Leaders or Team-Mates: Exploring the Role-Based Relationship Between Multiple Intelligent Agents in Driving Scenarios

Research on the Role-Based Relationship Between Multiple Intelligent Agents in Driving Scenarios

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Abstract. Intelligent agents (IAs) are increasingly used in vehicles and associated services (e.g. navigation, entertainment) to enhance user experience, as IAs were applied to the car and turned the vehicle into a service platform under the rapid development of the intellectualized and connected vehicle. However, various IAs may be employed by other services and devices. In the case of in-vehicle cross-device interaction, when users interact simultaneously with multiple services or devices, the actions and decisions of one IA may conflict with those of others. This paper presents a role-based relationship framework to resolve potential conflicts between different IAs in the driving scenarios. The article discusses four types of IA relationships: Partnership, Representative, Subordinate, and Co-embodiment. To examine people's perceptions and attitudes towards different types of relationships, we apply an evaluation system and conduct user studies (N = 30). In two scenarios (Navigation Plan & Music Switching), Participants are required to engage in conversations with IAs based on various types of relationships. Data analysis and user interviews show that Partnership is gaining popularity in leisure and entertainment settings. Moreover, Representative is more effective in efficiency-oriented use cases. In addition, the research on driver's attention behavior suggests that Representatives can convince the driver to focus on the road more efficiently in navigation scenarios than in music settings. After evaluating the different role-based relationships of IAs, design recommendations for user interactions with multiple IAs in driving scenarios are offered.

Keywords: Intelligent agents · Multiple agent interaction · Driving Scenarios · Role-based relationship First Section

1 Introduction

Intelligent driving agents are widely used in driving scenarios, and previous research on the characteristics of in-vehicle agents (IVAs) has provided very valuable insights [20, 52]. These studies inspire further discussion on how to optimize IVAs for the driving environment and what additional considerations should be taken into account. In real

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driving scenarios, there are often two IAs coexisting: a personal assistant represented by a cell phone and a driving agent represented by a car system. Since the two IAs may belong to different service providers, the IAs maintain their own uniqueness, which may lead to different task decision outcomes for the two IAs. Devising mechanisms to encourage autonomous agents to collaborate with each other is the central theme of multiagent systems [35], and to improve efficiency and ensure driving experience, IAs will share resources, exchange data, or perform operations collectively to bring decision results into an agreement among themselves.

Agents are often viewed as multimodal interfaces that provide useful information rather than as social partners with whom humans can build relationships [37]. But any form of interaction, including human-to-human interactions, can expand human horizons by presenting multilateral viewpoints. However, when humans view agents as mere tools for providing information, they cannot assume the agent's point of view. In human-computer interaction (HCI), humans first need to recognize that agent has different and meaningful viewpoints, and one of the mental positions that recognize this fact is known as the intentional stance. Thus, by designing social interactions and expressing information exchange between IAs, users can increase their confidence in IAs and change the user's perception of their capabilities. Currently, most relevant studies focus on the impact of a single IA feature on the driving experience, without considering the cross-platform and cross-context user experience issues when two IAs exist. To achieve this optimization, different IAs should use a criterion to mediate relationships, positions, and behaviors when cross-platform interactions occur. This raises the question of how the interactions between IAs should be designed to induce the user's intentional stance and enhance the driving experience during the collaboration.

In the driving scenario, Yoshiike et al. [19]. Developed a system called MAWARI, which consists of three social robots, and the multiparty conversation format reduces the driver's attention problem of overuse of the system and reduces the psychological load on the driver compared to the traditional one-to-one communication-based approach directly targeting the driver. When we reach SAE level 5 for automated vehicles (AVs), people will be free from driving tasks in AVs, and exploring the simultaneous presence of more than two IVAs and drivers enhances the user experience. Research on this topic is still in its early stages, but there are already teams [23] presenting futuristic situations of multiple IAs interacting with each other in the form of videos. We attempt to address the issue of cooperation between heterogeneous agents with different desires and principles by character-building relationships between the interiors of multiple intelligent systems.

This paper conducted a comprehensive investigation based on research in the field of mobile human-computer interaction. From the current literature, four relationships between multiple IAs were created and compared. They can answer some questions about the existence of role relationships: what are the manifestations of role-based relationships among multiple IAs and how do such role-based relationships affect the user experience? Second, at the application level, basic design strategies and guiding design principles are proposed for the different expressions of role-based relationships of IAs in driving scenarios. We help enterprises to develop IAs interaction design specifications and support the improvement of their product strategies. The aims of this paper are: (1) propose a framework on roles-based relationships to address how different IA's in a driving scenario behave during the collaboration process (2) compare people's attitudes toward different types of relationships and apply an evaluation system, (3) highlight design principles to help enterprises develop multiple IAs' interaction design specifications and support the improvement of their IAs platform technologies and product strategies.

2 Related Works

With the rising use of multi-agent technology in a variety of industries [33, 53], the social relationship between humans and intelligent agents (IAs) has also been widely studied. Katsunori et al. studied how IAs collaborated to persuade users from the standpoint of the balance theory and confirmed that the social relationship between two agents and a human user influences the effectiveness of persuasion. The notion of an intelligent system as a human collaborator is becoming more prevalent in interaction design [2], and in a collaborative partnership, IAs will aid humans in completing tasks more quickly. In a real-world driving scenario, however, there are likely to be more than two IAs for different devices, and their interaction is fundamentally distinct from that of a single IVA. Additionally, the interaction process has shifted from "one person to one device" to "one person to several intelligence." In this context, a number of research groups [19, 23, 40] have proposed research on challenges such as numerous agent priorities, negotiation with one another, and how to conduct autonomy to allow drivers to make decisions when conflicts emerge.

2.1 Design Characteristics of IAs in a Driving Scenario

Previous research investigated the properties of IAs in vehicles. Various topics, including IAs' forms [17, 22, 24], linguistic styles [43, 49], and variances in timbre [9, 18]. The deployment of such technologies supports the driver in doing driving or non-driving-related duties, hence enhancing road safety for both manual and conditional autonomous driving by preventing driver distraction [47]. For example, the study by Manhua Wang et al. [44] compared the differences between conversational and informative language; the research team confirmed that more confident voice reminders result in faster reaction times for drivers than less secure voices [49]; and other studies have investigated the linguistic characteristics of in-vehicle agents, such as voice age [18], and voice gender [9]. Braun et al. demonstrated [4] that voice assistant roles correspond with user personalities. They created various components for in-vehicle assistants in order to investigate the favorable effects of voice assistant customization on trust and likeability. Yoshiike et al. developed the MAWARI [19] system, which consists of three social robots engaging in multi-party dialogues to prevent driver misuse of the system compared to typical one-to-one communication-based systems that target drivers directly. The attention issue minimizes the driver's mental workload. As the reception technology for information grows more intelligent and complicated, the communication channel is presented in a more natural and fluid manner [28, 32].

2.2 Social Relationships Between IAs

According to some sociological research, the role symbolizes the agent's conduct inside a specific agent group, and the role model consists of obligations, goals, permissions, rights, etc. [29]. Multi-agent systems have been strongly influenced by related studies in behavioral ecology [51], sociology [54], and psychology [8]. In a multi-agent system, roles limit rivalry between agents in certain activities, hence it is vital to consider the issue of role relations [55]. Confucian ethics is a paradigm based on rules [46, 48], hence it is used to develop robot ethics by assigning robots various social roles to fulfill their obligations in their interactions with humans. Williams et al. [50] explain how Confucian Role Ethics might inspire Role-theoretic approaches to moral reasoning based on robot-oriented substitutes for Confucian Cardinal Relationships (e.g., supervisor-subordinate, adept-novice, teammate-teammate, and friend-friend). Ruchen Wen et al. [45] investigated norm violation responses based on role-based relational norms and elucidated the distinctions and characteristics of various robot roles. In these investigations, roles are assigned to control behavior and define responsibilities. We also consider linkages based on roles in natural systems. The notion of animal communities by Anderson and Franks [56] applies equally to humans and multi-intelligence systems. Roles allow teams to split their responsibilities. In interactions between humans and multi-intelligent systems, intelligent entities will either collaborate or compete to aid humans in performing tasks. In Yoshimasa's research [30], for instance, observing the interaction between multiple agents (colleague agent and instructor agent) can determine whether the person's intentional stance toward the agent can be encouraged and maintained; Venus & Mars and Recommendation Battlers are additional examples of retrieving or recommending Web information by multiple agents cooperatively or competitively, respectively [21].

According to past studies, the number of agents with social identities may vary in certain settings. For instance, in a given context, numerous agents with distinct social identities exist on separate smart devices. People are able to communicate with one another. Agents with social identities interact; it is also feasible that all devices are managed by one agent with social identities, similar to the one-to-many notion presented by Luria's research [26]; users primarily engage with this agent to control the equipment of other agents. We contend that the number of intelligent agent answers has a significant impact on how humans comprehend multi-agent relationships. On another level, role-based relationships in multiple agents' systems have also been widely discussed. It was mentioned above that interaction between multiple agents may induce intentional stances toward agents. People estimate the behavior of interacting partners through behavioral models, emotional aspects, and the partner's decision-making strategies [30]. The social interaction between two agents is usually an equal and cooperative relationship [57], and there is also a subordinate relationship to assist people in completing tasks [40]. The differences in information exchange brought about by the hierarchical relationship between agents may affect the behavior of humans interacting with them, which is an important factor in user experience. According to the hierarchical relationship and number of responses of the device, we split it into four categories: Partnership, Co-embodiment, Representative, and Subordinate.

Partnership. Hayashi studied the impact of user experience in the four communication modes of "passive-passive social-interaction-interactive social" in the paper [16]. Users can freely interact with the robots in the interactive social mode, which facilitates communication between many robots used to present the content of the information. In the social model, robots exchange user information through social discourse and direct contact.

Co-embodiment. Reig et al. proposed an intelligent agent concept: "Re-embodiment" [26], which described the migration of a kind of intelligent software among different robot subjects [14, 41]. Luria et al. studied the collaboration and insights of multiple IAs in task succession. They explored the driver's perception when the smartphone and in-vehicle agents appeared together in the autonomous driving scenario. This sort of manifestation is known as co-embodiment.

Representative. Tan et al. [39, 40] combined previous research and set up the communication modes based on different logic such as "silent- explicit -reciting" and "representative-direct-social" for robots. Fraune [11, 13] made some adjustments based on the research model and added new dimensions. The transparent mode refers to the process of information exchange between robots, but it will indicate that the information has been successfully communicated. The recitation mode means that the data is directly displayed through voice, and the information is shared. In the usual way, there is no direct communication or interaction between robots, but a robot communicates with users on behalf of other robots.

Subordinate. The current intelligent home assistant is a more fundamental and widely existing form in which an agent controls various other agents in the environment. In this case, users mainly communicate with this agent. This solution mode has been highly market-oriented and applied to many products, such as Alex audio [6]. This relationship can be summarized as a subordinate relationship, which is a relationship in which a high-level agent manages a low-privileged agent (Table 1).

Table 1. Multi-device interaction model framework

Response number of devices	Hierarchical	
	Equality	Inequality
Single	Co-embodiment	Representative
Multiple	Partnership	Subordinate

Through summarizing and sorting out previous studies, it is found that although many research teams have described the communication mode between multiple devices from different perspectives when multiple agents coexist, there is no framework to explain the relationship between them. Therefore, we hope to create a relationship to define the behavior between them. By summarizing the previous studies, it is found that the number of equipment responses may be the factor that affects driver distraction [19]; According to the division of cooperative relationships [34] in sociology, it can be concluded that hierarchical relationships (equal or subordinate) may become a factor affecting multi-agent systems. We construct a multi-agent role-based relationship model based on these two dimensions in driving scenarios. In this work, we ask two key questions: (1) How should the role-based relationships between IAs behave? (2) What is the user's preference for the role-based relationship between IAs in different scenarios? In response to these questions, we put forward the following assumptions:

Hypothesis 1: In the Navigation Planning scenario, the Subordinate has better driving performance than the Partnership; in the Music Switching scenario, the Partnership has better driving performance.

Hypothesis 2: Partnership and Co-embodiment have higher social attributes and are suitable for entertainment-oriented scenarios; Representative and Subordinate are more ideal for efficiency-oriented systems.

3 Material

3.1 Feature Design of Intelligent Agents

To maintain a decent interaction flow, the intelligent agent must display nonverbal cues of the present discussion state [1]. These signals may assist users' cognitive involvement during interactions, allowing them to concentrate on ongoing tasks [58]. Therefore, while building intelligent entities, non-verbal emotional expressions must be considered in addition to changes in timbre. To prevent insufficient feedback on the agent's status from influencing the interaction process. We refer to the research on sentiment analysis [27] and expand the expressions of mobile phone IAs based on the research of [59]. These include inactivity, regular operation, blinking, speaking, and left and proper rotation. A range of distinct expressions, such as moving in and out, mind control, information transmission, and dialogue, are designed. To prevent the potential impact of timbre on the role-based connection, we employ a somewhat flat female voice.

To distinguish the roles of different agents, the IVA's expression design is distinct from the mobile phone intelligent agent's expression design. For the expressions of car IAs, we first refer to the current commercial vehicle IAs, such as NIO Nomi, XPeng Motors X mart OS, and Baidu Apollo; secondly, in Michael Braun et al. studies [3, 47], we investigate the interface design of car dialogue. Certain expressions in the car, such as entering and exiting, mind control, information transmission, and maintaining contact with the mobile intelligent agent, are necessary to ensure that the participants notice continuity between them.

3.2 Multiple Intelligent Agents' Relationship Constructions

One of the approaches for influencing someone via numerous agents is overhead communication [42]. The technique demonstrates indirect contact through multiple agents and is frequently employed in online buying scenarios [38]. In the driving environment, Yoshiike et al. confirmed that the form of multi-party conversation reduces the driver's attention problem to excessive use of the system; under the premise of cooperation between intelligent systems and humans, between devices, we believe that the number of responses devices may become a factor that affects driving; Under the premise of cooperation between intelligent systems and humans, the class relationship between devices may also affect the driving experience. For example, in some sociological studies, the definition of collectivism (subordinate relationship, peer relationship). According to the characteristics of the role relationship, we divide the four role relationships according to the two variables of the number of responding devices and the hierarchical relationship of dialogue agents. Each role relationship has a special significance, as seen in Fig. 1's comparison of the four role-based relationships (Table 2).

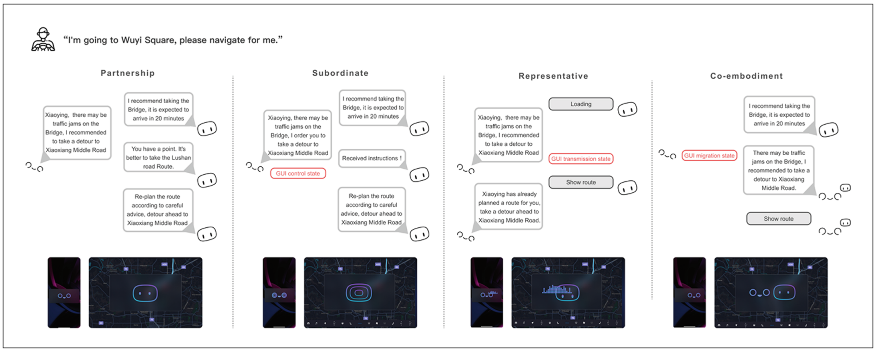

Fig. 1. Dialogue script

- Partnership means IAs with social identities in mobile phones and car machines. They exchange information through natural language, and people can communicate with IAs; mobile smart agents (Xiaoxin) Advise the intelligent agent of the car (Xiaoying) to change the strategy through communication and dialogue.
- Representative: It means that both mobile phones and cars have IAs with social identities. They exchange information through electronic signals, and people can only communicate with the intelligent agent group's agents. The mobile phone intelligent agent (Xiaoxin) changes the strategy of the car-machine agent (Xiaoying) by transmitting electronic signals, and Xiaoxin replaces Xiaoying to end the task.
- Subordinate: It means that among multiple devices, each device has an intelligent agent with social identity, but there is only one intelligent agent with control authority in various devices, and this intelligent agent controls others in a fixed agent with natural language capabilities. Equipment and people can communicate with any intelligent agent, and the intelligent agent with the control right can intervene. When a match occurs in this mode, the mobile phone intelligent agent (Xiaoxin) orders the car-machine intelligent agent (Xiaoying) to change the original strategy. Xiaoxin gave a speech to end the task.
- Co-embodiment: It means that among multiple devices, each device has an intelligent agent with a social identity, and the mobile phone intelligent agent (Xiaoxin) can be transferred between different devices, the intelligent agent will migrate according to the needs; the mobile intelligent agent will migrate to the car and change the default policy of the vehicle, and Xiaoxin will end the task by speaking on the car.

Table 2. Styles available in the Word template

Relationships	Interactive object	Interactive form
Partnership	Mobile phone & The dashboard	Conversational information exchange between IAs
Representative	Mobile phone	Mobile phone intelligent agent speaks instead of vehicle intelligent agent
Subordinate	Mobile phone & The dashboard	Mobile phone intelligent agent to control car and machine, intelligent agent
Co-embodiment	The dashboard	Mobile smart agents migrate to the car-machine system

3.3 Prototype Design

The prototype is divided into the mobile phone terminal and the car terminal. The car-machine terminal adopts the map interface as the main view. The feedback page for route planning and music switching is designed according to the scenario; the mobile terminal displays dynamic expressions. The Graphical User Interface (GUI) provides information transmission, listening, and receiving instructions during driving. Different dialogue forms and language styles [24] and animation effects are used to express other relationships between agents [7, 10]. The prototype is made by Protopie v 6.2.0, AE, Figma. The display screen is a three-channel display mode with a total resolution of 5760 × 1080 (long) × three connected horizontal displays; Logitech's driving simulator is used to make the experiment more realistic; iPad pro is used to simulate the car's central control, iPhone11 is used as a test phone.

4 Method

This work concerns the role-based relationship among multiple agents in the driving context. The experimental design was an offline study between 2 × 4 subjects. The independent variables were relationships (Partnership, Subordinates, Representative, Co-embodiment) and control variables (Navigation Planning, Music Switching), resulting in 8 situations. Participants were randomly assigned to these conditions to account for sequence effects [25] during the experiment. This paper deals with the process of information exchange between multiple IAs. We sequentially design equivalent and representative prototypes to equally compare the four role relationship concepts.

4.1 Setting

This experiment employs a two-factor mixed design. In-group variable role-based relationship between agents (Partnership versus Subordinate versus Representative versus Co-embodiment) is the first independent variable. The second independent variable, a between-group variable, was the driving task (Navigation planning versus Music switching). Each participant was expected to engage in four role-based partnerships in two different settings. In a simulated driving environment, the problems drove autonomously while adhering to traffic laws, but they also had to make turns. The quantitative examination of pertinent experiment questions is conducted mostly with the aid of the Likert scale. Some tweaks were made to the rankings to make them more acceptable for the assessment of this study, and some less relevant questions were eliminated to prevent participants from overproducing throughout the experiment and filling out the questionnaire. Investigate tiredness. The Robot Social Qualities Scale [5, 12] was used to determine whether the agent displayed good social attributes in the conversation mode; the DALI Driving Load Scale [31], a refined version of NASA-TLX [15], was used to determine the cause of driving stress and was applied to driving activities. In our study, we utilized five elements, with the exception of interference factors, which are most applicable in natural driving environments (Fig. 2).

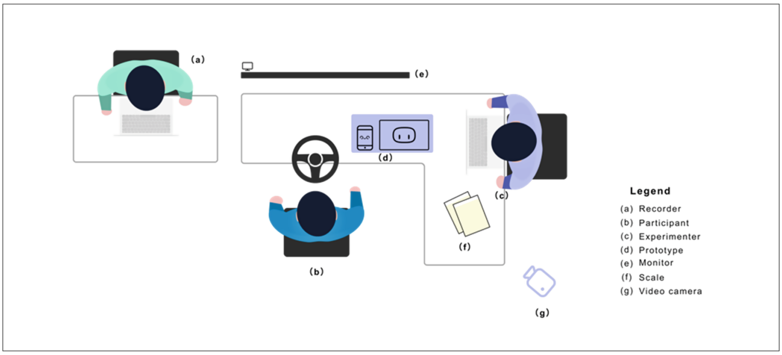

Fig. 2. Experimental scenario

4.2 Pre-experiment

Pre-experiments must be conducted to test the experimental environment and materials and ensure their validity. A total of 10 subjects were recruited to participate in the pre-experiment. The pre-experiment is divided into two parts. The first part is to test whether there are significant differences in the interaction forms of the role-based relational and whether the subjects can perceive the information in the simulated scenario. After the pre-experiment verification, the main feedback from the issues was "the difference between Representative and Subordinate is not obvious enough," "the voices between the two agents are too close to be distinguished," etc. These problems were all carried out before the formal experiment. Adjustment. The second part is to screen further and clarify the scenarios. We first listed a list of driving and non-driving tasks, which were further strained by the users who participated in the pre-experiment, and the scenarios were sorted according to the frequency of use. In the end, two scenarios of navigation planning and music switching were selected.

4.3 Participants

The experimental study used social media to recruit 33 participants. According to the statistics of the filled-in participant information form, the ages were concentrated in the 21–40 years old; 16 participants were males, 17 participants were females; 28 of them were participants Familiar with the intelligent voice agent or had a long-time use experience; ensure that all participants had a driving license. A total of 30 valid interview data were collected in the experiment.

4.4 Procedure

The experiment process is divided into the practice, formal, and interview stages. First, the experimenter briefly introduced the laboratory's functions and the simulation system's driving operation mode to the subjects and told them the general content of the experiment. Under the guidance of the experimenter, the subjects will first conduct a simulated driving practice on the same road setting as the setting in the formal investigation. During this process, the subjects were familiar with the operation of the simulator, adapted to the road conditions in advance, and listened to the specific guidance of the experimental tasks. In the formal experiment, subjects had to experience four different role relationships in two scenarios, navigation planning, and music switching, respectively. The completion order of the eight experimental groups has been balanced. Each time the subjects experienced a relationship, the issues were required to fill out a scale to score the driving experience. It takes about 5 min to complete the driving of one experimental group. Rest periods were arranged in the middle of the experiment. Subjects were asked to wear Tobii glasses two during the investigation to collect eye movement behavioral data. In the interview stage, the experimenter conducted semi-structured interviews with the subjects. The subjects ranked the role-based relationships in different scenarios according to their feelings and expressed their thoughts on the characteristics of each relationship (Fig. 3).

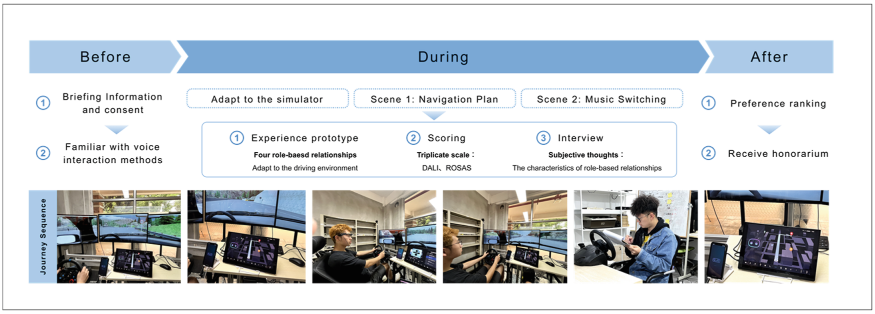

Fig. 3. Experimental flowchart

5 Results

The results mainly come from five aspects: mental workload, eye movement analysis, RoSAS analysis, and interview results. The eye movement response was largely explained from the behavioral level of the subjects, and the subjective psychological load and RoSAS analysis were mainly defined from the psychological level. As a supplement, the interview results verified the acceptance and rationality of the role-based relationship of multiple agents from the side.

A total of 30 valid interviews were conducted in the experimental study, and the overall rating data of the scale showed good reliability and validity. The alpha reliability coefficient of the driving load scale data was 0.841, close to the early Lucey[36] small sample study of 0.8552. The data of the three dimensions of the social attribute scale analyzed by the same method showed excellent reliability: $\alpha = 0.912$, $\alpha = 0.900$, $\alpha = 0.923$. Preliminary data mean-variance analysis indicated that some demographic attributes of the participants (e.g., gender and age) did not significantly affect the data's variability. Significant differences between different conditions are indicated in the figure, and the degree is indicated ($p < 0.05$, marked with*) ($p < 0.01$, marked with **) ($p < 0.001$, observed with ***).

5.1 Driving Activity Load Index (DALI)

DALI (Driving Activity Load Index) is a SWAT technique, and one of the main advantages is that it can identify the source of the driver's workload. It includes six predefined factors: attention, interference, situation stress, visual, auditory, and temporal demands. In this study, we used five elements, excluding interference factors, as this factor is most appropriate when used in natural driving environments. We judge the difference in DALI scores from two scenarios; each DALI factor is calculated from the subjects' scores according to work.

Mental Workload. To test whether the role-based relationship between agents in the navigation planning scenario impacts the driver's psychological load, one-way ANOVA and paired samples T-test were used to compare the driving load scores under different role relationships. The mean value analysis was carried out according to the four role-based relationship conditions. The mean value of DALI Attention Demand showed that the Co-embodiment index was the highest ($M = 21.90$, $SD = 8.938$), followed by the Partnership index ($M = 21.60$, $SD = 7.917$), the indicator of Representative was again ($M = 16.55$, $SD = 8.918$), and the Subordinate was the lowest ($M = 15.15$, $SD = 7.110$). One-way ANOVA showed: $F(3) = 3, 505$, $p = 0.019 (p < 0.05)$, $\eta\ 2 = 0.123$, so it was considered that at least one of the four groups was significantly different from the other. Paired t-test showed: Partnership and Subordinate ($T = 3.84$, $p = 0.016$, significant difference); Co-embodiment and Representative ($T = 3.12$, $p = 0.044$, significant difference); Co-embodiment and Subordinate ($T = 3.57$, $p = 0.012$, significant difference), these data show that Partnership requires more attention than Subordinate, Co-embodiment than Representative and Subordinate in remembering presented information. In terms of Auditory Demand, one-way ANOVA showed that $F(3) = 0.189$, $p = 0.903 (p > 0.05)$, $\eta\ 2 = 0.007$, the difference between the four relationships was not significant, which indicated that this kind of driving In terms of Visual Demand, $F(3) = 0.625$, $p = 0.601 (p > 0.05)$, $\eta\ 2 = 0.024$, among which the difference between Partnership and Representative is relatively higher. High but not significant ($T = 2.20$, $p = 0.232$, non-significant), and the differences among several other relationships were also not significant, which may be because the Participants did not pay more to the intelligent agent in the driving environment. Visual effort; in terms of Temporal Demand, $F(3) = 1.911$, $p = 0.135 (p > 0.05)$, $\eta\ 2 = 0.070$, the difference between the four relationships is not significant; in terms of Situation Stress, $F(3) = 0.032$, $p = 0.992 (p > 0.05)$, $\eta\ 2 = 0.012$, which indicates that the difference between the four role relationships is not significant, which may be because the experimental environment is a simulated driving rather than a more realistic environment (Fig. 4).

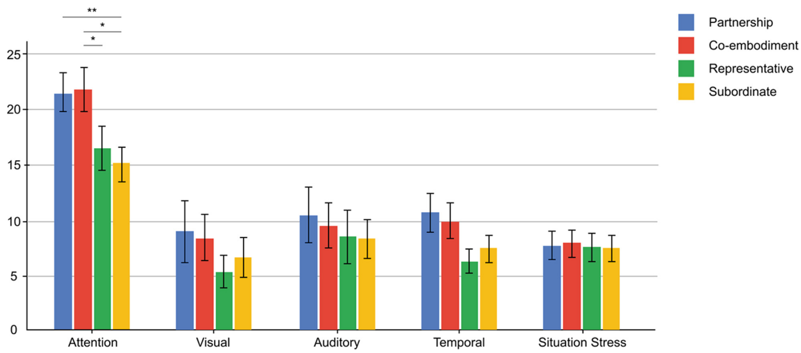

Fig. 4. The results of the DALI factors under the role-based relationship in the Navigation Planning scenario.

Analysis of Music Switching scenario: In terms of Attention Demands, the indicators of Co-embodiment are the highest ($M = 17.70$, $SD = 8.640$), the hands under the Subordinate are the next ($M = 14.40$, $SD = 7.214$), and the arrows under the Representative is again ($M = 14.30$, $SD = 8.670$), and the indicators under the Partnership is the lowest ($M = 13.55$, $SD = 7.075$), which indicated that the Partnership required less attention than the other three relationships in the Music Switching scenario. From the one-way ANOVA, it can be concluded that $F(3) = 1.084$, $p = 0.361$ ($p > 0.05$), $\eta\ 2 = 0.041$, so there is no significant difference among the four groups of data. In terms of Auditory Demand, $F(3) = 0.217$, $p = 0.884$ ($p > 0.05$), $\eta\ 2 = 0.009$, there is no significant difference among the four groups of data; in terms of Visual Demand, the differences between Partnership and Co-embodiment are relatively high, But it was not significant ($T = -1.976$, $p = 0.419$, non-significant), and there was no significant difference among the four groups of data; in terms of Temporal Demand, $F(3) = 0.472$, $p = 0.703$ ($p > 0.05$), $\eta\ 2 = 0.018$, there is no significant difference among the four groups of data; in terms of Situation Stress, $F(3) = 0.488$, $p = 0.692$ ($p > 0.05$), $\eta\ 2 = 0.019$, there is no significant difference among the four groups of data (Fig. 5).

Attention Behavior of the Driver. To explore the eye movement behavior characteristics of each information display mode in the navigation context, Tobbi glasses two was

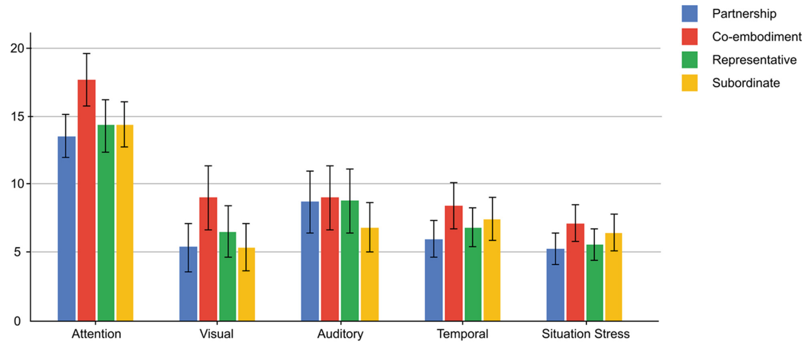

Fig. 5. The results of the DALI factors under the role-based relationship in the Music Switching scenario.

used to collect the eye movement data of the subjects, and Tobii Pro lab was used for data analysis. Gaze heatmaps and eye-tracking maps were generated according to the period of the issues.

The Fig. 6 below shows the feature comparison map of the participant's eye movement behavior in the Navigation Planning scenario. It can be found that no matter what kind of driving, there are common gaze characteristics. During the driving process, the participants' eyes were mainly focused on the front of the road and the car's central control; the driver allocated most of their attention to this area to focus on the road conditions and the route displayed on the screen in real time. Second, participants will jump between the mobile phone and the car's central control to obtain road condition information from the multi-party conversation. Eye movement heatmaps for Partnership, Co-embodiment, Representative, and Subordinate are presented separately. After comparing the thermal images of different groups, it was found that the Partnership and Co-embodiment relationships were more frequently concentrated on the mobile phone and the central control device of the car than on the other two groups. Therefore, it can be judged that in these two relationships, participants must allocate additional attention. Under the Representative, the gaze points of the eyes will be relatively concentrated on the road surface, and less is given to the two devices, so it can be judged that the participants are more focused on the driving behavior.

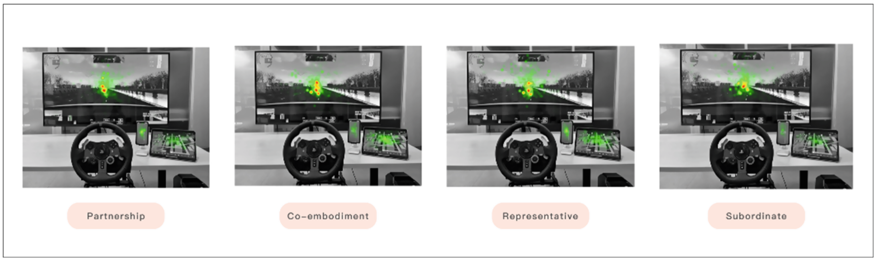

Fig. 6. Eye movement thermogram in the Navigation Planning scenario.

Figure 7 below compares the participants' eye movement behavior in the Music Switching scenario. As a non-driving task, the participants' load is relatively small so they will focus more on the road. In this scenario, the user's jump between two devices showed a more significant difference, with the participant in the Partnership being less distracted between the devices. In contrast, the participants in the Co-embodiment and Subordinate showed more significant differences; attention was switched between the two devices more frequently. This may be because, in entertainment-oriented scenarios, people see intelligent systems as a level relationship, so an equal and intimate form of a dialogue between intelligent systems will feel more natural and focus more on driving behavior.

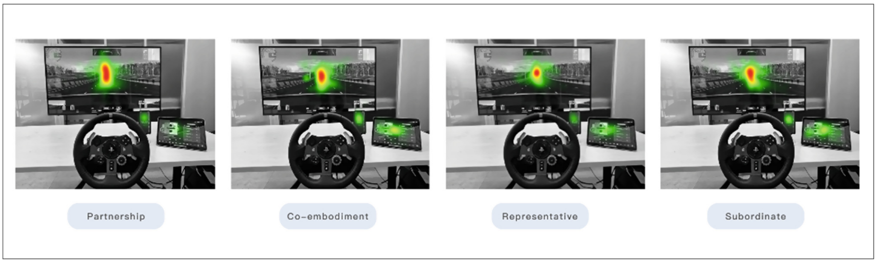

Fig. 7. Eye movement thermogram in the Music Switching scenario.

5.2 The Robotic Social Attributes Scale Index (RoSAS)

RoSAS is how people think about robots using an evaluation dimension, detecting whether agents exhibit good social attributes in communication patterns. We want to know whether the change in the role-based relationship between agents will have different perceptions of warmth, competence, and discomfort.

Competence Judgments. The figure below shows the mean difference between the four role-based relationships under the competence dimension. The indicator of Partnership is the highest (M = 5.36, SD = 1.064), followed by the indicator of Co-embodiment (M = 5.02, SD = 1.848), the indicator of Representative was again (M = 4.48, SD = 1.218), and Subordinate was the lowest (M = 4.82, SD = 1.044). Through one-way ANOVA and paired T-test, it was found that Partnership and Co-embodiment (T = 2.376, p = 0.128, significant difference); partnership and agency relationship (T = 2.211, p = 0.020, non-significant); Partnership and Subordinate (T = 2.834, p = 0.016, significant); Co-embodiment and Representative (T = 0.087, p = 0.420, non-significant); Co-embodiment and Subordinate (T = 0.363, p = 0.370, non-significant); Representative and Subordinate (T = 0.207, p = 0.928, non-significant).

Warmth Judgments. The figure below shows the mean difference between the four roles-based relationships under the warmth dimension. The indicator of Partnership is the highest (M = 5.18, SD = 1.004), followed by the indicator of Representative (M = 4.80, SD = 1.278). The Co-embodiment indicator was again (M = 4.54, SD = 1.297), with the lowest Subordinate (M = 3.84, SD = 1.131). Through one-way ANOVA and paired T-test, it was found that the Partnership and Co-embodiment (T = 9.115, p = 0.007, highly significant); the Partnership and Representative (T = 7.464, p = 0.110, non-significant); Partnership and Subordinate (T = 2.834, p = 0.000, highly significant); Co-embodiment and Representative (T = −1.198, p = 0.273, non-significant); Co-embodiment and Subordinate (T = 0.994, p = 0.003, highly significant); Representative and Subordinate (T = 2.142, p = 0.000, highly significant).

Discomfort Judgments. The figure below shows the mean difference between the different role-based relationships in the discomfort dimension. The index of Co-embodiment is the highest (M = 3.40, SD = 1.485), followed by the index of Subordinate (M = 2.66, SD = 1.437), the indicator of Partnership was again (M = 2.64, SD = 1522), and Representative was the lowest (M = 2.34, SD = 1.042). Through one-way ANOVA and paired T-test, it was found that Partnership and Co-embodiment (T = −4.806, p = 0.007, highly significant); Partnership and Representative (T = 0.444, p = 0.280, non-significant); Partnership and Subordinate (T = −1.148, p = 0.943, non-significant); Co-embodiment and Representative (T = 4.862, p = 0.000, significant); Co-embodiment and Subordinate (T = 3.355, p = 0.008, significant); Representative and Subordinate (T = −1.487, p = 0.249, non-significant) (Fig. 8).

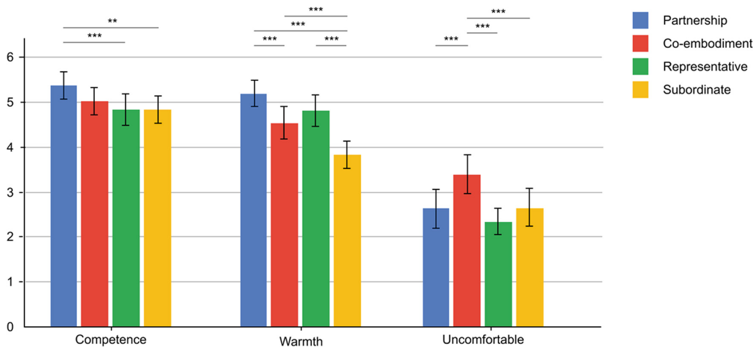

Fig. 8. Bar graph of RoSAS of role-based relationships

5.3 Analysis of Interview

To compare the user experience differences between the four role-based relationships in different scenarios, we conducted a multivariate analysis of variance. From the study of variance test results, it can be concluded that the significance of the role-based relationship is p = 0.000; the significance level of the scenario is P = 0.017. The importance of the interaction between the two factors is also less than 0.05, indicating that the exchange of the two factors significantly impacts user experience perception.

The four kinds of role-based relationships are sorted by preference in two different scenarios, and the results are shown in the figure. It can be seen from the figure that the user's choice for the role-based relationship is other in different scenarios: in the Navigation Planning scenario, 40% of the users prefer Representative, and 36.67% of the users rank the Co-embodiment last; In the Music Switching scenario, 46.67% of users ranked Partnership first, and 40% of users ranked Subordinate last. In short, users' preferences for role-based relationships also vary in different scenarios. Partnership and Representative are generally more popular, while Subordinate and Co-embodiment have typically little difference and are ranked lower (Fig. 9).

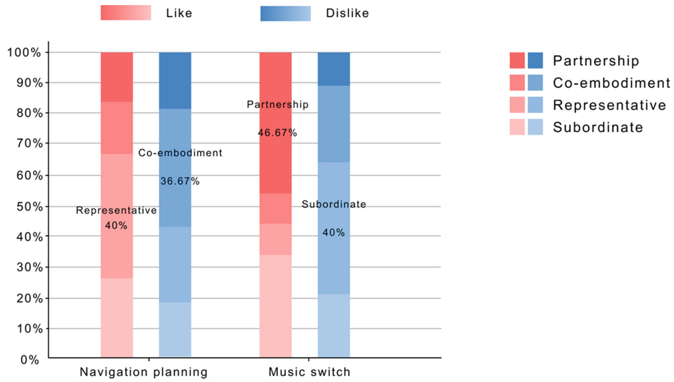

Fig. 9. Preference ranking percentage chart

6 Discussion

The results of data analysis are studied from the perspective of role-based relationships. From the corpus of users, it can be found that users have different views on different communication modes. Based on these analyses, we can start from the characteristics of different communication modes and apply different communication modes to appropriate scenarios to improve user experience. The comparison of different communication modes is shown in Table 3.

The findings for different communication modes seem somewhat different from the expected impressions, and hypotheses 1 and 2 are partially supported. In Navigation Planning scenarios, users prefer Representative and Subordination; in Music Switching scenarios, users prefer Partnership. The different role-based relationships between agents should be considered in conjunction with specific driving tasks and design requirements. Participants believe that Partnership shows more warmth than other relationships, and it is also interesting to apply it to agents. Still, subject to complex interaction logic and agent relationships, users generally believe this relationship seems redundant and unnecessary in efficiency-based scenarios (Navigation Plan). Therefore, Partnership is suitable for scenarios emphasizing attractive and emotional attributes, such as music switching, or some settings emphasizing easy-to-understand and natural social interaction. The Representative correlates with the experimental results of the representation pattern in Tan's study. Some participants said that their natural language when communicating with people and machine behavior when communicating with machines showed a sense of delay, but because a device replaced the speech throughout the whole process, it made the participants feel clearer, which was consistent with the expected impression. Is biased. Users said that the Representative is more concise and efficient, and they can pay more attention to the road conditions during driving. Some participants also noted that the Representative is suitable for scenarios that need to express multiple social identities without the spatial conditions for voice communication, such as remote control.

The Subordinate also deviates from our expectations. Some users said that although the Subordinate is very efficient, the apparent superior-subordinate relationship will bring a sense of oppression and discomfort. Bring a sense of authority. Therefore, Subordinate is suitable for scenarios with great attention to efficiency and trust, and it is safer to choose affiliation when the requirements are unclear. The Co-embodiment has novel and exciting characteristics. Participants said that under this relationship, the integrity of the devices is more robust, and the participants generally think of future autonomous driving scenarios. Of course, some participants said that the degree of freedom of form that can shuttle between different devices is too high, and there will be a feeling of losing control. Overall, the Co-embodiment applies to a wide range of scenarios, and there will be more exploration in future driving scenarios.

Table 3 .

Relationships	Advantage	Disadvantage	Features	Suitable scenario
Partnership	The highest social attributes	Not concise enough, slightly verbose	Kind and natural	Natural social, leisure, and entertainment scenario
Co-embodiment	Strong integrity	Confusion	Flexible and fun	Autonomous driving scenario
Representative	Can be connected remotely	Strong sense of delay	Concise	Scenarios that focus on efficiency and driving safety
Subordinate	Strong execution and high efficiency	Strong sense of oppression	Efficient and boring	Efficiency-oriented scenarios

After completing the experiment, we sent the Big Five Personality Scale to the participants in the experiment, hoping to make discoveries on the preference for the relationship between personality and role. According to previous studies, extraversion is the most easily perceived personality trait in oral language, and agreeableness represents an individual's attitude toward others. Therefore, the research on the relationship between personality and attitude-voice focuses on examining the extraversion in the Big Five. Extraversion and Agreeableness are two traits, so we also choose these two traits as the essential reference in this study. The questionnaire feedback shows that among the 30 users who participated in the test, the proportion of high Extraversion users is about

57%, the balance of high agreeable users is about 60%, the proportion of high openness users is about 47%, and the ratio of high Conscientiousness users is about It is 63%. The balance of high Neuroticism users is about 13%. After analysis, it is found that there is no apparent relationship between personality traits and role relationships. This may be because the participants will pay more attention to driving in the driving scenario, so when sorting preferences, they will prioritize completion efficiency, whether driving is distracted, etc. factor.

7 Conclusion and Future Work

This paper proposes a framework for roles-based relationships in driving environments and discusses the differences in user preferences for different relationships. We designed an experiment to test our hypothesis by comparing Partnership, Co-embodiment, Representative, and Subordinate through a simulated driving environment. In the current study, we compared the four role-based relationships regarding psychological conformity and investigated the differences in driving load and attention behavior among different role-based relationships. We evaluated our proposed framework using the DALI questionnaire, trend analysis of experimentally collected eye gaze data, and the Supervisor Impression Questionnaire. The results of DALI show that the Representative is prominent in driving scenarios. Its concise communication mode requires less eye-gazing behavior and is more suitable for task-oriented methods. It is also demonstrated that Partnerships have higher social attributes and need less eye-gazing behavior in entertainment-oriented scenarios, which is ideal for naturally social, casual, and entertaining systems. Therefore, in different scenarios, users show distinct preferences for role-based relationships. Trend analysis shows that our proposed role-based relationship framework is expected to play a design guiding role in multiple IAs designs in driving scenarios. More scenarios, including driving takeover and autonomous driving, will be considered in future research.

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