Exploratory Study into Designing Enhanced Commute Experiences in Autonomous Vehicles with Connected Sensors and Actuators

Zheng Sun(✉), Hugues Vigner, Shreyas Bhayana, Changhao Zheng, Ziwei Zhang, Euiyoung Kim, and Alice M. Agogino

University of California, Berkeley, CA 94720, USA
leceasun@berkeley.edu

Abstract. This paper discusses an exploratory study regarding user perceptions and behaviors associated with autonomous vehicles (AV). We conducted three research methods – interviews, observations, and surveys – to collect comprehensive user data for capturing useful insights. We found that comfort with light, vehicle safety, audio entertainment and itinerary transparency are the main four concerns that users in our study had in current transportation systems, especially in shared rides. Having these categories as our guidelines for design, we generated conceptsand built a low-fidelity prototype using connected sensors and actuators for user testing. Feedback from potential users and experts in the automobile industry were recorded to refine the proposed concept for further development.

Keywords: Automotive user interfaces · Traveler's behavior · User interfaces for (semi) autonomous driving · Women in transport · Car sharing in (semi) autonomous vehicles

1 Introduction

Breakthroughs in technology have allowed the opportunity to shift from full human-driven vehicles to autonomously driven vehicles (AVs), which partially or fully drive themselves and which may ultimately require no driver at all, based on different levels from 0 to 4. The current transition period of the vehicle assisting the decision-making for the human driver has introduced technologies such as crash warning systems, Adaptive Cruise Control (ACC), lane keeping systems, and self-parking technology [1]. The mobility sphere, which has undergone constant innovation in the past century, is going through a paradigm shift that seeks to transform the very core of the status quo [2]. The field of AVs has drastically revolutionized this mobility sphere, as dozens of startups and automobile manufacturers race to reach level 3, and 4 of autonomy [3].

With software controlling all the subsystems of the vehicles without human intervention, drivers will be able to use commute times more productively than ever before. Drivers (and passengers) will have the potential to use the travel time for a wide range of new tasks, such as preparing presentations and conducting mobile meetings or spending time on leisure activities, watching a video or reading a book during the

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commute time that wouldn't have otherwise been possible [4, 5]. While these are ideal mobility and travel experiences in future scenarios, previous research has shown that current commute experiences are typically negative with a wide range of onboard emotions, ranging from passengers feeling bored during a long-distance road trip to feeling extreme anxiety on the way to work [6]. The mobility experience is compounded while riding in a shared space. In a shared space, different users require different comfort levels; women, for example, revealed more concern than men in a constraint shared space [7].

In this paper, our research goal is to enhance the commuting experience in emerging mobility solutions (e.g., autonomous, shared, and connected vehicles) by employing connected sensors and actuators in the interior space of the vehicle. We employed a human-centered design methodology [8] to discover how users from various demographics interact with vehicles in daily life, and to identify pain points that need to be addressed in the context of emerging autonomous driving conditions for users. By analyzing the collected data, we aim to determine how to enhance the onboard experience in future mobility conditions. New concepts based on this user research were evaluated and a sample concept was selected to tackle identified user needs in various demographics. Finally, a reduced scale low-fidelity prototype was developed and tested. Feedback from potential users and domain experts were collected to refine the prototype for further research.

2 Methods and Analysis

Interviews, observations and a survey were triangulated to collect potential user information. We conducted in-person interviews focusing on potential sensorial experiences in automobiles and current sensors in automobiles; we distributed an online survey soliciting feedback before a prototype was developed; we also performed multiple observations of co-riders during rideshares trips to study their experience using the service. These different research methods allowed us to collect user behavior data. The findings from each research method were used to develop a prototype and served as the foundation for user testing. The sequence of research development and predicted outcomes is illustrated in Fig. 1.

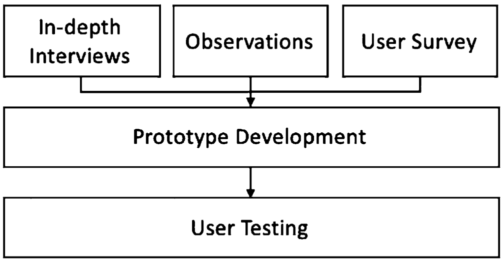

Fig. 1. Progression for research development and predicted outcomes.

2.1 Interviews

Interview Design. To obtain a broader view from the public, we conducted 19 in-depth interviews with potential users. We used snowball sampling—approaching potential interviewees via personal networks, co-riders during commercial shared rides, attendees in local tech conferences, etc. We selected interview participants based on their prior mobility experience in either shared or private transportation to gather their behavior, habits, and needs. We also targeted passengers with various dispositions. Through the interview method, we aimed to understand any specific issues or pain points with respect to the current transportation modes.

Interview Demographics. The demographic groups based on their age, gender, and occupation are detailed below.

Age. The age of interviewees ranged from 18 to 40. We mainly targeted young adults and working professionals as the recent study shows that more than 80% of rideshare users are aged between 18 and 49 [9]. In our interviews, the majority are either college students or young professionals.

Gender. In our study, we interviewed 19 rideshare uses – 12 males (65%) and seven females (35%). We focused on their ride-sharing experiences and their expectations in the development of autonomous vehicles. The extracted data from the seven female users shows that their perspective on autonomous vehicles are different than for male users, with a greater concern for security.

Profession. Thirty-six percent of the interviewees were college students who are attending either graduate or undergraduate programs. Among other interviewees, 26% of total interviewees work in technology fields.

Interview Analysis. With the data collected from the interviews, we applied grounded theory to analyze the gathered data and develop protocols and quantify the qualitative data. The analytic process takes the steps of coding data, developing, and refining theoretical categories [10]. Table 1 shows extracted sample scripts and resulting codes generated by two raters. To extract the key codes that are important to our research, two coders from our team recorded the categories of the selected code based on personal understanding. By comparing the similarity of our codes, we used the scored number to identify whether we successfully targeted the pain points of the interviewees. Two coders agreed on 65 out of the 74 scripts, which give us an 88% agreement in the data analysis.

According to the 2017 report on the demographics of Uber's user population in the U.S. [12], 48% of the Uber riders are female. In our research, we found female users tended to trust autonomous vehicles more in comparison to male users. Of all the interviewees that responded to the question of whether they would purchase/rent an autonomous vehicle for daily commutes, 83% females responded they would be looking forward to the bloom of autonomous vehicles whereas only 45% of males had a positive perception on the autonomous vehicle. Table 2 summarizes the breakdown of interests in using AV based on gender.

Table 1. Conduct grounded theory to quantify interview data (paragraph by paragraph) [11]

Script	Coder 1	Coder 2	Score
"I choose a rideshare service based on safety, convenience, cost. (It is) safer than bigger transportation. People taking pool are more mentally stable. There are crazy people on buses."	Mentally stable co-riders	Safety	0
"(I) don't care about the visual stuff, listening to music is nice. But I don't like staring at the screen. I am a software engineer, so I really value the time not staring at the screen."	Audio Entertainment	Audio Entertainment	1
"I want it (AV) to happen, I trust it more than a real person. Real people lose attention, people make stupid decisions. I personally really hate street lights. Bright light blinds me and distracts me from driving, especially at night!"	Comfortable light	Comfortable light	1
(I use ride share services) twice a week or more. I want to make sure that the drivers try to find where I am waiting for them… or at least make sure that they answer their phones. Some drivers might be politer."	Transparency	Transparency	1
"I hate driving in Indiana at night because it is so dark and people driving toward me […] their high beams always blind me."	Comfortable light	Comfortable light	1
"My favorite thing in a car is listening to music. I want good sound in the car to have my relax time."	Audio Entertainment	Audio Entertainment	1
		Total inter-rater agreement score:	88%

Table 2. Number breakdown of whether users are interested in using AV based on gender

	Will use AV	Will not use AV
Males	5	6
Females	5	1

The extracted reasoning from the interviewees explain that most of the female drivers expressed concern about their driving skills under current road conditions. Female drivers predominantly perceived that autonomous vehicles would provide more coherent and agile driving experiences compared to human drivers [13, 14]. Table 3 shows example quotes from female interviewees: trust levels towards their own driving skillsets and autonomous vehicles.

Table 3. Example responses from female drivers on trust of autonomous vehicles

Interviewee initial	Response
DY	"I want it to happen as soon as possible. Since I am so bad at driving (laugh). Driving in China is insane!"
DU	"Would make tasks repetitive easier, trucks which transport (would be easier, concerned about safety but it should be fine once finished."
SK	"There will be a lot less accidents out there if I stop driving."
FA	"I want it to happen, trust it more than a real person… real people lose attention, people make stupid decisions. There is no fatigue."
LK	"Only two recorded cases of failing (for Tesla), safer than human driving."

2.2 Observations

The findings from the interviews indicate that users who are not informed about AV technologies, do not really trust the technology. However, users who are under the impression that they have a good level of understanding about AV technology, are much less wary of using the technology [15]. Other studies have identified trust as important factor in the adoption of autonomous vehicles [16]. Some of our interviews, highlighted opportunities where AV's could address users' need for improved safety, such as in understanding road conditions and witnessing the operations of the system.

To dig deeper into the findings from the interviews, we conducted five observations on rideshare trips. Ride-sharing simulates an 'autonomous' ride since the users do not need to drive. However, since there are actual drivers operating the shared rides, we also focused on their interactions with the passengers to see whether there are any pain points that we missed while interviewing the potential users.

The riders we observed were all under 30 and college students. The first observation was a 20 min shared ride around the campus of UC Berkeley. We observed the quality of driving, the personality of the driver, and the passengers' reactions when interacting with the driver. The driver was around 50 years old and was an enthusiastic environmentalist. During the ride, the driver constantly requested the riders to listen to her talk about her interests and upcoming projects riders could join in with. Even though the riders were mostly interested in the conversations, one of the riders seemed anxious by the impact of her distraction on her driving, since the driver was focused on her conversation and was distracted from driving. One of riders was constantly checking the route on her phone and looked outside of the window. She eventually asked to be dropped off before she arrived at her final destination. From this observation, it was clear that some riders were concerned about safety when they sensed the drivers were distracted. To seek security from a "dangerous" ride, the riders chose to constantly check their current route, as well as choosing to exit the vehicle before arriving at their destination.

In another similar observation of a rideshare, we observed a 30-min ride from downtown Oakland to downtown Berkeley on a rainy day. The shared ride driver was a heavy smoker and the vehicle had a pungent smell during the ride. One passenger asked the driver to roll down the window, but this was refused by the driver due to heavy rain. The lack of transparency on the route itinerary was also commented on. The driver also raised safety concerns of passenger due to using his phone and driving with a single-hand to the steering wheel. It was clear that the passengers felt that it was important to have fresh and breathable air in the vehicle, as well as the driver's attention to safe driving practices.

We also observed interesting patterns between passengers, luggage and the shared space that motivated new concepts in seat layout for a social setting, with the role of the driver being part of the social functions occurring [17]. We observed riders on a Friday night sharing a ride across downtown Berkeley. The vehicle was cramped, as there were already two people, a couple, in the vehicle. It was difficult to see where to sit in the car due to the darkness and tinted windows. It was also inconvenient for another two-person couple to arrange their eating to their satisfaction, when one person sat in the front and the second behind them, preventing them holding a conversation.

For the return trip one and a half hours later, one of the riders was using two of the seats for storage of their personal items, making it difficult for a 4th co-rider to use the remaining space. The space could not be rearranged, and the seat belt buckle had become inaccessible, comprising the safety of the 4th passenger. After dropping off two other riders, the drivers asked if the rider at the front wanted to sit in the back with her friend. Ridesharing in low comfort conditions like these underlines' possible improvements on the standardization of seat space when a high volume of different unique users occupy the space with low retainment.

Finally, we conducted two observations to consider the role that trip length played in passenger behavior. We observed that when riding with friends, for a short distance, most of the time individuals had conversations during the entire trip. For longer trips, it was typical for passengers to be energetic during the first hour. Later, when topics of conversation were depleted, and dialogues are difficult to maintain, users started checking their smartphones. Some riders would fall asleep during the second hour of the trip. The driver had to remain alert, listening to the music to stay awake. During most of the observed commutes, music was connected to the car infotainment system through the driver's smart device. However, in long trips, passengers could generally access the music controls by connecting their devices.

Onclusion, passengers showed concern for their safety, particularly if the driver appeared to be distracted or hid the itinerary during the trip. Passengers expected their ride to be in a hygienic and comfortable environment with access to their friends while travelling in groups. Entertainment is appreciated during relatively short trips, but riders also valued time for resting during long trips.

2.3 Online Survey

We conducted an online survey regarding user experiences in current vehicles, their expectations and their attitudes toward autonomous vehicles.

Respondent Demographics. Data from a total of 52 participants was collected through online surveys. Among the dataset, three incomplete surveys were excluded from analysis. For the remaining 49 participants (male: 27, female: 22), the age breakdown was as follows: the 18–25 range (22 participants), 25–35 range (13 participants), 35–45 range (6 participants), 45–55 range (2 participants), 55–65 range (2 participants). Among these 49 participants, there were 18 students, 16 engineers, 4 salespeople, 2 business managers, 2 teachers, 1 faculty member, 2 full-time housewives, 1 entrepreneur, and 3 industrial workers.

Survey Design. The online survey used multiple choice questions, Likert scale, ordinal scale, categorical scale, and open-ended questions to collect participants' insights. The survey was composed of three sections and included a total of 20 questions (Part 1: 3 questions, Part 2: 11 questions, Part 3: 6 questions). The content and the design of the survey is shown in Table 4.

Table 4. Section breakdown for the designed survey

Section	Type of survey questions (quantity)	Functionality	Example question	Purpose of the survey design
Part (1)	Multiple Choice (3)	Gathers the demographic data of the participants including age, gender, and occupation	What's your current occupation?	Multiple choice questions enable us to categorize answers efficiently
Part (2)	Multiple Choice (6), Multiple Choice & Short Answer (2), Likert Scale (1), Ordinal Scale (1), Categorical Scale (1)	Inquiries into participants' habits in both ridesharing and private vehicles Asks participants' pain points when taking or driving vehicles	What are your favorite things to do while driving/being a passenger? What sensing experience do you value the most in a vehicle?	A combination of multiple choice and short answer question was used to assure that participants had a chance to justify their corresponding decisions thereby providing us with underlying insights The Ordinal Scale question asks the participants to compare and rank a range of core user needs[a]
Part (3)	Open-ended (5)	Gathers general opinions and expectations about the autonomous vehicle	How do you want to interact with your vehicle?	An efficient way to make respondents feel less constrained and express their deeper insights freely

[a]The core user needs included entertainment, privacy, comfort, safety, hygiene. It was rated by a 5-point scale, with (1st = 5 points, 2nd = 4 points, 3rd = 3 points, 4th = 2 points and 5th = 1 point).

Survey Analysis. We designed histograms to demonstrate the main reasons why users feel unsafe about a driver in a shared car-ride (Fig. 2). The result shows that the riders believe that the driver is the most distracted when he or her cannot see well. The riders also feel unsafe when the driver is in a physical health or emotional state that is unsuitable for driving, with concerns about health slightly above emotions.

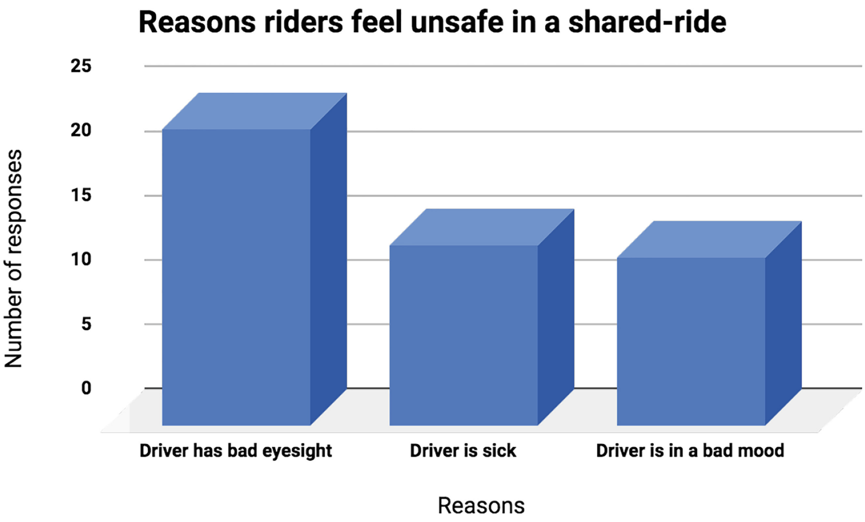

Fig. 2. Histogram of user needs scoring and demographic

Participants also valued sensing experience in autonomous vehicles. We manually processed the short answers and open-ended questions by categorizing participants' expectations, pain points, and demands by utilizing similar keywords. We found 35 participants showed their interest about how autonomous vehicle can improve their sensing experience including, lighting, sound system, visual entertainment, and comfort.

Among those 35, 12 outlined detailed scenarios that they wish to see in the future autonomous vehicle. For example, one participant envisions: "*I wish I can sleep, listen to music, play video games and work in autonomous vehicles. It would be like hiring a driver.*" Other quotes include: "*I am annoyed by the high intensity sunlight in California, sometimes I can't see anything outside or check my phone because it's too bright.*", and "*I enjoy the sightseeing and I want to see the views from all directions*".

2.4 Discussion

After analyzing the data collected from interviews, observations and surveys, we coded the four main pain points (ranked based on the number of times they are mentioned in our data) that concern most of our targeted population:

1. Comfort with light
2. Safety inside of the vehicle
3. Audio entertainment
4. Transparency of itinerary

Comfort with Light. Bright light, either sunlight or high beams from other vehicles was mentioned most frequently as a pain point. To solve this issue, we recommend future autonomous vehicles embed connected sensorial systems that could detect intense light that could cause discomfort. Actuators can potentially be used to adjust the user position to avoid the light. We performed a round of user testing for this concept, which is presented in the "User Testing" section.

Safety Inside of the Vehicle. Safety is a major concern with autonomous vehicles, even though statistically they appear to be relatively safe in test areas [18]. To help users feel safer in autonomous vehicles, we will simulate different concepts to improve real-life driving experiences inside a vehicle, to study whether these features will meet the safety demands of autonomous vehicle riders.

Audio Entertainment. Listening to music was an important feature while in automobiles since it helps relax both the drivers and the riders after a long day of work [19]. Having more engaging music on board can potentially enhance users' experience and fill the "chasms of silence" [20] that occur when traveling in groups. This motivation opens up many avenues for creative solutions to enhance the listening experience. For example, autonomous vehicles could potentially connect the music with other sensing and surroundings of the user. A sensor could detect the beat of the music and enhance the sensorial experience with actuators that could provide tactile vibrations, making the automobile acts like a sonic machine [19].

Transparency of Itinerary. Transparency of demographic data and GPS locations have an extensive effect on trust [21]. There are many options for improving the transparency of the itinerary or driving schedule, such as use of sharable displays next to each passenger. There is much to learn from current ridesharing applications allow riders to see the location of the car and the exact route the vehicle is taking to the rider's destination. Future improvements like this can be achieved by implementing real-time control of the vehicle, by the rider. For instance, users could choose to have the vehicle drop them off when they feel unsafe during the ride.

3 Prototype Development

Based on the analysis and identified pain points from the three methods we used, we found out that one of the major user concerns regarding comfort and safety is the high-intensity lights that project through the windows directly into passengers' eyes. After going through brainstorming, open card sorting, and a Pugh chart analysis [22], we selected the concept of a rotating mechanism for a chair that continuously monitors incident sunlight at eye level to help users avoid direct sun glare.

Subsequently, we built a low fidelity scaled prototype for the concept as a tool to test user feedback (Fig. 3). The prototype was built in the maker space in the Jacobs Hall at the University of California, Berkeley. The prototype contained a stepper motor that had a 3-D printed car seat mounted on it, along with a printed base and motor housing, and a photo-sensor on the seat. An Arduino Uno unit controlled the motor rotation based on input data from the sensor, so that any time when light passed an intensity threshold, the motor would rotate the seat a specified amount until the light intensity dropped below the defined threshold.

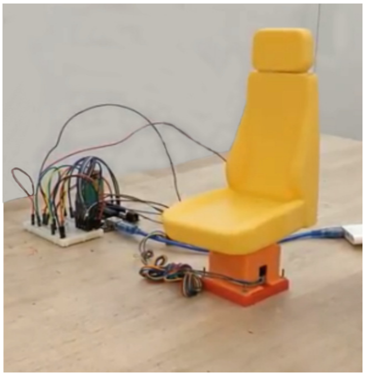

Fig. 3. Low-fidelity scaled prototype for user testing

4 User Testing

4.1 Prototype Demonstration

We demonstrated the prototype at a public exhibition at UC Berkeley campus to record the general feedback from the event participants. We collected feedback from 15 participants at the exhibition. Even though some believed that it was an innovative idea and should be developed further, many of the people we demonstrated the prototype to were concerned about its safety, as the chair rotation might limit the passenger's ability to see outside the front of the car. Some also suggested that it might take too much space inside the vehicle.

4.2 Expert Interviews

We presented the prototype and testing results to four industry experts in automotive, user experience design fields to evaluate the developed prototype. All the experts agreed that light is a common concern for passengers inside of a vehicle. However, they expressed concern on the safety of the mechanism when the vehicle has a sudden change of motion. One expert advised us to add a "sleep mode", or "manual option" that enables users to either lock the chair's movement or manually adjust the chair based on their personal preferences. Another expert also mentioned that the space arrangement inside of the vehicle needs to be more flexible to allow and reserve enough leg room 360° around the chair to achieve the higher extent of rotation. Another expert implored us to play the devil's advocate and view the problem from different angles and come up with more solutions that we can later judge as more or less feasible than the current one. One such example was to investigate the tradeoffs of tinted windows as a possible solution to the same problem or photochromatic lenses. "*Comparing two solutions often leads to more insight and possible generation of a third, integrated solution*", recommended one of the experts.

5 Limitations

Although interviewing is an efficient method to have in-depth conversations with potential users in order to identify their pain points and user needs, the extensive time it takes to conduct an interview limits the total number of interviews that we were able to conduct given our time constraints. The observations provided qualitative comparisons to contrast differences in what people said and what they did. Although the number of respondents was larger, the survey may be less reliable than the interview or observations as the users participated remotely and individually without guidance from the moderator. As the surveys were anonymous, we opted out follow-up questions afterward.

6 Closing

To better understand how to improve passenger experiences in autonomous vehicles with embedded sensors and actuators, three user research methods we used: (i) user interviews for potential sensorial experiences on autonomous vehicles and current sensors in the transportation system, (ii) multiple observations of our co-riders during rideshare trips to study their experience with ride-sharing services, (iii) an online survey for feedback on our designed prototype. We identified four user pain points: comfort with light, safety concerns, audio entertainment and transparency in itinerary. Findings from the research gave us the necessary pointers to determine what sensors could be used to avoid external bright lights and glare from reaching the user during their transportation experience, to address the aspect of comfort with light. Other pain points that were identified, such as transparency of the itinerary, are less enabled by sensor integration but still help in providing guidance in designing displays for the future of shared rides, which would not be only visible to one user, but also benefit the whole group, considering that no single user would be operating the vehicles. The audio entertainment emphasis opens up creative opportunities that could integrate music with the surroundings of the user, using a fusion of both sensors, transducers and displays, to take advantage of new forms of interiors for AVs and their seating arrangements. Solutions might allow rotating chairs with a sleep mode option to control whether the chair will adjust automatically to the sunlight, as well as adding a screen in front of the user with a real-time display of the outside scenery.

7 Future Work

This exploratory study will be expanded to more subjects and used to create new designs and prototypes that address the pain points identified. We plan on designing a connected sensor system for detecting intense light that could cause discomfort. Actuators will be used to adjust the user position to avoid the light. Another future implementation will be an integrated common display to locate the car and the exact route the vehicle is taking to the rider's final destination, as well as to provide easy access to emergency intervention controls to the users. This could take the form of a window-embedded, in-wall, or projection form-factor adapted to autonomous vehicle shared spaces.

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