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Investigating user activities and the corresponding requirements for information and functions in autonomous vehicles of the future

Pinyan Tang [1], Xu Sun [1], Shi Cao [2*]

[1] Department of Mechanical, Materials and Manufacturing Engineering, University of Nottingham, Ningbo, China
[2] Department of Systems Design Engineering, University of Waterloo, Waterloo, Ontario, Canada
[*] shi.cao@uwaterloo.ca

The potential benefits of autonomous vehicles, including safety, convenience, fuel economy, and low emissions can only be achieved when consumers are comfortable with the vehicle design. There are only a limited number of user studies in the design of future autonomous vehicles, owing to the difficulties of shifting focus "from the present to the future." An integrated method of simulator study and user enactment was applied in the research to bridge the gap between the current and the future. Thirty drivers participated in the study to experience enacted driving scenarios in an autonomous vehicle simulator. The participants were divided into two groups, i.e., driving-alone drivers and driving-with-a-passenger drivers, to investigate the effect of passenger presence. Rich data were elicited about possible in-vehicle activities, the corresponding requirements of information and functions to support any such activities. Also identified were the preferred methods of interacting with the information and functions. Passenger presence was found to have an influence on the attributes of activities undertaken as well as the preferences for in-vehicle information and functions. Dominant themes were identified in future autonomous vehicle designs, including a more flexible and adaptive design language, concerns of trust and safety, and trade-offs between safety and convenience and between privacy and social connection. Based on the findings, design implications for future autonomous vehicles are discussed.

Keywords:
User requirements; autonomous vehicles; driver-vehicle interaction; passenger presence; in-vehicle activities

1. Introduction

Autonomous vehicles have the potential for the future of transportation that will be safe, convenient, quick, economical, clean, and efficient (Fagnant and Kockelman, 2015; Strömberg et al., 2018; Verberne et al., 2012). However, before it becomes a reality, there are still many challenges (e.g. technological problems, policy and regulation problems) (Martínez-Díaz, Margarita Soriguera and Pérez, 2019; Merat et al., 2014) to overcome, among which the human factors issues in the interaction between human driver and autonomous vehicle are one of the essential concerns (Driggs-Campbell et al., 2017; Merat et al., 2014). The Society of Automotive Engineering (SAE) defined six levels of automation, whereby the human driver performs part or all of the dynamic driving tasks (DDT) from L0 to L2, while the automated driving system performs the entire DDT (while engaged) from L3 to L5 (SAE International, 2018). Human drivers play an essential role in SAE L3 automation— they don't need to monitor the system, which separates L3 from other partly automated systems (Gold et al., 2018), but they are expected to operate the vehicle in conditions not supported by the system (Kyriakidis et al., 2017). Such special circumstances make L3 automation a complicated level and a main challenge in human factors research (Jarosh and Bengler, 2019; Kyriakidis et al., 2017). The current paper focuses on advanced L3 automation whereby the human drivers are allowed with sufficient time to react to a request of intervention.

In comparison to manual driving, the interaction between driver and vehicle in such a level of automation is subject to tremendous changes for the following two reasons. First, automation will release drivers from the task of driving and allow them to undertake new activities that would not be possible in vehicles controlled manually (Jorlov et al., 2017; Large et al., 2017). It has been shown that users have high expectations for autonomous vehicles to relieve them from driving so that they can engage in other activities (Jorlov et al., 2017). Such non-driving related activities are open to all possibilities, which means that any corresponding driver-vehicle interaction will be subject to high levels of diversity.

Second, new in-vehicle activities will require the redesign of in-vehicle information and functions and lead to new interaction mechanisms. Automation changes the information processing and action of drivers as it both "replaces some or all the functions required to complete a task" and "changes the requirements for a task" (Yamani and Horrey, 2018, p. 2). The in-vehicle information and functions should meet the cognitive characteristics of humans and ensure the efficiency and safety of any interaction during autonomous driving (Yamani and Horrey, 2018). In particular, because humans and machines differ significantly in terms of their capacities and competences (Habib et al., 2017), any redesign should enable the driver and the automation to function as a team to guarantee high-quality system performance (Kleij et al., 2018).

For the success of autonomous vehicles, it is very important to ascertain the following questions, i.e., What will be users' in-vehicle activities? What will be the information and functions required to support such activities? To date, only a few studies have tried to answer the first question. For example, Ive et al. (2015) used a simulated autonomous car to explore occupants' sitting and activity situation. They identified a few activities, including tablet usage, laptop usage, reading a book, and sleep, and the most common activity was phone usage. Kyriakidis et al. 's (2015) large-scale survey found that the higher the level of automation, the more non-driving activities people would intend to engage in, which include rest\sleep, watch movies, or read. Karlsson and Pettersson (2015) applied two qualitative approached to explore users' expectations and identified a series of non-driving activities as well as some design implications. However, the understanding of drivers' activities during autonomous driving is still scanty. For example, passenger presence has been identified as a critical factor that affects driving behaviour. It was related to the risk of taking unsafe actions (Bédard and Meyers, 2004; Ouimet et al., 2015) and could also influence a driver's situational awareness (Chandrasekaran et al., 2019). There is little published data on the corresponding aspect of autonomous driving. In particular, as Jorlov et al. (2017) pointed out, situations in conversation position with two occupants, where the driver's seat is rotated to face the rear, have not been explored previously. Yet, this could be a typical scenario in which a variety of new interactions between human and vehicle would be induced.

Besides, limited attention has been paid to the corresponding user requirements for in-vehicle information and functions to support the non-driving activities. There are studies investigating drivers' interaction with in-vehicle information from the perspectives of driving performance (e.g. Kaber et al., 2012; Merat et al., 2014; Radlmayr et al., 2014), workload and situational awareness (e.g. De Winter et al., 2014; Reimer et al., 2016), and trust (e.g. Schneider et al., 2017; Verberne et al., 2012). Nevertheless, most of such research was conducted in a top-down manner, i.e., researchers assigning a predefined non-driving task to the participants to test any possible human factors issues. For example, Kaber et al.'s (2012) study applied predefined visual and cognitive distraction tasks to test driver performance, while Radlmayr et al. (2014) and Hergeth et al. (2015) applied the Surrogate Reference Task as a non-driving related task to test the take-over behaviour. There remains a paucity of research into understanding how users should be supported to perform any potential activities in an autonomous vehicle from a User-Centred Design (UCD) perspective. Since it was originally proposed by Donald Norman in the 1980s, UCD has been widely used in industrial and interaction design (Abras et al., 2004; Costa et al., 2017). UCD begins with the understanding of users and places user characteristics, goals, needs, requirements and preferences at the centre of each stage of the design process (Costa et al., 2017; Robins et al., 2010). The application of UCD in the research into autonomous vehicles is limited, owing to the difficulty of shifting focus "from the current into the future" (Karlsson and Pettersson, 2015, p. 695). The technology that enables autonomous vehicles is still at an early stage in its development. There is still a lack of understanding of actual users and their requirements, as well as the expected design state (Strömberg et al., 2018). To address such problems, methods such as simulator studies (e.g. Beattie et al., 2014; Hergeth et al., 2015), and the context user enactment (e.g. Odom et al., 2012; Strömberg et al., 2018) have been proposed.

The aim of the current research was, therefore, twofold. First, to investigate the variety of user's potential activities in an autonomous vehicle. Different driving scenarios were designed to investigate the effects of passenger presence on the corresponding in-vehicle activities. Second, to understand users' requirements for information and functions to support in-vehicle activities. Some previous studies have investigated human-automation interaction in autonomous driving from the perspectives such as resource allocation,(e.g. Parasuraman and Manzey, 2010; Yamani and Horrey, 2018), and human-machine trust (e.g. Larsson, 2012; Seppelt and Lee, 2007). In contrast, the current research aimed to address this issue from a UCD approach and specifically focused on the corresponding user requirements for future autonomous vehicle design. It aimed to validate the existing findings with further empirical data by using the integrated methods of user enactment and simulator study and complement the relevant research by developing a comprehensive understanding of driver-vehicle interaction in autonomous vehicles from the perspective of end-users, and thereby offer guidance for future autonomous vehicle design.

2. Method

The current study used both user enactment and driving simulator methods. User enactment is a method whereby using drama or enactment, designers may conduct both the physical form and the social context of future designs, with users enacting loosely scripted scenarios of dealing with different situations of both familiar and novel technical interventions (Odom et al., 2012). It has been used as a rapid means of envisioning new ideas with future technology and for exploring future use in an evaluation-like context (e.g. Odom et al., 2012; Strömberg et al., 2018).

Simulator study is another method often used in autonomous vehicle research to test design features and also the relevant user behaviour (e.g. Beattie et al., 2014; Hergeth et al., 2015). In the research of future designs, the methods used need to facilitate the users by creating a space for imagining and testing possible future experiences (Strömberg et al., 2018). Simulator study offers the users such a space, and the design of the simulator is critical to its success. Both simple and complex simulators have their advantages and disadvantages. A simple and open design of a simulator has the advantage of stimulating participants' fantasies to a much greater extent when compared to more elaborate designs (Karlsson and Pettersson, 2015). However, it requires the participants' imagination (Krome et al., 2015), which relies heavily on speculation and may consequently lack face and ecological validity (Large et al., 2017). Conversely, if the design of the simulator is detailed and specific, it may work in providing more exposure or artefacts for participants to use, and thereby reduce reliance on speculation (Large et al., 2017). Still, it could also have the potential to hinder the engagement of participants during the exploration of any design concepts. The trade-off between the richness and validity of any results should always be considered when adopting simulator studies to explore future designs.

For this research, the methods of simulator study and user enactment were integrated to set the stage for future autonomous vehicles research as well as to make the experience more concrete for the participants and help them to clarify their potential requirements for future designs (Strömberg et al., 2018). A simple fixed-based simulator (Figure 1), which was made from the body shell of a Chery QQ, was introduced as the main space for user enactment. The simulator was fixed-based with a 360° visual field of view. Four projectors were used for the display (1920 x 1080 pixels each) of driving scenes generated by an open-source driving simulator OpenDS[1]. Inside the simulator, there were only two seats. All the other components, such as steering wheel, brake, and centre console were removed to leave the participants a simple and open space. A scenario-based interview study was designed to help the participants enact daily driving scenarios in future autonomous vehicles. The method of user enactment was applied because the simulator does not have a functioning information and entertainment system nor the interface for drivers and passengers to interact with. When the participants were asked to think about what they would like to do in the car, e.g., navigation, playing music, or reading news, they must imagine and enact because the simulator did not have the functions implemented. The scenarios-to-enact include a driving-alone journey to a business meeting and a driving-with-a-passenger journey to a shopping mall (with a companion of the participant to enact as the passenger), which would be introduced to the participants who came alone and with a friend\family member respectively. There was no functioning information and entertainment system nor the interface for drivers and passengers to interact with in the simulator. When the participants were asked to think about what they would like to do in the car, e.g., navigation, playing music, or reading news, they must imagine and enact because the simulator did not have the functions implemented. The detailed scenarios would be elaborated in the interviews to help the participants ignite their imagination of the specific driving situations and stimulate their in-vehicle activities preferences.

Figure 1. A fixed-based driving simulator with a 360° visual field of view

2.1. Driving scenes

Two types of scene were developed in OpenDS, namely an urban street scene and a highway scene (Figure 2). In the urban scene, the road was a 2-lane road (one lane each way), and the speed limit was 60 km/h. There were houses and tall buildings along the road. Different traffic situations were created, including waiting for traffic lights, changing lanes, following cars, and yielding to cars from the other direction. In the highway scene, the road was a 4-lane road (two lanes each way), and the speed limit was 120 km/h. Different traffic situations including merging in from ramp, lane changing, and car following were created. Regarding weather, it was sunny in the urban scene and

[1] https://opends.dfki.de/

snowy in the highway scene. The scenes were designed to help participants imagine different experiences that they may encounter in common daily transportation. Both scenes were presented to each participant.

Figure 2. The urban scene (left) and the highway scene(right)

2.2. Participants and experimental design

The participants were recruited from the local city (Ningbo, China) via an advertisement sent on social media. Thirty drivers were recruited, of which sixteen participated alone, while fourteen were accompanied by a friend or a family member. They were divided into two groups, i.e., driving-alone driver (DAD) group and driving-with-a-passenger driver (DPD) group respectively. The drivers were screened for their experience of driving, with the criterion that they could demonstrate at least one year's driving experience, while the driving frequency criterion was at least three times per week. In total, there were 21 male drivers and 9 female drivers, with an average driving experience of 7.5 years (SD = 7.8 years). Table 1 shows the demographic information of the drivers and the companions, i.e. the passengers. The passengers were there to create a conversation context and to help the driver become immersed in the scenarios and generate any corresponding requirements. They were encouraged to join the conversation together with the drivers during the interviews. Some of the answers came from the passengers but were confirmed by the drivers. The participants were from different professional backgrounds, including education, finance, marketing, freelance work, etc. No professional drivers were involved. Only three participants reported having previous experience with autonomous vehicles, two of whom had a test drive in a Tesla Model X, while the other had some experience with the Adaptive cruise control system and the automatic parking of a Volvo.

Table 1 Participants' demographics

	Age						Gender	
	Under 18	18-24	25-34	35-44	45-54	55-64	Female	Male
Driver driving alone	0	1	10	3	1	1	5	11
Driver driving with a passenger	0	1	7	3	2	1	4	10
Passenger (friend/family member of the driver	3	2	5	1	1	2	6	8

2.3. Procedure

On arrival, participants were introduced to the study and screened by a questionnaire to ensure that they were at low risk of motion sickness. They were also informed of the ethics approval of the research and ensured the collected data would be confidential. After signing the consent form and completing a demographic questionnaire, they were introduced to the simulator. They were advised that the simulator represents an autonomous vehicle that enables the driver to cede full control of all DDT under certain traffic or environmental conditions. They were also advised that when the driving conditions exceed the boundaries of the automation capabilities, the system will alert the driver in advance, with sufficient time to complete the transition procedure. After the introduction, they were invited to sit in the simulator, and the driving began with the urban street scene. At first, the participants were given five minutes of trial drive to sit by themselves in the simulator to adapt themselves to the environment and to see if any motion sickness was experienced. They were then introduced to the driving task as follow: "Imagine that you are sitting in the autonomous vehicle with a friend, going to a mall", or "Imagine that you are sitting in the autonomous vehicle by yourself, going to another city for a business meeting", and "The vehicle is driving itself." The researcher joined them in a rear seat and asked the following questions: "What activities would you like to do now?", "What kind of function would you like the vehicle to have, and how would you like it to be realised?", "What kind of information would you like the system to offer, and how would you like it to be presented?", and "how would you like to interact with this information/function?" As the scene continued, similar questions were repeated until the relevant answers were exhausted. The duration of the urban drive lasted for about 20 to 30 minutes. The researcher then changed the simulation to the highway scene, following which the same procedures were repeated. This highway drive lasted for about 10 to 15 minutes. The participants would then be left in the simulator for ten minutes to experience the scenario by themselves. They were instructed to perform any activity of their choice with any of the resources available. Their activities during this period were video-recorded for post-hoc analysis. The researcher then checked if they had any new ideas about in-vehicle activities and\or requirements for information and functions. During the whole process, the participants were not required to actually take over control from the automation. The duration of the whole process lasted for approximately 45 to 60 minutes.

2.4. Data analysis

Four participants reported slight motion sickness during the trial drives, but the symptoms were relieved after the driving scene was paused. They agreed to continue with the interview with the scene paused, so there was no drop-out and all data were collected.

Two types of data were collected. The main body of the data is the interview transcripts, which were transcribed and translated into English by the researchers. A content analysis was applied to the transcripts, which were divided into two categories, i.e., activities, and information and functions. The other part of the data is the 10-minute period of video recordings when the participant/s was/were sitting in the simulator during the driving scenarios. The activities shown in the video were also transcribed and categorised according to the specific activities adopted. The translation was completed by one researcher and proofread by the other researchers within the research group. While the categorisation of activities, information and functions was done manually by one researcher and examined by another researcher independently. The average Kappa coefficient between the researchers was 0.62 (SD = 0.17), which showed a good level of agreement.

3. Results

3.1. In-vehicle activities

3.1.1. Activities discussed

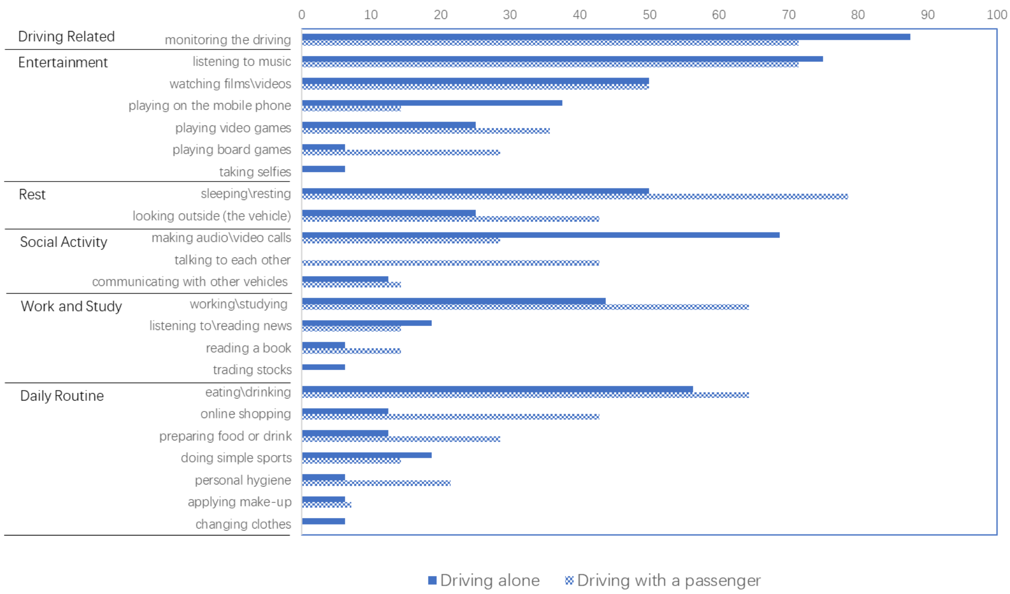

Figure 3. Percentages of reported activities in an autonomous vehicle: driving-alone scenario vs driving-with-a passenger scenario (The numbers on the horizontal axis indicate the percentage of drivers who mentioned the corresponding activities in the respective group.

The activities were categorised into six main types, i.e., Driving-Related Activity, Entertainment, Rest, Social Activity, Work and Study, and Daily Routine (Figure 3). Differences were identified in each category. Compared to DPDs, more DADs tended to concern about the driving task. For Entertainment, there were common activities preferred by both groups, such as listening to music and watching films\videos. DADs preferred activities that can be done by themselves such playing on their mobile phones and playing online video games. In contrast, DPDs preferred participatory activities such as playing video games or board games with other passengers. Concerning Rest, much more DPDs would sleep\rest or look outside the vehicle while driving compared to DADs. For Social Activities, DADs tended to make audio\video calls, whereas DPDs tended to talk to the other passenger driving together. DPDs were more inclined to do work\study related activities and read in the vehicle. They also tended to engage more in daily routine activities, especially for activities such as online shopping, preparing food\drink, and doing personal hygiene (such as washing hands, washing face). There were also activities from different categories mentioned only by DADs, such as taking selfies, trading stocks, changing clothes.

3.1.2. Activities observed

Figures 4 and 5 show the activities observed when the drivers were left by themselves in the simulator for ten minutes. In both groups, more than half of the time was spent on resting, namely sitting on the seat and watching the projected scene ahead. The major difference between the two groups lies in the second dominant activity, where single drivers spent approximately one-third of the time playing on their phones, whereas drivers with company tended to spend more time on talking. In both groups, a small number also looked around to see the scenes projected to the sides and the rear. The other activities for both groups include drinking\eating, writing something, etc. A majority of the drivers commented that “such a period was too boring” and it “should be occupied by some activities”.

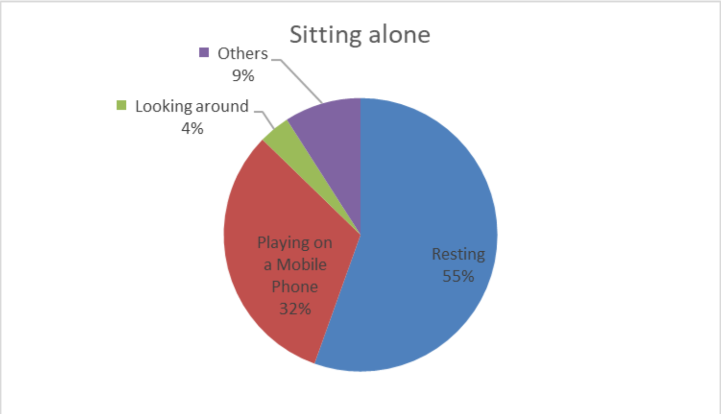

Figure 4. Percentages of activities observed in the simulator during the driving-alone scenario. Resting refers to situation when the participant was sitting in the seats without doing\watching anything. The other activities include drinking\eating, writing something, etc.

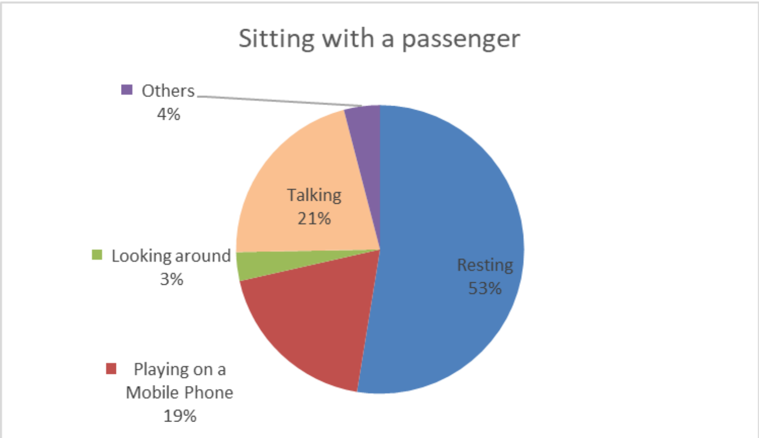

Figure 5. Percentages of activities observed in the simulator during the driving-with-a-passenger scenario. Resting refers to situation when the participant was sitting in the seats without doing\watching anything. The other activities include drinking\eating, writing somethings, etc.

3.2. In-vehicle information and functions, and the corresponding methods of interaction

In addition to the activities, the information and functions that were needed to support such activities are summarised in Table 2, which have been divided into the categories of Driving-Related Activities and Non-Driving Activities. The number of DADs (out of 16) and DPDs (out of 14) who mentioned the corresponding items were counted and labelled. Detailed information is explained and discussed in Section 4.

Table 2. Summary of requirements for information and functions

Category	**Information**	**Function**	**Interaction**	
Driving-Related Activities	• traffic information: traffic situation, traffic signs, road situation (10\8*) • navigation (7\4) • vehicle information: speed; general parameters (5\5) • location (4\2) • distance from the surrounding vehicles (2\1)	• showing\informing the surrounding traffic\road situation (7\6) • hazard alerts (6\3) • adjusting the driving mode (e.g. speed) according to changes in the environment or the physical and cognitive status of the driver (3\3) • adopting the driver's driving style and create a corresponding driving mode (1\4) • informing surrounding vehicles (e.g. being in autonomous driving mode) (2\0)	Presenting	• visual information: projecting on the windscreen\HUD; a screen in the centre console\dashboard • auditory information: come out when necessary • augmented reality (AR)
			Control	• manual control • voice control
			Intelligent interaction system	• real-time information\feedback • transferring driving modes (e.g., sports mode, eco mode, reflex mode, etc.,) smoothly • adjusting driving modes automatically according to environment changes • adjusting driving modes automatically according to the physical status of the driver

Non-Driving Related Activities	• in-vehicle environment (temperature\luminance\ noise level\air condition) (6\9) • information of the passing areas (e.g., shopping\service\tourism information) (3\7) • daily news\weather (6\2) • information from the social network (1\2)	• adjustable\multifunctional seats: rotatable; reclining; massage function; memory function (adjust to the preferred position automatically according to the specific driver) (11\11)	Presenting	• visual information on the windscreen; a screen in the centre console\dashboard • auditory information • MR; 3D-glasses
		• a screen - a screen\projection on the windscreen (7\7) - a movable screen (4\7) - a screen on the centre console\dashboard (4\4) - a screen on the surface of the steering wheel (3\0) • playing music\audio programs (10\10) • playing videos (11\6) • adjusting the temperature\luminance\noise level\air condition (6\9) • PC for work (7\6) • integrating the mobile phone with the system (7\4) • storing\preparing food and drinks (5\6) • space for preparing\storing food\drink (5\6) • resting\supporting surface for playing games, working\studying, eating, etc. (5\5) • digital game (in a touchscreen\MR) (4\5) • connecting to the Internet (4\5) • movable or smaller steering wheel, hide when not in use (6\3) • more in-vehicle space to move around (5\2) • an intellectual steward: monitoring the status of the driver (such as mood, appearance, physical status) and the in-vehicle environment, checking emails, reminding daily issues, making conversation (3\4) • simple gym equipment (4\2)	Control	• voice control • touch-screen control • controlled by mobile phone

Note. N=30. *The number on the left side of the "\" stands for the number of DADs (out of 16) who mentioned the corresponding items. The numbers of the right side of the "\" stand for the respective number of DPDs (out of 14). The column headed Interaction lists the declared methods of presentation and interaction of the aforementioned information and/or function.

4. Discussion

4.1. Passenger presence and driver's in-vehicle activities

Passenger presence was found to have an impact on the nature of activities adopted by the drivers. When driving with others, the drivers tended to take participatory activities such as playing video games (together with the passenger) or board games or simply talking to each other. In contrast, when driving alone, drivers tended to do things that could be done individually, such as playing on their mobile phones. DADs also tended to do things of a more private nature, such as changing clothes, trading stocks (as personal investments), or making audio/video calls. Another interesting finding is that, for DADs, they tended to direct more attention to the driving tasks by monitoring the driving. In contrast, when they were with other passengers, they were more inclined to take a sleep/rest. It suggests that the drivers tended to be more relaxed and have higher trust in the automation when they were with their companions. This is an interesting finding. Previous research has found that passengers may have a positive effect on driver's attention (Chandrasekaran et al., 2019). Is this also true in autonomous driving? Would the drivers' more relaxed state and higher trust in the system resulting from passenger presence lead to safer autonomous driving? Future research is needed to explore this topic in further detail.

4.2. Requirements to support driving-related activities

Understandably, those individuals who are experiencing autonomous driving for the very first time tend to be suspicious of the manoeuvres made by the autonomous system. Mok et al. (2015) and Habibovic et al. (2016) have identified the needs of autonomous vehicle drivers to control tactical decisions. Lin et al. (2018) also found that in the period of behavioural adaptation (when people begin to use new technology), drivers tended to feel nervous and focus on the driving task. Such state of vigilance was also found to be common in the current research at the beginning of the interviews and was slightly more common among DADs compared to DPDs. They were found to be concerned about the driving performance and showed strong intentions to monitor the driving tasks.

This monitoring focused mainly on two types of controls, namely the operational control of the vehicle (braking, accelerating), and the tactical control, meaning the manoeuvring of the vehicle in response to the road conditions (Kaber et al., 2012). For the former, five DADs and five DPDs were concerned about the speed and also other general parameters and wanted to have real-time feedback. One DPD even requested that all the common settings available on the dashboard of a conventional vehicle, i.e., the speedometer, odometer, fuel/electricity gauge, and temperature gauge., should be presented on a screen located in the centre console. For the latter, ten DADs and eight DPDs expressed the need to receive information about the traffic situation, which would include the surrounding traffic, traffic signs, and the road layout, etc. Seven DADs wanted a real-time presenting of such information to have constant monitoring, and six wished to have the function of hazard alerts when there were abnormal situations in the surrounding area. Eleven wanted the information related to navigation and real-time location. The corresponding numbers of the DPDs are six, three, and six, respectively.

In addition to their safety concerns, six drivers (three DADs and three DPDs) also concerned about their comfort during the journey. They expected more advanced and humanised functions such as adjusting the driving mode based on the changes of the environment (e.g. weather, road situation, etc.). Five drivers (one DADs and four DPDs) requested that the system should be capable of learning from the driver when in manual driving mode. They expected the system to adopt the driver's specific driving patterns (such as their braking style, how they accelerate, and their overtaking technique, etc.) and thereby create a corresponding driving mode in the system. In terms of the interaction process, voice control and touch control were mentioned most frequently. As Karlsson and Pettersson (2015) proposed, with voice control, the system provides a higher level of comfort and better accessibility for all passengers, as well as presenting a "hi-tech" feeling about the vehicle/system. Drivers also mentioned that, for simple controls, such as turning some functions on\off, voice control would be preferable, whereas, for controls of complex functions, a screen with touch control would be better for presenting the information and illustrating any corresponding operations.

Concerning in-vehicle information, a real-time manner was preferred by the majority of drivers. One DPD mentioned a 360° panorama of the surrounding environment to provide a high level of situational awareness, which echoes the "360 projection of the car's awareness" proposed by Strömberg et al. (2018). The most preferred method of presenting such information was to show it as visual information on the windscreen as a head-up display, with an alternative of presenting the same information on the centre console (located in the centre of the control panel) or on a conventional dashboard (located behind the steering wheel). Some drivers also mentioned the integration of technologies such as augmented reality (AR) in the head-up display. According to Tretten et al. (2009), when facing complex tasks, drivers preferred a head-up display over a head-down display, because it is close to the line of sight and therefore the information is less demanding. Technologies such as AR were mentioned many times as a method for realising such a function. Two DADs also anticipated the vehicles to communicate with each other as responsible agencies. For example, they should be able to inform other cars in the surrounding area about specific situations, such as accidents, or send messages about their driving status to activate corresponding levels of attention from any surrounding vehicles\drivers. With regard to emergencies, if a hazard were of low risk and easy to deal with, a voice alert would be sufficient. In contrast, if the situation were complicated, complementation of visual information would be required. When facing a severe condition, drivers tended to prefer a variety of alerts (e.g., audio + tactile + visual alarms) to ensure rapid and efficient responses. Visual communication was always preferred when related to driving tasks, as this was expected to help in maintaining situational awareness as well as any corresponding trust in the system, which is following the conclusion of Strömberg et al. (2018)

4.3. Requirements to support non-driving related activities

Automation allows the possibility of non-driving related activities in a vehicle to become a reality, and the realisation of such activities is based on the information and functions provided by the system. According to Jorlov et al. 's (2017), drivers tended to expect autonomous vehicles to release time for activities that would not otherwise be undertaken owing to a lack of time. Such a claim is validated in the current research. The requirements for in-vehicle information and functions to support such activities between the DADs and DPDs are also slightly different, which is in accordance with the activities mentioned by the two groups.

For Entertainment, most of the drivers requested the function of playing music\audio programs (ten DADs and ten DPDs) or videos (eleven DADs and six DPDs) in the vehicle, with the number of DADs a bit higher than that of DPDs. Similar are the numbers of requirements for the information and functions to support other activities. For example, the information of daily news\weather, the function of simple gym equipment, and the function of integrating the mobile phone with the system to support activities such as playing on a mobile phone, playing video games, and making audio\video calls. Most of the activities can be done individually and therefore are more common among DADs compared to DPDs.

There are also requirements found to be equally common in both groups. A typical example is a function of connecting to the Internet. It was to support a variety of activities in categories of Entertainment (e.g., watching film\video programs, playing video games, playing on the mobile phone), Social Activities (e.g., making audio\video calls), and Work and Study (e.g., working\studying, trading stocks). Other common requirements include functions of a PC for work and space for storing\preparing food and drinks are also consistent with numbers of mentioning the related activities of both groups.

For non-driving activities, visual communication also dominated the preferred methods of information presenting. About controls, in addition to voice control, touch control was also the most preferred method of interaction. As the central execution was freed from driving tasks, the drivers felt inclined to be involved with some other forms of manual manipulation. For those activities requiring visual information, a screen was always needed, with the preference being for touch-screen control. For some technology enthusiasts, technologies such as mixed reality (MR) or 3D glasses were also preferred. For those who requested to integrate their mobile phone into the autonomous system, there seem to be two different ways. Some claimed that their mobile phone should be combined with a touch-screen in the vehicle to release their hands from holding the phone, while others tended to control some in-vehicle functions directly via their mobile phones.

4.3.1. Interior design requirements to support both driving and non-driving related activities

Existing literature reveals that an interior metamorphosis of the vehicle is a common topic from the perspective of users (e.g. Jorlov et al., 2017; Karlsson and Pettersson, 2015; Large et al., 2017). Owing to the possibilities of a variety of non-driving activities in an autonomous vehicle, people tended to view it's interior space as an "extended living room" (Karlsson and Pettersson, 2015). Among the requirements to support non-driving activities, there are a series of requirements related to interior metamorphosis, with similar importance attached by both groups of drivers.

The majority of the drivers referred to the expectation of a more relaxed and comfortable environment. Six DADs and nine DPDs were concerned about the interior environment of the car. They wanted to have the information of in-vehicle temperature\luminance\noise level\air condition and also expected the system to be able to adjust these parameters to create a more comfortable and personalised environment.

One dominant theme concerning the idea of interior metamorphosis was concerned with a more flexible and adaptive design. A typical finding was the request for a more adjustable and multifunctional seat design, which was mentioned by over two-thirds of the drivers (eleven DADs and eleven DPDs). Such a requirement was to support the activities related to Rest. Specifically, some of them wanted the seats to be more flexible. They expected the seat could be expanded as a small bed to lie down during autonomous driving. They wanted the seat to be rotatable to turn around to interact with those in the rear and to be collapsible to release more space for more kinds of activities. Some also mentioned that the seats should have a memory function to adjust automatically to the preferred position of different drivers. These findings echo the results from Karlsson and Pettersson (2015) and Jorlov et al. (2017), who proposed that more adjustable seats would be a trend in future vehicles. A resting\supporting surface for working, studying, or playing games, as emphasised by Large et al. (2017), was also mentioned by a third of the drivers. For DADs, the surface was expected to be placed where a conventional steering wheel located, to support activities such as working\studying. In contrast, for DPDs, such a surface was expected to appear between the front and rear seats.

It could be used for interactive activities among the occupants, such as board games or having a meal. It should also be foldable and, therefore, hidden when not in use. Consequently and consistent with Karlsson and Pettersson (2015), a smaller or movable steering wheel was also preferred by six DADs and nine DPDs, as this would leave out more space since driving would not be a primary task most of the time.

Another common request is for a screen, which would either be movable or located at different positions (e.g., on the centre console\dashboard, on the surface of the steering wheel, or on the windscreen). It was expected to support activities in the categories of Entertainment and Work and Study and was equally appreciated by both groups. Such a request echoes an argument by Karlsson and Pettersson (2015), who claimed that in-vehicle screens will provide a sense of hi-tech novelty and will symbolise a shift from driving as the main task to other activities in autonomous driving scenarios. A small difference was that more DPDs expected a mobile screen whereas more DADs expect a screen on the surface of the steering wheel, which is consistent with the usage scenarios. There were also several drivers who expected more in-vehicle space for preparing\storing food\drink, or only for moving around as they awaited the traditional steering wheel would no longer be needed.

The hi-tech aspect of an autonomous vehicle is full of possibilities. Three DADs and four DPDs proposed a function as a virtual steward. The steward would monitor the status of the driver and help him\her to cope better in terms of driving safety (e.g., monitoring the driver's physical and cognitive status). Also, it would help to improve the in-vehicle experience (e.g., monitoring the in-vehicle environment to ensure the comfort of the driver) and even the driver's issues (e.g. monitoring the moods, dressing, and overall looking of the driver). Such topics were in line with the theme of "everyday life in an autonomous car" identified by Karlsson and Pettersson (2015). With autonomous vehicles, people expected to have less mental engagement with the traffic during driving and have a smoother and less demanding mental transition when travelling between places.

4.4. The application of the integrated method of simulator study and user enactment

The current research applied the integrated method of simulator study and user enactment to elicit people's potential activities in a future autonomous vehicle and also their corresponding requirement for in-vehicle information and functions to support such activities. The driving scenes developed in OpenDS simulate the possible driving conditions with different road situations, traffic situations, views, and weather to facilitate the participants merging into the driving scenarios. The simple simulator (with only the body shell of a car and two seats inside) used helped the participants develop imaginations about the interior space of a vehicle in future driving scenarios and elicit their preferred interaction with the vehicle. In particular, by enacting the scenario of driving with a passenger, it has successfully revealed the impact of passenger presence on driver's in-vehicle activities and their corresponding requirements. Such an integrated method gave the possibility to examine drivers' expectations for and interaction with future vehicles in great details rather than at a broad and rough level.

5. Design implications

The findings on the potential in-vehicle activities and the corresponding interaction with the vehicle offer informative guidelines for future vehicle design from the following perspectives:

First, it has identified the potential everyday activities in the vehicle and the corresponding interior metamorphosis requested to support such activities. In general, as a consequence of being released from providing permanent manual control, the variety of activities to be undertaken within a vehicle is unlimited. To support such a variety of activities, the interior design of a future autonomous vehicle is deemed to be revolutionary compared to traditional vehicles. The features of more adjustable and intelligent designs indicated that people preferred a more personalised and flexible interior space for the activities mentioned. Requirements such as a rest\support surface or movable screens also suggest that there would be more design implications in the interior space to support the potential activities. Also, as the observed activities revealed, being released from the driving task would be highly likely to cause a driver to feel bored when sitting in a self-driving vehicle. Consequently, it leaves the space for new interior designs to engage the driver with reasonable cognitive input.

"Second, this research has revealed some main themes concerned with in-vehicle interaction in autonomous vehicle design. The first theme relates to trust and safety. In previous research, the level of trust was found to have an influence on a driver's information processing (e.g. Seppelt and Lee, 2007), their use of the in-vehicle functions (e.g. Larsson, 2012), and in-vehicle activities, such as driving performance and car-driver interaction (e.g. Koo et al., 2015). As shown in the results of the current study, drivers with little experience of autonomous vehicles tend to keep monitoring the operational and tactical control of the autonomous vehicle. It is common for them to have doubts and questions regarding the reliability and safety of automation, demonstrating under-trust in the case when automation is in fact highly reliable. As drivers gain more experience with highly reliable automation, their level of trust is expected to increase (e.g. in Lin et al., 2018) . Nevertheless, for such cases of under-trust, researchers have suggested measures to enhance trust in automation. For example, Seppelt and Lee (2007) suggested that providing drivers with continuous information about the state of automation is critical for enhancing trust. Reassuring the user was also found to be important for user trust (Karlsson and Pettersson, 2015). According to evidence gained from the interviews, visual information was considered to be an essential form of reassuring, and therefore the visual presenting of information in addition to alerts from a combination of different sources (e.g., audio + tactile) was most preferred when complicated hazards were being handled. People also tended to believe that information presented by a combination of different sources would be more efficient. Nevertheless, things could be much more complicated in real situations. According to the Multiple Resource Theory (Wickens and McCarley, 2008, p. 132), two tasks that both demand attention from the same dimension level (e.g., two tasks both demanding visual perception) will interfere with each other, compared to two tasks that demand separate levels of attention (e.g., one visual and one auditory task). Lu et al. (2013) also proposed that in the context of ongoing visual tasks, a non-visual interrupting task would be processed more effectively than a visual one. The delivery of the alert information needs to be designed according to the ongoing activities of the occupants and should be based on Multiple Resource Theory. Additional research is required to examine the efficiency of information delivery in different situations."

The second theme was concerned with comfort and adaptability. People tended to expect autonomous driving to be a comfortable and highly adaptive experience. They envisioned the system as a humanised steward who would keep an eye on the occupants to ensure a match between the driving and their physical and cognitive status. Comfort-related functions also help in supporting the building of trust in automation (Karlsson and Pettersson, 2015). With an increase in comfort and confidence in automation, an acceleration in the implementation and penetration of autonomous vehicles may be expected (Rupp and King, 2010). One the other hand, the findings on adaptability also suggest the importance of open choice in terms of in-vehicle interaction. On the premise of being provided with adequate and sufficient information about the driving status, people tended to appreciate the freedom of having the choice of a different driving status in different situations. The expected interaction would change significantly according to the changes in the driving scenarios, the environment, and the traffic situations, therefore various and open choices are always expected from the smart and adaptive systems of autonomous vehicles.

Another theme is concerned with convenience. As Rupp & King (2010, p. 1) pointed out, one of the motivating factors for developing the "ultimate personalised, on-demand, door-to-door transportation" system is personal convenience. However, as the drivers concerned, the trade-off between convenience and safety is always noteworthy. For example, voice control may provide better accessibility to occupants sitting in different positions, but it is only appropriate for simple controls. For some more complicated and critical controls related to operational and tactical decisions, simple voice control could induce hidden dangers.

In particular, passenger presence is found to have an influence on the driver's activities as well as the corresponding requirements on in-vehicle information and functions. While some of the differences in activities are caused by the possibility to engage in social interaction, there is also the suggestion that passenger presence may affect a driver's level of relaxation or trust. It may also simply be an artefact of the experiment method. Drivers who were accompanied by a friend or family member might feel more at ease in the laboratory experiment setup than driver who were alone. Future research is needed to further examine this issue in on-road driving. The social context, owing to the presence of other passengers, requires the interior space to be suitable for activities that may be shared by the occupants. Such requirements may also become prevalent in future vehicles when more than one occupant shares them. On the other hand, the findings also indicate that when driving alone, the interior space seemed to become a more private space, so privacy would become a higher priority in the relevant design. This is consistent with Kun et al. (2016), who claimed that autonomous driving should exploit new mobility options with the premise of preserving user privacy. Strömberg et al. (2018) also found that there was a need for users in autonomous vehicles to be unsocial during their daily commuting. It suggested that a design which helped drivers to refrain from social interaction could also be important for people who travel alone in autonomous vehicles. The coexistence of and trade-off between the attributes focused on privacy and those concerned with social relatedness should be taken as one critical consideration for the interior design of future autonomous vehicles.

6. Limitations and future directions

The current research applied a qualitative approach to explore the possible in-vehicle activities and the corresponding user requirements for in-vehicle information and functions. The integration of the methods of simulator study and user enactment ignited the participants' imagination of their interaction with future autonomous vehicles. The findings elicited from them focus on the nuances of the features, rather than statistical differences. For example, in the section of the interviews when the participants were left alone in the simulator, no objects were used to enable them to perform any specific activities. Such a method is consistent with the aim of the current research, which was to explore the possible human-vehicle interaction when the driver was released from the driving tasks.

However, it also limited the possibilities of observing specific behaviour and requirements while the participants were interacting with particular objects. Future research may focus on more specific perspectives of human-vehicle interaction in autonomous vehicles. The potential topic could be the detailed interaction with some particular objects in the vehicle, the prioritisation of the required information and functions with large samples, trust and safety issues in autonomous vehicles with the implications suggested, etc. More detailed scenarios and a well-designed in-vehicle space could be applied to help the drivers to become immersed in any specific situations.

In the automotive field, the translation of user needs and preferences into actionable information is challenging owing to the different attained actionability level and different ways of evaluating consumer preferences (Gaspar et al., 2019). The elicitation of user requirements in the current research could be viewed as an early stage of requirement engineering of the future autonomous vehicle design. To translate such requirements into design inputs would require further participatory work with different stakeholders. For example, for each user requirement, an evaluation of how much the requirement is satisfied need to be conducted by industrial designers, engineers, and stakeholders of a design project from different aspects such as operability, performance, safety, security, reliability, etc. (Alexander, 2009). Trade-offs between technological constraints, costs, and user preferences need to be considered and balanced. There are still lots of future work required to bring together experts and stakeholders to translate the wish list into a want list.

7. Conclusion

This research used a UCD approach to investigate the driver-vehicle interaction in future autonomous vehicles. The integrated method of simulator study and user enactment was applied to bridge the gap between the current and the future and to immerse the drivers in concrete driving scenarios, while at the same time leaving sufficient space for the imaginary exploration of the possibilities of the autonomous vehicle design. Such a method helped in eliciting rich data from the users. In general, it has revealed a comprehensive picture of the potential future interactions between driver and vehicle. Possible in-vehicle activities and corresponding requirements for in-vehicle information and functions were identified, which has validated and also expanded the previous research. The effects of passenger presence on in-vehicle activities and the corresponding user requirements were revealed and discussed.

Some dominant themes for future vehicle design have been identified. A feeling of control is still necessary for autonomous vehicles, which may be attributed to the concerns about safety as well as comfort in autonomous driving. A variety of non-driving related activities was also identified, together with a common requirement for interior metamorphosis, echoing the findings of Jorlov et al. (2017) and Large et al. (2017). Some interesting trade-offs in design were suggested. For example, due to the effects of passenger presence, the in-vehicle space was expected to be a private space when driving alone, providing help for the driver in refraining from social interactions. In contrast, it was expected to support socialising in situations where a passenger is present. Also, the trade-off between concerns about convenience and safety was found to be essential, especially when concerning some complicated controls.

In general, a more flexible and adaptive design was expected by most drivers for the design of future vehicles. Such a request manifested itself in items such as adjustable and multifunctional seats, extended space, more variety in the design of controls, and more personalised functions, etc. The findings offer valuable references for driver-vehicle interaction research in autonomous vehicles as well as for the implications of the future vehicle design.

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