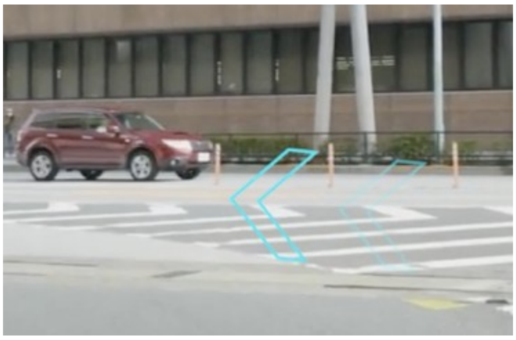
37 。 I found it easy to recognize and interpreted the displayed navigation hints. 表示されたナビゲーションのヒントを認識し、理解するのは簡単だと思いました。 *



1 つだけマークしてください。

	1	2	3	4	5	6	7	
Very Strongly Disgree	◯	◯	◯	◯	◯	◯	◯	Very Strongly Agree

38 。 I don't think this AR is very useful in this driving environments. この運転環境では、このAR はあまり役に立たないと思いました。*



1 つだけマークしてください。

	1	2	3	4	5	6	7	
Very Strongly Disgree	◯	◯	◯	◯	◯	◯	◯	Very Strongly Agree

10/7/21, 10:44 AM Evaluation of AR elements S

39 。 I found it easy to recognize and interpreted the displayed navigation hints. 表示されたナビゲーションのヒントを認識し、理解するのは簡単だと思いました。 *

1 つだけマークしてください。

	1	2	3	4	5	6	7	
Very Strongly Disgree	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Very Strongly Agree

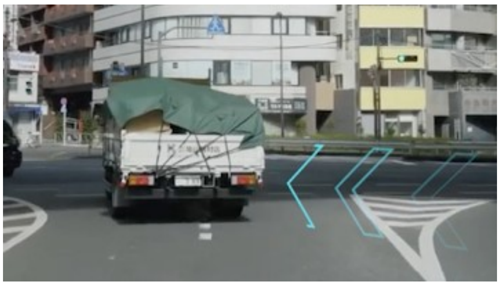
40 。 I don't think this AR is very useful in this driving environments. この運転環境では、このAR はあまり役に立たないと思いました。*

1 つだけマークしてください。

	1	2	3	4	5	6	7	
Very Strongly Disgree	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Very Strongly Agree

https://docs.google.com/forms/d/1aWYvWMa6CaSIkvu_UFtlQcWbn_jh8E_MuPh4atyMDQs/edit 9/15

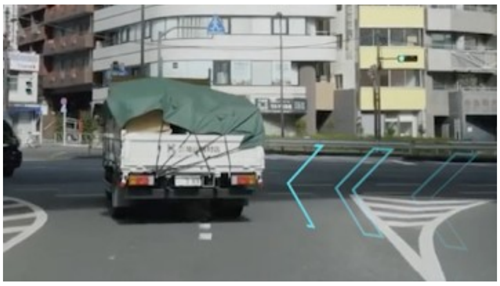
41。 I found it easy to recognize and interpreted the displayed navigation hints. 表示されたナビゲーションのヒントを認識し、理解するのは簡単だと思いました。
*



1 つだけマークしてください。

	1	2	3	4	5	6	7	
Very Strongly Disgree								Very Strongly Agree

42。 I don't think this AR is very useful in this driving environments. この運転環境では、このAR はあまり役に立たないと思いました。*

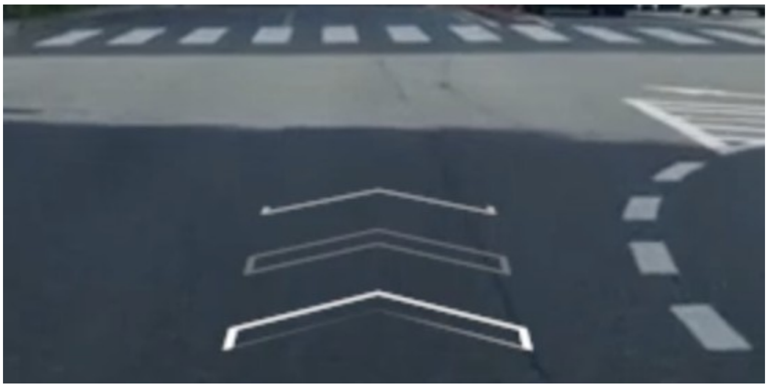


1 つだけマークしてください。

	1	2	3	4	5	6	7	
Very Strongly Disgree								Very Strongly Agree

Urban Road2

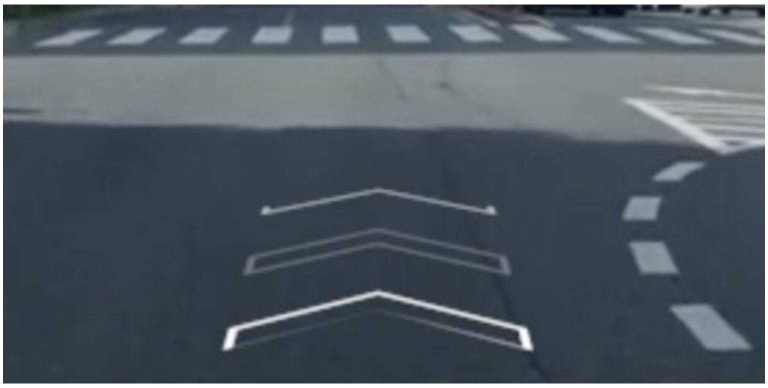
43。 I found it easy to recognize and interpreted the displayed navigation hints. 表示されたナビゲーションのヒントを認識し、理解するのは簡単だと思いました。
*



1 つだけマークしてください。

	1	2	3	4	5	6	7	
Very Strongly Disgree	◯	◯	◯	◯	◯	◯	◯	Very Strongly Agree

44。 I don't think this AR is very useful in this driving environments. この運転環境では、このARはあまり役に立たないと思いました。*



1 つだけマークしてください。

	1	2	3	4	5	6	7	
Very Strongly Disgree	◯	◯	◯	◯	◯	◯	◯	Very Strongly Agree

45。 I found it easy to recognize and interpreted the displayed navigation hints. 表示されたナビゲーションのヒントを認識し、理解するのは簡単だと思いました。*

1 つだけマークしてください。

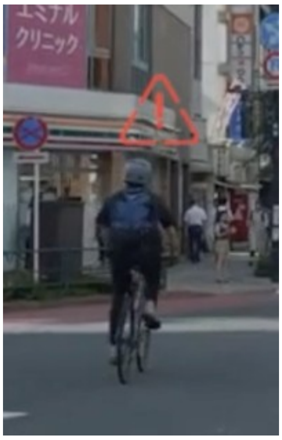
	1	2	3	4	5	6	7	
Very Strongly Disgree	◯	◯	◯	◯	◯	◯	◯	Very Strongly Agree

46。 I don't think this AR is very useful in this driving environments. この運転環境では、このAR はあまり役に立たないと思いました。*

1 つだけマークしてください。

	1	2	3	4	5	6	7	
Very Strongly Disgree								Very Strongly Agree

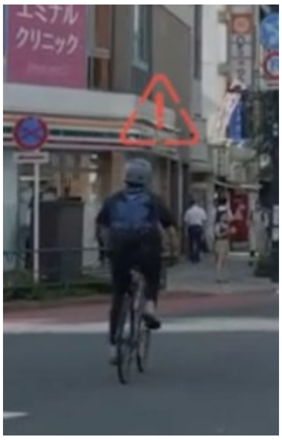
47 。 I found it easy to recognize and interpreted the displayed navigation hints. 表示されたナビゲーションのヒントを認識し、理解するのは簡単だと思いました。
*



1 つだけマークしてください。

	1	2	3	4	5	6	7	
Very Strongly Disgree	◯	◯	◯	◯	◯	◯	◯	Very Strongly Agree

48。 I don't think this AR is very useful in this driving environments. この運転環境では、このAR はあまり役に立たないと思いました。*



1 つだけマークしてください。

	1	2	3	4	5	6	7	
Very Strongly Disgree	◯	◯	◯	◯	◯	◯	◯	Very Strongly Agree

A.3 Pre-experiment survey

10/7/21, 10:43 AM Pre-experiment survey

Pre-experiment survey

*必須

- Q1、What is your age? あなたの年齢を教えてください。

  1 つだけマークしてください。

  - 20-25
  - 26-30
  - 30-35
  - 36-40
  - 41-45
  - 46-50
  - Greater than 50

- Q2 、What is your gender? あなたの性別を教えてください。

  1 つだけマークしてください。

  - Female －女性
  - Male －男性
  - Prefer not to say
  - その他: ______

- Q3 、How many years of driving experience do you have? 運転経験年数を教えてください。

  ______

- Q4 、How Many Miles do you drive ? 総走行距離を教えてください。*

  ______

https://docs.google.com/forms/d/1_VsbaXEhKMf4l8hd39gtpJS3KcEYroDjxl2kNY6iRnI/edit 1/3

A.3 Situation Awareness Rating Technique

SART Situation Awareness Rating Technique

Watch the video and answer the questions based on how it feels to drive in this environment.
動画を見て、この環境で運転したときの感覚をもとに質問に答えてください。

*必須

- 。 Instability of Situation 走行環境の不安定さ

How changeable is the situation? Is the situation highly unstable and likely to change suddenly (High) or is it very stable and straightforward (Low)?

1 つだけマークしてください。

	1	2	3	4	5	6	7	
Low	◯	◯	◯	◯	◯	◯	◯	High

- 。 Complexity of Situation 走行環境の複雑さ

How complicated is the situation? Is the complex highly unstable and likely to change suddenly (High) or is it very stable and straightforward (Low)?

1 つだけマークしてください。

	1	2	3	4	5	6	7	
Low	◯	◯	◯	◯	◯	◯	◯	High

- 。 Variability of Situation 走行環境の変化要素

How many variables are changing with the situation? Are there a large number of factors varying (High) or are there very few variable changing (Low)? 環境に応じて、変化する要因が多い(High) のか、変化する変数が非常に少ない(Low) のか?

1 つだけマークしてください。

	1	2	3	4	5	6	7	
Low	◯	◯	◯	◯	◯	◯	◯	High

A.3 Research on Beginner driving behaviors

Research on Beginner driving behaviors

Hello! In order to better understand users' needs for beginner driver assistance and clarify the subject direction of vehicle navigation systems, we conducted this questionnaire. We will do the following points:

- The questionnaire was filled out anonymously, and any information will be strictly confidential.
- Please answer according to the actual situation. When more than 50% of the questions are not answered, this questionnaire will be invalidated.
- There are 17 questions in this questionnaire, and it is estimated that you will take up to 4 minutes to answer.

Your answers will provide us with valuable information. Thank you very much for taking the time to fill out this questionnaire!

==

Part 1 Basic information

1. What is your gender?

A. Male

B. Female

2. What is your age?

A. ~20

B. 1~25

C. 6~35

D . 36~45

E . 46~55

F . 56~

3. Do you have a driver’s license?

A. Yes (Jump to the part 3)

B. No (Jump to the part 2)

Appendix B

Part 2 Beginner driver behavior

4. Have you ever been in a car driven by a beginner driver? How do you feel?

A. I've been sitting, feel not good

B. I've been sitting, feel good

C. Never, afraid to sit

D. Other____________

5. What behaviors of the beginner make you afraid?

A. Make the mistake of Accelerator for brake

B. Reverse the wrong gear

C. Exceed the speed limit

D. Make the mistake for right direction of the steering wheel when parking

E. Do not pay attention to the distance between cars

F. Forget to turn on the pointing light

G. Sudden acceleration or sudden braking

I. Other___________

Part 3 Driving behavior

6. How long is your driving experience?

A. More than two years

B. Between one year and two years

C. Within a year

D. Have a driver license but haven't been to drive

7. Which of the following scenarios are you not good at driving?

	Good	It is ok	Just so so	Not good
A. Park				
B. Driving on a narrow road				
C. Reversing on a narrow road				
D. U-turn				
E. Driving on a rainy day				

F. Night driving				
G. Mountain driving				
H. Highway confluence				
I. Highway overtaking				
J. Driving on an unfamiliar road				

8. How often do you have the driving state that described below？

	Often	Sometimes	Occasionally	Never
A. Ignore the signal light				
B. There is a car behind you suddenly appeared, but you didn't notice				
C. The signal light turned green, but you were not noticed in time, and you were honked by the car behind				
D. Entering a narrow road, don't know how to drive				
E. Can't catch the right time when doing U-turn				
F. Can't catch the right time when confluence				
G. Turned without turning on the turn signal				
H. Return is too slow when parking				
I. It is difficult to control the specified speed				
J. Turning too hard, the tires are on the pedestrian path				
K. The fellow passenger said, "You make me scared when driving"				

9. Can you accurately control the distance to the vehicle in front?

A. Always

B. Often

Appendix B

C. Sometimes

D. Rarely

E. Never

10. Do you think the speed is easy to control while driving?

A. Easy

B. Difficult

11. What situation are you easy to exceed the speed？ (Multiple choice questions)

A. When driving with inattention

B. Too nervous

C. Fatigue during long driving

D. There is a car behind urging

E. Overtaken

F. Rarely speeding

G. In a rush

I． Others (when driving on a wide unmanned road)

12. What are the reasons why you think the speed is not easy to control? (Multiple choice questions)

A. Loosen/step on the accelerator when you panic

B. No speed reminder, just by feeling

C. There is a car behind urging

D．Fatigue, inattention

E．Others____________

13. What problems do you encounter when overtaking? (Multiple choice questions)

A. Unable to predict the movement of surrounding vehicles

B. Forget to turn on the light

C. Poor speed control

D. Poor timing

E. Others____________

14. What problems did you encounter when changing lanes? (Multiple choice questions)

A. The car coming behind is too fast

B. Unclear distance from rear

C. Forget to change to the corresponding lane when turning

D. Forget to turn on the signal light

E. Step on the solid line and change lanes

F．Other________________________

15. What problems did you encounter when turning the road? (Multiple choice questions)

A. The steering wheel turns at the wrong time

B. Wrong angle of steering wheel

C. Turning speed is too fast/slow

D. Not paying attention to pedestrians and non-motor vehicles

E．Other________________________

16. How often do you deviate from the lane？

A．Often

B．Sometimes

C．Rarely

D．Never

17. Have you ever encountered unclear road conditions? (If it is not clear whether it is a one-way street)

A. Yes__________________________

B. No

==

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