Guiding Preferred Driving Style Using Voice in Autonomous Vehicles: An On-Road Wizard-of-Oz Study

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ABSTRACT

Matching the autonomous vehicle's (AV) driving style to its user's preference is core to a satisfactory user experience. The recent HCI community has undertaken a significant amount of research to understand user-preferred driving styles in AVs. Due to its multi-faceted nature, understanding these driving preferences is difficult unless users take roles in an adaptive system and share their needs explicitly. However, there is a lack of a proper channel for users to express their driving-style needs in AVs. To bridge this gap, we suggest a *user's preferred driving-style guidance using voice* as a novel input channel for human-centric AV control. We conducted a Wizard-of-Oz driving study on real roads, aiming to explore the guiding experience with the AV agent to reflect their driving-style preferences. This paper presents the value of driving-style guidance along with its burden to users, and concludes with its implications in designing a better AV-guiding experience.

CCS CONCEPTS

• **Human-centered computing → Empirical studies in interaction design**.

KEYWORDS

Autonomous Vehicles, Driving Style, User-centered Design, User-centered Control, VUI Agent

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1 INTRODUCTION

As the term *backseat driver* states, passengers on the road have their driving preferences and have a need to communicate them. Matching the autonomous vehicle (AV)'s driving style with the user's preference is key to satisfying AV user experience by building trust in the vehicle's driving [9, 37]. One's driving style is multi-faceted in nature: while comfort in driving, constituted by maximum turn speed and braking distance, [52] is one major factor, how the vehicle behaves in a social road, where a variety of vehicles communicate, yield, and compete, is also core in defining the driving style [15, 46]. The combination of these facets results in unique driving preferences of users.

The importance of reflecting different driving preferences has already been acknowledged throughout the automobile industry. Recently, Hyundai attempted to recognize and analyze user driving patterns to apply to its smart cruise control [31]. Tesla introduced a new 'driver profile' function in which users can choose from different driving-style parameters including acceleration, steering mode, regenerative braking, and stopping mode [32]. The HCI community also has focused on understanding the user's preferred driving style in AVs. Utilizing various methods from post-simulation interviews to bio-signal sensing, there are a few known parameters that affect user preferences [45]. Under the assumption that learning these parameters from users' driving would be beneficial, researchers used a user-demonstration to adapt the AV's driving style based on the data collected [22]. However, in the latter study, it is shown that users were not content with the AV's driving style when the AV simply mimics the users' driving style; users had a tendency to overestimate their driving's defensiveness and safety. Thus, the true value of AV driving-style customization is not fulfilled when it learns how the users drive, but is fulfilled when it learns how the users actually want to be driven [4].

It is difficult for the intelligent system to learn how users would want to be driven unless users take part in an adaptive system and share their multifaceted driving preferences. The quality of user experience in AVs would be increased once the users can express their needs and when the intelligent system can support the user-centered input process [18]. Moreover, providing user-driven information changes the passenger state from *second-class citizens* who fit themselves to the automated system to *riders* who are in control of the learning cycle [36]. However, to the best of our knowledge, there still lacks a proper channel for users to express their driving-style needs to control the AV. Without such a channel, user experience in AVs is likely to be controlled by machine-oriented learning, resulting in a less fitted driving style, as it is currently.

In this paper, we suggest a concept of the user's preferred driving-style guidance as a novel input channel for user needs in AVs. The aim of our study is to explore how driving-style guidance could be conducted in a realistic AV context and to figure out possible benefits and hindrances in the user-driven guiding interaction. From this motivation, we conducted a Wizard-of-Oz based user study in

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a real-road environment to explore the guiding experience of AV passengers without consideration for limitations of current technologies. The study result showed the benefits of the user's driving style guide when it comes to adjusting AV's behavior to better fit the user's genuine preference. Also, we found the value of preferred driving-style guidance in building the sense of controllability in AVs and constructing different human-agent relationships with AV agents, factors which could accelerate the acceptance of AVs to our everyday life. In conclusion, we suggest design implications that will help designers create better guiding experiences for AV users.

2 RELATED WORKS

2.1 Preferred Driving Style in AVs

While AVs are widely studied and early attempts at fully self-driving vehicles are already being driven on real roads, there is still much to be resolved with regards to user experience in AVs. Value incongruence and lack of control are two important factors degrading trust and comfort in AVs. AV passengers are uncomfortable with situations that the autonomous system works differently from what they expect, especially when they perceive their controllability level is low [24].

To align the autonomous systems to work in accordance with user needs, it is core to understand the preferred driving styles in AVs. Elbanhawi et al. explored the comfort parameter in AVs as user's roles change from active to passive driving [10], and Scherer et al. investigated the subjective parameters to model driving styles [38]. Dillen et al. criticized the currently fixed AV driving style focusing on safety only and lacking consideration of passenger comfort. He argues the importance in learning from passenger feedback to generate driving-style presets [9]. Given the significance of reflecting passenger response within the AV user experience, Park et. al used video prototypes to understand the user-centered perception of the semi-autonomous vehicle's decision-making process. It is acknowledged that individuals have different interpretations about the same situation, resulting in requiring various decisions for AVs to make [37]. Also, passengers may not only have individual driving-style preferences, but these preferences may alter depending on the road situation and context [9, 37].

Possible explanations for the varying preferences can be found in the social aspect of driving. Interacting with other vehicles is inevitable on the road, and the existence of other vehicles affects passengers' perception of safety and anxiety levels [9]. Vehicles' action of moving and stopping is considered as communication, and studies have focused on the social interaction on the road [14, 23, 35]. Following this, Brown et al. found that gaps between vehicles are the display of attitudes or norms, but at the same time these gaps are the norms to be bent through negotiation [6]. While which social factors (i.e., pedestrians, other vehicles, other passengers) affect the driving-style preferences in AVs is ambiguous, it is clear that these factors influence the interpretations and context of driving.

Although the holistic understanding of user needs in the driving situation is core to providing a suitable driving style in AVs, fewer studies focused on exploring channels to learn a wide range of information through user's expressions. In this study, we suggest a driving-style preference guiding as a novel input channel for controlling the AVs.

2.2 AV Passenger's Role in Human-Machine Collaboration

Advancement in AV technology brought a transition from driver-centric to passenger-centric experience. Although some studies focused on maximizing the convenience of automation and free-time opportunities [41], many concerned passengers being out-of-the-loop from automation systems. Since driving automation does not simply replace human drivers but creates new roles for the passengers to co-perform with the AVs, collaboration and interdependency is core to successful driving [7, 8, 11, 36, 49]. To investigate what is required for such co-performance, Horvitz reviewed principles in designing for a mixed-initiative interface within which intelligent services and users can collaborate efficiently [16].

A few studies explored the hand-over mechanism for automation to manual transition, considering the passenger's role as support for system failure [29, 44, 47, 48]. Walch et al. studied the new AV interface that offers multiple options in case of system uncertainty to involve the driver in the continuous decision-making process [49]. However, in many of the cooperative AV studies, the automation system still decided when humans and machines would cooperate and failed to make passengers the main decision-makers. Because the AV level 3 or below focus on the situation of system malfunction, there is no developed mean for users to maneuver AV's driving when the AVs function correctly, a situation which is more relevant to AV level 4 or 5. While the system failure or uncertainty functioned as the trigger for human-AV cooperation in lower level AVs, it is now to consider new triggers or roles for users in higher level AVs which would not have an issue with system failure.

Norman criticized the automation system functioning as the first-class citizen and human becoming the second class, meaning that people are more forced to behave according to the requirements of the automation technology [36]. Flemisch et al. suggested that there should be a dynamic balance in human-automation, sharing the authority, ability, responsibility, and control according to the context. Negotiation and arbitration between two partners is core in this dynamic balance, under the principle of maintaining human as the final authority all the time [11]. However, it has been yet unclear how to apply the human-AV cooperation from a human-oriented perspective. Thus, we would like to explore the potentials of users' explicit guiding for the rather novel application of human-centric AV interaction.

2.3 Natural Guiding Through Voice User Interface

The preferred driving-style guides in this study are the commands to the AVs to behave in a certain manner. In this rather novel concept, the key to appropriate guidance would be providing users with the most natural interaction method with their vehicles. While a few researchers studied the possibility of using gestures as a modality for natural interaction [26, 43], more studies have focused on implementing a voice user interface (VUI) or conversational agents to communicate with users. There are known benefits of vehicle-VUI, such as that VUI helps drivers to focus on driving [3, 25, 34]. Regarding users in fully automated vehicles frequently checked its performance [30], high-level AV users would still be benefited by VUI to keep their eyes on the road in case of road events. In addition, automobile manufacturing corporations like BMW and Benz designed their own voice assistant systems, and existing voice assistants such as Android Auto, Siri, and Cortana became more commonly implemented in vehicles. It is reasonable to expect the trend of in-car VUI would be continued in full AVs due to its naturalness and easy-to-use functions. Lin et al. designed a conversational in-vehicle assistant to help drivers understand advanced driver-assistance systems (ADAS) features. Although the scope of conversation was focused on asking questions and commands to use low-level autonomous driving functions, users found the voice assistant to be useful support [28].

There are also VUI usability problems, such as that users are not fully aware of the VUI system's capability or how to structure utterances to express desired intents [13, 33]. For example, in a more recent study on Robo-taxi service by Meurer et al., the researchers also used voice interaction for users to communicate with Robo-taxi and found that the participants felt insecure about how to interact with it [30]. It is yet unclear how voice interaction should be designed in highly-automated vehicles.

2.4 Wizard-of-Oz Study on Real-road

While more AV studies used simulators for study methods, significant amounts of naturalistic driving studies were conducted [1]. A predefined driving study conducted in circuits revealed that the presence of another vehicle heightened the users' anxiety level, implying the importance of the real-road study environment [9]. On-road driving simulations have more benefits for the participants in that they receive real-world sensory information when actual vehicle movement is involved. Krome et al. conducted a contextual inquiry in a real commuting situation in an attempt to understand more immersive future everyday routines in fully autonomous vehicles [21]. Yeo et al. designed six self-driving simulation platforms to compare the simulator fidelity [51]. While using virtual and mixed reality helps to close the gap between the simulator environment with fully autonomous vehicles, the simulators could only function properly in pre-modeled roads, thus limiting the degree of randomness and freedom for the passengers to interact with the AVs in real-roads. The real-road is full of contextual information with unprecedented circumstances, which are core to understanding the driving experience.

The most prominent real-life study method is the Wizard-of-Oz to implement the AV system beyond the technical constraints. In the WoZ, the 'wizard', a human experimenter, operates as an intelligent system to let the study participants experience a more immersive autonomous system [39, 50]. Baltodano et al. designed a real road autonomous driving simulator (RRADS) for WoZ [2]. Following this, a number of studies used similar real road simulators for prototyping and experimenting with the AV system. Meurer et al. explored what the everyday Robo-taxi service experience would be like in real-life settings when users become active passengers [30]. WoZ enables the researchers to 1) more freely design the details of the scenarios to allow participants to be absorbed in the hypothetical AV situation, and to 2) maximize the freedom of interaction, allowing the researchers to observe multi-faceted and unforeseen findings [19, 30].

The modified form of WoZ studies uses two wizards to operate as different computer agents or give the wizard-role to the participant instead of the experimenter. Benford et al. illustrated how studying the combinations of expected, sensed, and desired actions gives chance to take a fresh perspective on finding the new approaches to design [5]. To observe the three different actions, Lee et al. [26] included an interaction wizard for giving feedback to the participant while another wizard functions as a computer system to operate as the participants give orders. The possible design problems and solutions were found by recruiting pairs of participants and giving one participant a wizard's role. It is articulated that, especially for the initial stage of design, unexpected insights could be found from the free interactions of the participant pairs [26, 27]. Also, the possible preconceptions from the experimenter could be minimized by the role of participant wizards.

In our study, we implemented the modified form of WoZ in a real-road driving setting, which involves a pair of participants with one participant being a driving wizard. Details of the method would be illustrated in research methods.

3 RESEARCH METHODS

In this study, we conducted a Wizard-of-Oz study in real-road situations with 10 pairs of participants having two roles: driver and passenger. The drivers took the role of an AV agent (i.e., driving wizard) and drove the vehicle reflecting the passenger's guide. We defined a study situation as a fully autonomous vehicle (SAE level 4 or 5), which is able to deal with all road situations and requires no user-assistance for safety and legal issues. The passengers became the owner of the AV and had the role of guiding their preferred driving styles. For the study, the passengers were asked to guide every driving-style preference they can come up with while being driven in the study vehicle. The researcher was in the back seat as the interaction wizard to provide voice feedback on passengers' guiding commands through the *Text-to-speech* application. The aim of our method is to observe the passengers' experience in guiding their preferred driving styles in AVs. After each driving, we tried to figure out the intentions and further thoughts of both participant types through post interviews. The researchers provided a Kia K3 vehicle with full insurance for all drivers and passengers. All participants agreed to voluntarily participate in the study after signing an informed consent form approved by the institutional review board (IRB).

3.1 Study Setting

We employed the wide-angle action cameras to record the events of the on-the-road experiment. The locations of the cameras are shown in Figure 1. Two cameras (a, b) were affixed to the windshield in front of the passengers and drivers using a suction mount. The cameras were set up in a way to record the live reactions of the participants including facial expressions, hand motions, and postures. Another camera (c) was set to record the road situations to understand the context of the user guides. In addition, an iPad (d) was attached in front of the passenger seat to display the voice agent's state of waiting and processing the guide.

We referred to the RRADS method regarding the setting of partitions for in-vehicle WoZ to provide a more immersive AV experience to the passengers [2]. To make drivers invisible from the passenger seat, the partitions (e) were set between the drivers and passengers. The different partition sizes were tested prior to the study to cover various heights of participants. Both side-view mirrors and a rear-view mirror were visible from the drivers' point of view, for drivers to check traffic conditions and safety (Figure 2). The partition was made of a black foam core board to prevent additional damage in the event of accidents while fitting into the interior color of the study vehicle.

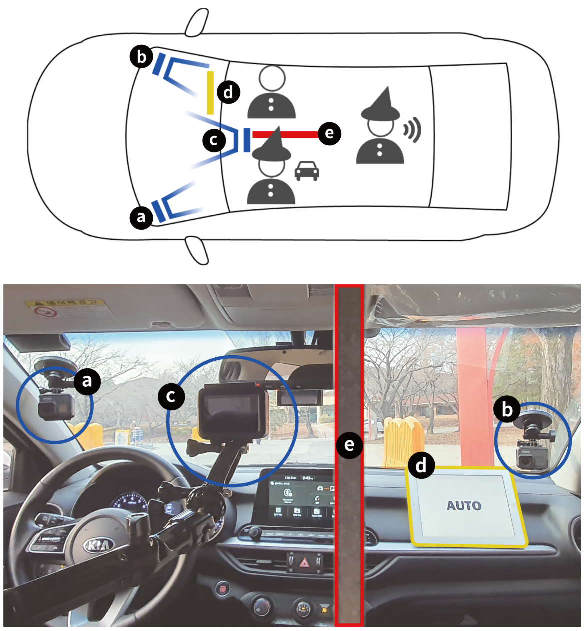

Figure 1: Instrumented setting

3.1.1 Two Wizards in AV VUI setting. We modified the WoZ setting to consist of two wizards: a driving wizard by a driver from a participant pair, and an interaction wizard by a researcher. The driver acts as the driving wizard to reflect the passengers' driving-style guides. While passengers' guides help researchers to capture the user-needs in the guiding process, we also planned to explore how drivers interpreted and reflected the driving-style guides. Although it is expected that human interpretation of information would not be identical with actual AV agent's interpretation, it is investigated that interactions between the participant pairs give unexpected insights in the early stage of design [26, 27]. Accordingly, the drivers were invited to share thoughts of how AV agents would interpret the guides and how to aid the passengers in guiding their preferences. The driving wizards helped build further ideas on how to modify the guiding process in a more human-centered way through post interviews. In addition to the known problems of current VUI mainly from natural language processing errors, there is a possibility that voice assistants give incorrect reactions to users due to the system's inability to understand the contextual information of the real road. To avoid hindrances of technological limitations of current VUI in guiding preferred driving styles, the researcher proceeded as the

Figure 2: Partition setting

interaction wizard. Passengers could get a more advanced voice interface and voice feedback to freely guide their needs, at the same time the drivers could only concentrate on driving tasks to prevent possible accidents (Figure 3).

The interaction wizard gave real-time voice feedback according to the passengers' guides using a *Text-to-speech* application. To maximize the feeling that the AV was producing the voice feedback, we used the vehicle's Bluetooth speaker to provide feedback. The examples of actual dialogue are shown in Table 1, which were devised according to situations when the user's intention, is clear to the system, when the user's intention is unclear, and when the answers require time to be generated. Passengers were suggested to use the wake-word "AUTO" when starting the guide, to mimic the existing VUI experience which many passengers were familiar with. In addition, the iPad tablet in front was displaying the agent's state by showing the wake-word when waiting for the user-guide and showing animations when preparing voice-feedback, to help passengers get a more vivid guiding experience (Figure 4).

3.2 Participants

We recruited 10 pairs, a total of 20 participants through an online campus community and a department's communication channel. The driver participants were experienced drivers with no accident-record for over 3 years to assure safety in the driving study. The passenger participants had relationships with the drivers but had little experience in riding with them, in order to prevent their driving-style familiarity from affecting the passengers' guiding experience. The reason why we recruited the pairs who know each other well is to minimize the potential risk of pairing strangers for study due to COVID-19. Among 10 pairs of participants, 7 pairs were friends and 3 pairs (pair 2, 8, 9) were co-workers. Participants were

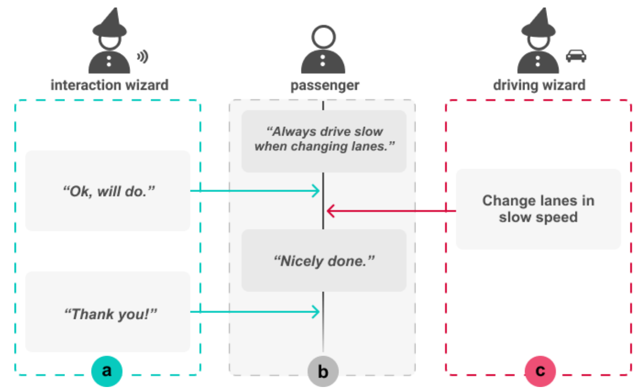

Figure 3: Interaction flow: (a) the interaction wizard gives voice feedback, (b) a passenger gives guides to the AV, (c) a driving wizard applies the driving-style preferences (an actual example from P3)

Table 1: Example of actual dialogue according to situations

The system understood the user's intention
"You may speed up when there is enough room between us and the vehicle in front" (P9)
"Okay, will do."
The system is uncertain about the user's intention
"Auto, the road here is not paved well." (P1)
"I'm sorry, I didn't get what you meant. Could you repeat that?"
When answer takes time
"Auto, how long does it take from here?" (P3)
"Please wait for a second."
(pause)
"It will take 8 minutes to destination from current location."

Figure 4: Tablet showing the wake-word and listening state

in their 20s and 30s, with a 20 percent female and 80 percent male ratio. There was one female among the drivers, while 30 percent were female among the passengers. The average driving experience of drivers was 5.2 years (max:16, min:3) and the passengers had a variety of driving experiences (maximum 7 years), but 50 percent of the passengers had very little driving experience. 8 participants had low-level AV experiences such as a self-parking, a smart cruise, or a partial automation. The participants' knowledge regarding AVs varied from low, medium (i.e., knowledge from news or media), to high (i.e., ability to explain the concept to others) (Table 2). We

Table 2: Participant Demographics

No.	age	sex	driv' exp.	driving style	AV exp. / knowledge	time of study
D1	25	f	3	neutral	yes / high	day time
P1	24	f	5	neutral	no / low	
D2	27	m	3	neutral	yes / high	day time
P2	23	m	7	neutral	no / medium	
D3	25	m	7	neutral	no /high	night time
P3	25	f	0	neutral	no / medium	
D4	32	m	16	speedy	yes / high	day time
P4	27	m	1	speedy	no / medium	
D5	25	m	3	neutral	no / medium	day time
P5	25	m	0	speedy	no / medium	
D6	28	m	3	neutral	no / high	night time
P6	30	m	1	defensive	no / medium	
D7	28	m	4	neutral	no / medium	day time
P7	26	f	0	neutral	yes / medium	
D8	25	m	3	defensive	no / medium	rush hour
P8	25	m	0	neutral	no / medium	
D9	26	m	4	neutral	no / medium	day time
P9	26	m	0	defensive	no / medium	
D10	24	m	6	speedy	yes / high	day time
P10	24	m	1	neutral	no / medium	

recruited participants with different combinations regarding the driving experience, AV knowledge and experience, preferred driving style in manual driving, and available time for the study as shown in Table 2, in order to cover a variety of guiding circumstances.

3.3 Procedure

We designed our study process in five phases: 1) *pre-questionnaires* to get basic demographic information and initially preferred driving styles of passengers, 2) *mission-cards* to give instructions of participants' roles, 3) *test-driving* to get used to AV VUI and study vehicle, 4) *on-the-road driving* as the main guiding phase, and lastly 5) *post-interviews*.

In the *pre-questionnaire*, participants were asked to fill out a demographics questionnaire including questions for self-reported age, gender, preferred driving styles (i.e., speedy, neutral, defensive), usual driving routes, prior experience and knowledge with AV, and the relationship with the paired participant.

Mission-card instructions were given before *test-driving*. The mission-card had different information depending on the roles. Driver's cards consisted of descriptions of the driving wizard's role with the operational information of the study vehicle. The cards for the passengers had descriptions of the AV agent's intelligence along with short questions to trigger them to be immersed in WoZ study setting. Both passengers were given information on their driving routes for the study (Figure 5).

We carefully designed the *test-driving* phase for participants to take a test course (on-campus) driving to immerse themselves in their roles and situations. It was time for the drivers to become familiar with the study vehicle while allowing passengers to get used to the voice interaction and guiding processes. Passengers were asked about their preferred driving style for an initial setting of the AV's driving style. We asked the drivers to stop the vehicle when they were confident in operating the vehicle, and the length of the *test-driving* phase was left to the driver's judgment. We proceeded to the *on-the-road* phase only when all participants were ready.

The *on-the-road* study began with the passenger's guide: "Auto, go to destination A". To minimize the risk of accidents from unfamiliarity, we assigned the destinations and routes that each driver answered through the pre-questionnaire that s/he is most familiar with. Participants drove through a variety of routes (7 different destinations all in urban areas) for approximately 30 minutes traveling back-and-forth. Through the initial pilot trials, we decided that 30 minutes was optimal to experience various road conditions without causing too much stress or fatigue of participants. To observe diverse experiences from different road environments, the driving studies were conducted at different times of the day, including nighttime, daytime, and rush-hour (Table 2).

After each driving study, participants were interviewed for approximately 35 minutes. Passengers and drivers were interviewed individually to observe more natural thoughts. In addition to the semi-structured interview questions according to the different roles of participants, we asked detailed questions related to guiding experience in real-road conditions. The interview questions for the passenger participants include 1) expectations for guiding interactions, 2) driving-style guiding experience as a passenger, and 3) guiding experience through voice feedback. For drivers, the questions consisted of 1) experience as an AV agent, 2) how they interpreted and reflected the guides in driving, and 3) how they would have guided differently if they were passengers.

3.4 Assuring Safety Regarding COVID-19

We conducted the study in compliance with national norms and rules to minimize the risk of COVID-19. We recruited the participants in pairs who already had relationships to avoid new gatherings. All studies proceeded when the nation's COVID-19 standard was 'social distance level 1', which is given when the pandemic situation is least serious. It allows daily economic activities, gatherings, meetings, and events once proper safety procedures are provided. The body temperatures of all study members including the researcher were measured before the study. During the study, the windows were opened for ventilation with everyone wearing masks the entire time. We kept contacting information of all participants for 2 weeks to assist the epidemiological survey in case of participants having symptoms. And ever since the study was conducted, none were reported for any issues of COVID-19.

3.5 Data Collection and Analysis

To explore the participants' guiding behaviors on real-road, in-the-wild driving and guiding were recorded and transcribed. Three sets of 6-hour-long driving video clips from different camera angles were re-organized to match each guide with the road situation, the passenger's behavior, the driver's behavior, and voice feedback given at the time. The guiding dataset was qualitatively analyzed using provisional coding. The initial codes used to analyze the guides were partly referring to AV comfort measures from literature [10, 12]. Using the initial code list generated by a researcher, another researcher coded each guide made by the participants while expanding the code list. The two researchers continuously shared opinions about the codes throughout the analysis process aiming to reach consensus on the codes. For example, in case of coding the action types for guides, two codes, *Preferred driving style* and *Training the norms* required frequent coordination, because it was complex to determine whether to classify the social norms as the passenger's preference or not. We decided to consider only the guides regarding the official traffic rules as the *Training the norms* and sort the social norms as the *Preferred driving style. e.g, "Auto, don't start driving too early when we are in very front of the lane (before the traffic signal), stay still for a second before begin driving"* (P6). Because the guide was not based on the official traffic rule but was based on the participant's personal anxiety that people might come out from the side, P6's guide was coded as the *Preferred driving style.* At last, both researchers went through the coded data to finalize our agreement on the codes.

Accordingly, over 700 minutes of post-interview audio transcripts from both the passengers and drivers were coded and qualitatively analyzed. Primarily, a total of 8 initial codes were generated by the researchers including the *1)meaning of driving, 2)meaning of autonomous driving, 3)value of guiding, 4)way of guiding, 5)difficulty in guiding, 6)requirements for guiding, 7)way of conversation, and 8)voice feedback.* Each initial code was expanded into 6 to 10 secondary codes. e.g, a secondary code, 'building relationships with an AV via guiding' was generated from the initial code, *value of guiding.* We collaboratively analyzed the secondary codes to obtain comprehensive meanings to suggest the findings. The analyzed results are shown in our findings.

4 FINDINGS

Total 278 guides were made by the passenger participants. An average of 27.8 guides was made per passenger during an average driving time of 36 minutes. Even in the WoZ setting of our study, most passenger participants were immersed in their roles as AV owners. P9 commented that, while he thinks he would have guided more frequently when the AV agent was a real AI, the existence of human driver did not influence him guiding driving-style preferences he intended to. P6 specifically mentioned that, *"It could be annoying to people if I'm giving the same guides over and over.*

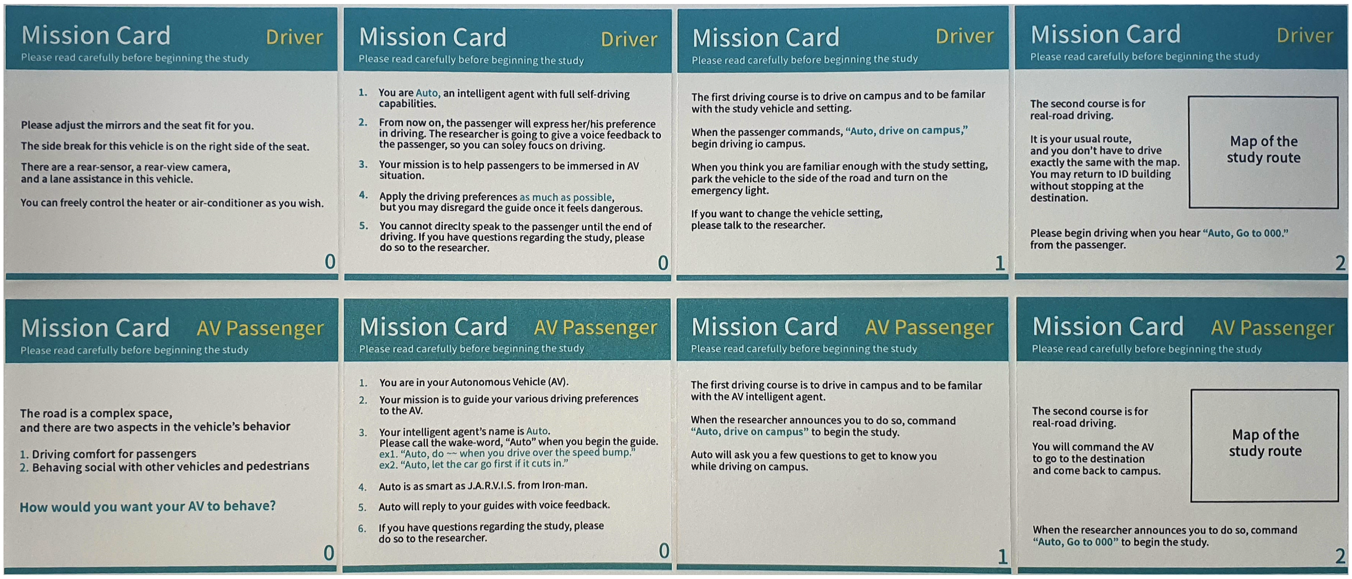

Figure 5: Mission cards explaining (0) the roles, (1) the *test-driving* phase, and (2) the *on-the-road* phase (translated in English)

But this time I was comfortable giving guides because I didn't worry about that (annoying others), since I didn't consider the driver as human." On the other hand, P2 answered that he gave less guides because D2 was his senior at work. P1 shared her initial concern of hurting the driver participant's feeling and mentioned that she would have guided more. Still, the existence of the partition helped P1 alleviating the concern and led her give 26 guides. Other participants, although they acknowledged that the driver was human, the close relations among the participant pairs allowed the passenger participants to guide their preferred driving styles more freely to the agent without much concern of hurting human feelings.

From analyzing the guides and interviews of passenger and driver participants, we found the value of driving-style guidance in 1) learning users' genuine driving preferences, 2) building a sense of controllability by in-situ guidance, and 3) forming various human-agent relationships beyond mere master-servant mental model. In addition, we observed the burden of guiding driving styles to AVs.

4.1 Guiding Driving Styles to AVs

4.1.1 Guiding driving styles to adjust AV's behavior. From the interview, participants shared their pre-existing needs in guiding their preferred driving styles in road situations. Most participants felt a strong urge to tell the drivers to behave differently when the driving styles were unmatched with the participants' preferred styles.

We found the benefits of driving-style guiding in micro-adjustment of the AV's driving behaviors to various road situations. If there was a discrepancy between the AV's driving style and the preferred style of the users at first, the explicit guiding enabled users to alter the driving more fit to their needs: *"No matter how well the AV corporations designed it, it is much nicer to have the capability to express what I want. Because if you design considering the entire population... there are minorities that could be disregarded. I can't stop thinking that being general does not fit for everyone"* (P10), *"If I said 'I like this type', or 'I like how you drive', it (AV) would continue that style. Then it is more clear that I can feel the place fits me"* (P3).

4.1.2 What users guided for their driving-style preferences. To understand what users want to guide, the type of the guide actions and the containing intentions were analyzed. Note that certain guides were given multiple codes for action. The 278 guides were categorized into 17 types of guide actions including *preferred driving style, compliments, comparison to the current state* (Table 3). The most frequent guide type was the *preferred driving style* (104 times), which is the personal preference related to driving styles such as to slow down vehicle speed when pedestrians are around or to avoid following heavy-load vehicles. Many guides had forms of *compliments* (53 times), and passengers frequently used the *comparison to current driving state* (50 times), such as guides to drive faster than the current speed or to put on the brakes more gradually than braking was conducted at the moment.

Along with guide types, each guide action contained the intention to alter the driving style of AVs (Table 3). A great number of guides contained intentions related to *safety* (114 times), showing the passengers' interest in safety issues in AVs. Various guide action types including *defining the situation, explaining the reasons, training the norms, and criticizing* were used to express safety concerns in AV driving. While *preferred style* expressions were often related to *driving comfort*, the personal preferences also contained safety needs, suggesting that perceived safety is different among users. Note that guides such as to *yield* and to follow *norms* were conducted multiple times to adjust AV's behavior in social roads.

4.2 The Real-Road Cues: Making Driving-style Guidance Feasible

4.2.1 Using real-road cues for in-situ guiding. While AV corporations are trying to pre-set the driving style by users' choice, we observed the need for in-situ driving-style guiding as the participants were not clear about how they want to be driven unless they face the situation. In a test-drive, prior to the real-road driving study, we asked each participant what their usual driving preference is.

Table 3: Guide Action Types and Containing Intentions

Guide Action Types (# of times)	Guide Examples and Intention of the Guide
Preferred driving style (104)	P6: "Auto, I like changing lanes slowly even if it takes time." (Safety)
Compliments (53)	P7: "I like how you drive softly. It is good, just keep this way." (Driving comfort)
Comparison to the current state (50)	P8: "Driver more slowly when going over the speed bump." (Driving Comfort)
Defining the situation (39)	P9: "If there is enough room between us and the vehicle in front, you may speed up a bit." (Speed)
Explaining the reasons (34)	P2: "Slow down because there are people in front." (Safety)
Training the norms (28)	P8: "Drive in 30km/h near residential area." (Norms, Safety)
Non-driving related guides (27)	P6: "Auto, open up the window and close it after a minute." (Convenience)
Requests (26)	P10: "Take the turn left after that vehicle." (Yield)
Emotion expression (23)	P5: "What the hack is that?" (Speed-the study vehicle changed the lane to speed up, and the car in front also changed the lane to block)
Questions (21)	P4: "Auto, would you tell me which routes you are going to take?" (Information, Routes)
Preferred conversation style (14)	P3: "Auto, if you stop so sudden, I would like you to say something to make me feel relieved." (Communication)
Criticize (14)	P4: "Auto, I told you to reply with shorter words. Just say yes." (Communication)
Delivering facts (7)	P1: "Auto, the road here is not paved well." (Driving comfort)
Comparison to the past state (6)	P1: "Auto, I prefer this kind of wide road than the road before. Let's keep driving on this kind of roads." (Driving comfort, Routes)
Driving check (5)	P4: "Oh, you are turning right, okay." (Information)
Providing examples (5)	P3: "So for example, when you stop suddenly in yellow lights, cars behind might hit us because we stopped abruptly." (Safety, Norms)
Struggling to guide (3)	P3: "It is very dark. If I want to be able to see far enough... what should I do? (talking to herself)" (Safety)
Intention (# of times)	
Safety (114), Driving comfort (45), Communication (29), Information (25), Yield (23), Norms (23), Convenience (20) Speed (18), Routes (12), Entertainment (11)	

Using the mission-card that has questions and examples to trigger users to think about how they want to be driven, the participants answered what came up in their mind. The initial answers were vastly vague: *"I want comfort"* (P6, P7, P8) or *"I like defensive style"* (P5, P9). Although few participants could think of detailed examples of their preferences such as *"Something safe. Let other cars in if they want to cut in, and… be stable?"* (P1), or *"Keep the distance, and if there are cars trying to cut in, let them in if we have room"* (P2), they also struggled to think of more examples. Interestingly, one of our participants, P5, told the AV agent the preference that was opposite to what he actually guided during the driving study. While he answered that he wants safety as his priority, what was implied in his guides and interviews was that he actually prefers speedy and bold behaviors of AVs. To learn the genuine preferences of AV users, in-situ guiding would be required.

The real-road is full of unexpected instances with a dynamically changing environment. The vast majority of guides given during the driving study were made after the participants witnessed the cues for guidance in real-roads. The range of cues varied from traffic signs, pedestrians on crosswalks, to road conditions. P4 shared his experience of using the triggers once he faced them: *"To be honest, I didn't have a clear vision of the driving factors that I consider important when I read the mission-cards… I think I tried guiding after I observed the situation. So I said, 'hey, don't do that' after the action occurred rather than giving directions in advance."* Although participants might struggle at first to get an idea of what to guide to the AVs, the driving context itself provides enough cues for users to utilize to understand how they want to be driven and which preferences to guide.

4.2.2 Types of information that constitute the AV driving context. It is still unclear what constructs the AV's driving context from a user's guiding perspective. From the analysis of the guides made by passengers, we organized the cues AV users utilized to guide their preferred driving styles in a real-road context. All the triggers occurred during the on-road study were coded by the researchers to classify the information sources. The initial codes were then merged to conclude that a total of six types of information form the driving context. The information types required to interpret the driving-style guides include *vehicle state, surrounding environment, route-related data, past-driving data, weather*, and *user emotions.* The vehicle state is composed of the elements related to the AV's movement such as speed, the timing for the turn signal, and the turning speed. The vehicle state elements are mainly studied to define AV's driving styles in prior studies [9, 52]. In addition, the surrounding environment consists of the elements such as the uniqueness of surrounding vehicles (i.e., emergency vehicles, heavy-loads), distance with the vehicles, and the speed of other vehicles. The comparison of the speed of the AV and other vehicles was important for users to decide the flow in traffic, affecting their guides to overtake or to slow down by following the norms of the road. Also, we found that users often referred to the past driving state to compare it with the current state, making the past driving data one of the types of information that forms the driving context.

Although acquiring all types of information is expected to be complex, the combination of the information types forms how the users want to be driven in AVs. In this sense, designing the system to accommodate more information types has the potential to improve the AV experience.

4.3 Achieving a Sense of Controllability from Guiding Experience

Users' perception of lack of controllability is a well-known problem in AVs because concepts of advanced AVs with higher levels of autonomy lack systems for users to directly control the vehicle or to express their needs while driving. We observed the value of driving-style guides in giving a sense of controllability to AV users by allowing users to decide when to have control.

The majority of passengers answered that they perceive more controllability upon the AV's driving through driving-style guidance. Interestingly, the sense of controllability gave few passengers an implication that they are 'driving' the AV. While they couldn't get the live feedback of movement like when pushing the accelerator pedal, the driving-style guide imitated some extent of driving experience: *"It is not exactly the same with driving cars, but it is much like driving than riding in a taxi ... maybe I got that feeling because I gave feedback (to AV)"* (P4), *"Because it's driving with actually reflecting my needs, it would eventually feel like I'm driving it"* (P7).

The most basic value of driving-style guiding was in avoiding unwanted road situations. Multiple participants commented about avoiding narrow roads or driving next to large vehicles. As passengers were not accessible to the steering wheels, they were afraid of the absence of clear ideas how long the AV would continue the unwanted situation. Whether they have the ability to express their dislike about the situation or not was important for participants in perceiving safety and mental comfort. P2 was in a situation where he had to ride next to a large truck. He commented about the value of feeling in control regarding the experience: *"At least you can escape from the situation you don't want. For example, suppose you ride next to a dump-truck and the vehicle keeps on driving by the side without dodging it. If you are allowed to order the AV to pass the truck ahead, that helps me avoid that situation and gives me mental relief."*

Moreover, guiding interaction enabled the participants to have temporary user control for a more human-like or flexible driving experience on the road. For instance, P8 faced a selfish driver who tried to cut off the lane in rush hour during a real-road driving study. While he consistently guided the AV agent to yield and let other vehicles in if they had the turn signal on, the participant did not want to let the selfish driver in at the moment because many cars had waited behind the line: *"The AV was trained to let the cars in if they have their winkers on. But if I have control, I can say let's just go this time (without yield). I prefer to have temporary human control."* We also observed that a few participants wanted momentary breach of traffic rules by guiding *"drive faster because there is nobody around,"* if they were sure about safety at the moment.

Likewise, the driver participants shared their thoughts about the importance of following the cultural or implicit rules according to different road contexts. The driving routes for the study were chosen to be familiar with the driver participants, and they understood the specific rules of each road. For example, D7 shared his opinion about the importance of knowing the regional knowledge about the road: *"I think that kind of knowledge should be accumulated too. I drive on that road every day. If you stop at that corner and don't move, the cars behind will honk at you crazy. And there was a car behind us with the right winker on."* Although the implicit rules are critical to traffic flow in social roads, it would be difficult, if not impossible, for AVs to know all the implicit rules of every road. Thus the AV user's role in guiding such rules has the potential in adjusting AV's behavior to follow the cultural and implicit rules.

4.4 Change in Relationships with AV Agent Through Driving-Style Guiding

Although the AV agent's personality or user's building rapport wasn't particularly suggested to the participants, a few passengers built their own perceived relationship with the agents. For example, one of the participants used a metaphor of role-playing game characters to describe AV agents: *"It feels like an RPG game to me because, after time, I can make an exactly the same driving style as I have, or something safer. I can raise the character level to make something better"* (P6). The perceived relationship P6 built with his AV agent helped him build trust in AVs because he thought the safety would be developed (i.e., level-up) by his effort in guiding the AV, the RPG game character.

Two passengers, P3 and P4, had a more educational relationship with the AV agent as they had instructor-student and father-child relationships. Their focus was on preventing the negative behaviors of AVs based on the idea that the AVs would still have to learn driving skills from the passengers: *"You can imagine the feeling a father would want when he is in his son's car. Something safer, and something more stable. I think I guided to optimize the AV focusing on safety to stabilize the vehicle even when I'm not there in the future"* (P4). Their will to educate the AV agent led them to guide frequently, ended up guiding 112 times (P3) and 53 times (P4) as a result. Unlike general expectations that instructors are well experienced in the field, P3 had a year of driving experience and P4 only had a license with no actual driving experience. Although the relation between the little experience in driving with their educational relationship was not clear at this point, it is interesting to see that participants' limited experience in driving did not seem to affect users to consider the AV agents as more expert in driving than themselves.

Some participants considered their relationship complex as they put themselves in multiple positions. For example, P3 also mentioned relationships such as owner-servant and a sense of unity between a user and an AV. P1 also felt the sense of unity as *"My entire body is inside it, and the change in body state changes my mind* *too."* (P1). The different relationships might have influenced their perceived controllability of the AVs, as most of the participants formed a higher position in relationships or considered the AV and the user as one. Moreover, we could observe the possibility to build trust with AVs by changing relationships. P6 shared his thoughts about how to build more trust in full AVs: *"If I'm the only one talking and training the agent, it (AV agent) would continue to feel like a child. But if it suggests something first and I can judge or agree with the suggestions, the relationship would be more like friends. And I would trust it better."*

4.5 Burden of Driving-style Guiding

While most participants agreed with the value of driving-style guiding in AVs, and three participants (P1, P3, P4) specifically mentioned that they succeeded in reaching their driving-style preferences to a certain level during the short amount of driving study, many also commented about the burden of guiding in the AV context. The burden was somewhat similar with the participant's perception of burden in manual driving. While driving was refreshment and rest to some participants, it felt like work for others.

4.5.1 Exhaustion from the prolonged focus of guidance. Even during driving-style guiding, many participants (P1, P2, P3, P4, P6, P8) wanted to relax more in between the guides. Participants also mentioned the true value of AVs comes from earning extra time to focus on themselves and not on the road. From autopilot cases, it has long been proved that users have a hard time staying alert in autonomous systems for a long period of time [7]. Their time spent focusing on the road gave participants a sense of controllability, but along with the fatigue. It was common among the participants that the guiding frequency decreased as time passed during the real-road study. While the decreased frequency was a sign of trust to some participants, others gave fewer guides as they got tired.

In a real-road situation, there occurred multiple instances in which participants felt the need to calibrate the AV's driving style. D9 commented about the burden he expects in driving-style guiding: *"If I go into details of driving styles, there are so many elements to adjust. Guiding each element would be very difficult … and tiring."* Although many participants agreed that they would actively and repetitively guide the AV their preferred driving styles in the early stages of guiding, they also wanted AV to learn as quickly as possible to gradually lower the frequency of guiding.

4.5.2 Concerning the consequences of user's guide. The biggest factor causing the added burden from explicit guiding may be attributed to the fact that the participants perceived the act of driving as a social behavior; not only should one focus on individual safety, one must also pay attention to traffic flow and surrounding cars so as to drive responsibly. The sense of controllability made participants feel responsible for the AVs behavior: *"If I train this car, I am in control, and I am responsible for it … Even though this is an AV, because I have control, I wasn't relaxed and had to consider more things"* (P8). From the interview, P8 shared more thoughts about how he would still feel psychological responsibility even when the companies that designed the AV system take the legal responsibility.

Likewise, participants were generally concerned about the consequences of their driving-style guides. While participants wanted consistency in their guides, they also worried about the idea that giving consistent guides would degrade the AV agent's ability to adapt to various situations. Although we informed the passenger participants that any guide having a risk of accidents would be filtered by the driving wizards, some passenger participants were still anxious about the accidents induced by their driving-style guides. Experience in driving influenced the concern because users with little or no driving experience had a difficult time expressing how they actually want to be driven. The absence of both general and contextual knowledge on traffic systems hindered participants from verbalizing their preferred driving style because they were unsure whether their preference is acceptable or not. We found the need to consider the concerns and the psychological responsibilities users perceived when designing the driving-style guide interaction. Accordingly, we suggest the initial ideas to alleviate the burden of guiding in our design implications.

4.5.3 Guiding in the machine-interpretable language. Similar to common VUI usability problems occurring from users not being fully aware of the VUI system's capability or how to structure utterances to express desired intents [13, 33], we also observed the burden of driving-style guiding due to openness of voice interaction. Few participants were not confident about expressing their needs through words because they were not commanding pre-defined functions but had to define the preferred movements of the AVs by themselves. Especially, many participants kept in mind that they were guiding the intelligent agent and tried to put their words in their perception of machine-understandable sentences. For example, while passenger participants seldomly used vague expressions such as to *"put on the brake more softly"* (P5, P10), more participants wanted to use detailed phrases to make guides interpretable to AV agents: *"If I gave abstract guides to drive smoothly, there was no standard for what smooth driving is … I would guide more particularly like, 'do not stop so suddenly as you just did'. Or 'keep the distance with the car in front for at least 5 to 7 meters when driving'"* (P7). Although the participants felt the need of guiding in detailed language, the process of refining their words to be machine-friendly felt unnatural and troublesome for the participants. In some instances, the burden of guiding in machine-understandable language even deterred the participants from giving any guide. P4, who mentioned how bothersome the explanatory guiding was, shared the moment he gave up guiding at one point: *"There was a jaywalker and the AV wasn't moving because it was a red light for us. I wanted to guide the AV to look around even in our green lights, but I thought it was a bit too much and stopped. It felt like I would need to explain the situation in a tiring way."*

As the burdens of driving-style guiding are observed, the guiding process should be carefully designed in order to derive the value of guiding by alleviating such burdens.

5 DESIGN IMPLICATIONS

The findings of this study reveal passenger experiences in guiding their preferred driving styles to AVs. The results suggest the value of driving-style guidance in learning users' genuine driving preferences and providing user-centered control. However, we also found the burden of guiding driving styles. In automated systems like AVs, the elegant coupling of automated driving with a direct user-guide is key for obtaining genuine user-inputs while keeping the burden of guiding low [16]. Based on the findings and the principles of mixed-initiative user interfaces, we provide three design implications to make the guiding experience more pleasurable and acceptable to users.

5.1 Support Self-reflection on User's Preferred Driving style

Many participants reported difficulty in expressing their own driving-style preferences since they haven't had a chance to think about the style. Although they experience the driving elements on a daily basis, people pay little attention to the everyday driving elements. As the driving-demonstration studies have shown [4], understanding preferred driving styles in AVs is difficult to be achieved from the user's driving. Also, we observed that user's self-reported driving preferences often do not match with their actual preferences. Therefore, AV agents should assist users in self-reflection of their preferences to obtain more genuine guides. Enabling the users to understand how they want to be driven would shorten the amount of time required for the AV's learning period by providing more suitable pre-sets defined by the users. Also, the shortened learning period would help alleviate users' perception of guiding as a tiresome work, fatigue from excessive guiding their preferences. We observed the value of simple questions in mission cards in triggering thoughts of passengers on how they want to be driven. Given the situation, one possible direction is providing users the chance to organize their thoughts through carefully designed questions in the user's early-stage of driving in AVs. The questions should offer a reflective thinking process that AV users can answer through their daily experiences and mundane ques occurring on everyday roads. These questions are aiming to maximize learning-by-riding the driving preferences themselves and thereby increasing the guiding ability. Although the continuous in-situ guidance would still be necessary to adjust the AV's driving more fit to the user's preferred style, self-reflection of the users would empower them to be prepared to express their needs in a shorter amount of learning period.

5.2 Support Conversation Using Questions and Suggestions

All driver participants and the majority of passengers commented on the needs of the agent asking questions and making suggestions to the passengers in order to help the guiding experience of users. Guiding through back-and-forth conversations has two main values: 1) lessen the burden of guiding in machine-interpretable language and 2) help users guide with less concern about the consequences of their guidance.

Although the questions from the AV agents could be irksome to some users, the questions can function as a means to clarify their needs to others. Since it is burdensome to guide how they want to be driven in a machine-interpretable language such as by offering numbers in meters or by giving specific timing in seconds, the AV agents should aid the passengers in expressing their needs. As for one possible method of asking questions, the AV agent may apply the guide first and ask passengers for confirmation: *'would this distance be comfortable for you?'* Another possible method is to suggest options to choose from. For instance, options such as, *'When do you want me to put on a turn-signal before the lane change, 2 or 3 seconds?'* could be offered to passengers in case the passenger guides to put on a turn signal earlier. The suggested options should be carefully chosen by the agent using the reference of previous guides made by the passenger, to minimize the cost of poor guessing [16]. Thus, the user's guiding interaction has the possibility to not only adjust the AV's behavior but also provide user-generated information for a better recommendation of driving-style suggestions. Once the passengers acknowledge that the agent will provide aid in clarifying the guide, the concern with giving guides in a machine-interpretable language would be lessened.

The findings of this study show that users feel a burden in giving the right guide to AVs when they are unsure about the consequences of their guides. We also observed many faulty guides made from the passengers because they guide with less awareness of the road condition than drivers [7]. Considering that numerous different data - including, but not limited to, information about the routes or traffic laws - can be collected by vehicle-communication technology, the AV agent should aid the decision-making of the passengers. The AV agent could ask questions for the purpose of double-checking the intention of the user-guide in case the guides are faulty or too vague, in order to resolve the uncertainties and reflect the true intentions of users [16]. For example, if the passenger commands the vehicle to stop at the side of the road where parking is prohibited, the AV agent can easily inform that the parking is prohibited in the area and ask whether the passenger still wants the AV to park. Once the AV users are informed of the agent's ability to double-check the intention of their guides, the concern of their guiding consequences would be alleviated. Moreover, if the wrong guides were given due to the passenger's lack of knowledge from the little driving experience, informing suggestions could be given to the passengers to obtain knowledge regarding the driving situations. The passengers with less driving experience tend to feel more afraid of the outcome of their guides when they simply do not have relevant knowledge. Given the situation, users can utilize the knowledge suggested by the agent in guiding, with less burden of making wrong guides in later situations.

We reported earlier that perceived relationship changes to be more trustable by the questions and suggestions of AV agents. The value of supporting conversation with AV's questions and suggestions in lessening the burden of driving-style guiding should be taken into account when designing to support user-agent conversation.

5.3 Deliberately Examine Passenger-Interruptibilities in AVs

While the concept of driver-interruptibility in manual driving has been well studied with the emergence of driving assistants and in-vehicle VUI [17, 20, 40], the concept of passenger-interruptibility in the AV context has yet to be studied. Driver-interruptibility is mainly decided based on driving safety because the driver's distraction may be the direct cause of on-road accidents. However, with guiding interactions taking place in AVs with SAE level 4 or

5, the risk of accidents is no longer dependent on the user. Hence, the main standard in deciding passenger-interruptibility becomes the passengers' subjective will to adjust their driving preferences, necessitating a new, different set of standards altogether than that of driver-interruptibility, some of which are hinted by results of our study.

As Strömberg et al. showed that there are clear individual differences in desire for control in AVs [42], it is expected that the will to guide driving styles would differ by users. Thus, it is necessary to understand the user-patterns in guiding to adjust the frequency of proactive behaviors of agents. At the same time, as AV users expect to give fewer guides as the AV fits better for the users, the passenger-interruptibility should be redefined according to the changed will of the passengers giving driving-style guides. The proactive actions should be given to aid users guiding, based on the understanding of passenger-interruptibility in AVs. The preferred driving-style guiding experience could be enhanced with the proactive questions and suggestions of AV agents. Having decided to give questions and suggestions to AV users, it is important to minimize the cost (i.e., bothering the users) while maximizing its benefits (i.e., resolving uncertainties of user-intention) of the AV's proactive behavior.

6 CONCLUSION

From the WoZ study in a real-road setting, we explored the preferred driving-style guiding as a novel channel for expressing AV user-needs. The findings of this study add value to understanding the user's expression of how they want to be driven in AVs. The findings of this study reveal the benefits of driving-style guidance in comprehending the genuine AV driving-style preferences of the user as well as in augmenting the sense of controllability of the AVs. Also, we have discovered the burden of driving-style guiding and suggest main points to consider upon further investigation. To accomplish a valuable synergy in human-vehicle collaboration, we suggest the design implications with the aim of developing the guiding interaction to be less burdening.

We expect the relationship passengers built with the AV agent through guiding driving styles to suggest another value in AV usage. In our further studies, we plan to investigate what affects passengers in building different relationships with AV agents. We hope that the result inspires both designers and engineers to future study in creating human-centered automated systems, to empower AV passengers to communicate their needs and values in AVs.

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