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Investigation of older drivers' requirements of the human-machine interaction in highly automated vehicles

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ABSTRACT

The population of older drivers is increasing in size. However, age-related functional decline potentially reduce their safe driving ability and thereby their wellbeing may decline. Fortunately, the forthcoming highly automated vehicles (HAVs) may have the potential to enhance the mobility of older drivers. HAVs would introduce a revolutionary human-machine interaction in which drivers can be completely disengaged from driving, and their control would be required occasionally. In order to inform the design of an age-friendly human-machine interaction in HAVs, several semi-structured interviews were conducted with 24 older drivers (mean = 71.50 years, SD = 5.93 years; 12 female, 12 male) to explore their opinions of and requirements towards HAV after they had hands-on experience with a HAV on a driving simulator. Results showed that older drivers were positive towards HAVs and welcomed the hands-on experience with HAVs. In addition, they wanted to retain physical and potential control over the HAVs, and would like to perform a range of non-driving related tasks in HAVs. Meanwhile, they required an information system and a monitoring system to support their interactions with HAVs. Moreover, they required the takeover request of HAVs to be adjustable, explanatory and hierarchical, and they would like the driving styles of HAVs to be imitative and corrective. Above all, this research provides recommendations to inform the design of age-friendly human-machine interactions in HAVs and highlights the importance of considering the older drivers' requirements when designing and developing automated vehicles.

1. Introduction

The numbers of older people in the UK and across the world are increasing as is their percentage of the total population, and this trend is predicted to accelerate in the future. In 2016, 18% of the population of the UK was aged 65 and older, and the proportion is predicted to increase to 24.7% in 2046 (ONS, 2017). In the world, 12% of the population was aged over 60 years in 2015, and the proportion is predicted to grow to 22% in 2050 (WHO, 2018). To a great number of older adults, driving is important for them to stay mobile which is closely linked to their health and wellbeing (Gabriel & Bowling, 2004; Metz, 2000). In the UK, driving a car has been an important travel mode for older adults (DfT, 2017). Driving is a complicated activity that needs multiple sensory, physical and cognitive functionalities (Karthaus & Falkenstein, 2016; Rimmö & Hakamies-Blomqvist, 2002). However, age-related sensory, physical, mental and cognitive functional decline may have a negative influence on their safe driving ability which potentially make older drivers to be more vulnerable to traffic crashes and collisions

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(Ball et al., 1998; Rimmö & Hakamies-Blomqvist, 2002). In order to counteract age-related functional impairments on driving, older drivers sometimes have to adjust or regulate their driving, such as avoiding speeding, driving alone, driving at night, in heavy traffic, or in adverse weather conditions, or along unfamiliar routes or for longer journeys (Ball et al., 1998; Charlton et al., 2006; Karthaus & Falkenstein, 2016). Ultimately, older drivers may have to give up driving altogether (Hakamies-Blomqvist & Wahlström, 1998; Hwang & Hong, 2018). The price of adopting self-regulatory driving behaviours is a significant reduction in older people's mobility and this may lead to increased social isolation, loneliness and depression and reduced self-esteem (Charlton et al., 2006; Hakamies-Blomqvist & Wahlström, 1998). Meanwhile, the forthcoming roll-out of automated vehicles for public roads may offer the potential to reduce traffic emission and crashes as well as improving road efficiency. Additionally, they may also have the potential to enhance older drivers' mobility by offering new functionalities to compensate for their functional decline.

1.1. Highly automated vehicle

Vehicle automation systems could be classified into several levels according to their different functionalities and capabilities. The 'Level 0' refers to the bottom level of vehicle automation (SAE, 2014), systems of this level are not supposed to perform the longitudinal or lateral control of a vehicle, however they could assist drivers in various ways through several advanced driver assistance systems (ADAS), including enhancing their visibility such as in advanced forward lighting systems and night vision systems, providing drivers with information and feedback such as in-vehicle navigation systems and lane departure warnings (Edwards, Emmerson, Namdeo, Blythe, & Guo, 2016; Emmerson, Guo, Blythe, Namdeo, & Edwards, 2013; Gish, Vrkljan, Grenier, & Van Miltenburg, 2017; Guo, Brake, Edwards, Blythe, & Fairchild, 2010). Compared to 'Level 0', the 'Level 1' automation systems can perform either longitudinal or lateral control of the vehicle (SAE, 2014), for example, adaptive cruise control, intelligent speed adaptation and lane keeping assistance systems (Gish et al., 2017; Guo, Blythe, Edwards, Pavkova, & Brennan, 2013). Next, the 'Level 2' automation systems are capable of executing both longitudinal and lateral controls of a vehicle at the same time, enabling the drivers to release from the driving physically, however, they must constantly monitor driving and are still responsible for the safety of driving (SAE, 2014). A typical example of systems at this level of automation is the Tesla Autopilot (Lin, Ma, & Zhang, 2018). Notwithstanding the multiple levels of support and assistance that the above automation systems could provide, they would still require the drivers to be fully engaged in dynamic driving tasks at all times (DfT, 2015; SAE, 2014). The upcoming highly automated vehicles (HAVs), as known as the level 3 automation (SAE, 2014), could allow the drivers to be disengaged from driving both physically and mentally, but sometimes require drivers to take over the vehicle control. Finally, the 'Level 4' and 'Level 5' systems represent the ultimate levels of vehicle automation. The 'Level 4' automation systems are able to automatically initiate safe mode even if the drivers cannot respond to the TOR safely and promptly, and the 'Level 5' full automation systems are able to perform self-driving under all conditions and do not require any takeover from drivers during a journey (SAE, 2014).

However, before the ultimate levels of vehicle automation become available into the road traffic, the HAVs (SAE Level 3) are predicted to be available within next five to ten years (UKAutodrive, 2016). HAVs could bring a revolutionary automated driving experience which would allow drivers to be completely disengaged from driving and may safely perform other non-driving related tasks such as reading, while the driver's control is still required occasionally (DfT, 2015).

In situations when the HAV systems are not able to deal with, such as missing road signs, constructions areas, the driver's takeover of control is required. The HAV informs the driver by initiating a takeover request (TOR) and providing sufficient lead time for control to be taken over. Following the TOR, drivers are required to stop performing any non-driving related tasks and take over control of the vehicle and then manually drive the vehicle (Gold, Körber, Lechner, & Bengler, 2016). Above all, compared to conventional cars, HAVs would change the driver's role in and responsibilities for vehicle control, especially during automated driving periods as well as during the process of taking over control.

1.2. HAV and older drivers

Previous studies have identified the potential of the existing ADAS in improving older drivers' driving safety and maintaining their mobility and independence (Edwards et al., 2016; Emmerson et al., 2013; Gish et al., 2017; Guo et al., 2010; Musselwhite & Haddad, 2007). Guo et al. (2010) suggested that in-vehicle systems have the potential to help older drivers to build a clear understanding of their weakness and the vulnerability of road users and enhance their driving performance. Additionally, several studies have investigated the interaction of older drivers with the HAV. Miller, Johns, Ive, Gowda, and Sirkin (2016) conducted driving simulator research to compare the takeover performance of younger and older drivers in HAVs. The results of their study did not show any significant influence of age on the takeover performance. Their findings were supported by those of Molnar (2017) who examined age-related differences in driver's takeover performance in HAV on a driving simulator. It was found that participants aged 65–75 exhibited similar takeover behaviour to those aged 25–45. However, some other research has observed the age effects in terms of the performance of interacting with the HAV. Körber, Gold, Lechner, and Bengler (2016) implemented a driving simulator study to examine participants' takeover behaviour in HAV. They reported that although age did not affect takeover time, older drivers exhibited safer and more cautious takeover behaviour. This was in accordance with the findings of Clark and Feng (2017), who found that older drivers performed more cautious and stable takeover than younger drivers. Apart from focusing on takeover behaviour among older drivers in HAVs, previous research has also examined age differences in preferences for non-driving related tasks in HAVs and reported that younger drivers were more likely use electronic devices whereas older drivers preferred to talk to other people, and they were likely to become more heavily engaged in the non-driving related tasks than younger drivers (Clark & Feng, 2017). Previous research has also investigated how the experience of interacting with an HAV changes the driver's trust in and attitudes towards automation, and Gold, Körber, Hohenberger, Lechner, and Bengler (2015) reported that the driving experience enhanced the trust in automation, and older drivers had more positive attitudes towards the HAV than younger drivers. In addition, Li, Blythe, Guo, and Namdeo (2018) examined older drivers' interaction with the HAV under a variety of weather conditions, they found significant age difference in terms of the takeover time and quality. Specifically, older drivers exhibited slower reaction to the takeover request, slower first active input to the HAV and took longer time to decide to change lane to avoid collision compared to their younger counterparts. They were also found to exhibit stronger barking and accelerating patterns as well as less safe takeover than the younger participants. In addition, adverse weather conditions (rainy, snowy and foggy conditions) slowed the takeover time and reduced the takeover quality for the younger drivers. However, for older drivers, the adverse weather conditions did not further increase their already slower takeover time but greatly worsened their takeover quality.

1.3. Designing human-machine interactions for older drivers in HAVs

The human-machine interaction in a vehicle generally includes the driver's operation of the primary vehicle controls as well as their interaction and communication with a variety of in-vehicle systems and applications. Previous research has pointed out that there is a tendency for the current designs of in-vehicle systems to have not adequately considered the opinions, capacities and needs of older drivers (Guo et al., 2010; Musselwhite & Haddad, 2007; Young, Koppel, & Charlton, 2017). The potential consequences of ignoring older people in the design of the in-vehicle systems could be that these systems may cause more difficulties for the older people than they resolve (Guo et al., 2010; Young et al., 2017). And numerous studies have pointed out the importance and necessity of considering older people's attitudes, capabilities and requirements when designing the in-vehicle systems (Edwards et al., 2016; Emmerson et al., 2013; Guo et al., 2010, 2013; Li et al., 2018; Musselwhite & Haddad, 2007). As the HAV is soon to be introduced into road traffic, it is crucial to draw lessons from past experience to integrate older drivers into the design process (Yang & Coughlin, 2014).

At the present time, the design of in-vehicle systems focuses on providing feedback, information and support to drivers at the same time as when they are manually driving the car (Damiani, Deregibus, & Andreone, 2009; Guo et al., 2010). However, in the HAV, the human driver's role is extended from solely being an active driver to include passive monitoring and being a more passenger. Drivers also have the freedom to engage in various types of non-driving tasks during automated driving. In terms of takeover situations they need to reassume control of the vehicle effectively and promptly. These changes in the driver's roles in the HAV have created an urgent need to explore the design of new types of human-machine interaction for HAVs, especially during automated driving periods and the takeover control period. A review of the literature suggests that current studies of HAV involving older drivers are dominated by quantitative research and tend to focus on the performance perspective of older drivers during the takeover control process (Clark & Feng, 2017; Gold et al., 2015; Körber et al., 2016; Li et al., 2018; Miller et al., 2016; Molnar, 2017). The significant age difference in the takeover behaviour in HAVs found by these studies (Clark & Feng, 2017; Körber et al., 2016; Li et al., 2018) have emphasized the need to considering the needs and requirements of older drivers during the design of the HAV. In addition, hands-on experience is found to be crucial in designing and developing technologies for older people and can help them to build a spontaneous and realistic understanding of new technology as well as laying the foundation for the collection of data on their attitudes and needs (Buckley, Kaye, & Pradhan, 2018; Davies & Lam, 2009; Eisma et al., 2003). Although a great number of previous studies have provided older drivers with hands-on experience of HAV, using driving simulators (Clark & Feng, 2017; Gold et al., 2015; Körber et al., 2016; Li et al., 2018; Miller et al., 2016; Molnar, 2017), however previous research has not fully explored their opinions and needs concerning the human-machine interactions in HAVs after providing hands-on experience to them.

1.4. Purpose of this research

The above review suggested that older drivers' opinions and requirements towards the HAV is still under-researched. And knowledge concerning how to design the human-machine interaction for HAVs that satisfies the older driver's needs and requirements is still limited. Therefore, in order to fill the gap in knowledge, the aim of this research is to investigate the opinions and requirements of older drivers after having hands-on experience of HAVs in order to provide knowledge to inform the design of the safe and comfortable human-machine interaction in HAVs for older driver coherent.

2. Methods

2.1. Participants

Participants were recruited through a mailing list of an older driver user group (VOICE North) as well as personal approaches at the local communities in Newcastle upon Tyne. The VOICE North user group was established at Newcastle University and aims to make use of the valuable experience of the older people (people aged 60 years and over) to address the challenges and opportunities of an ageing society. The group has approximately 1000 users which form a representative sample of the population older drivers in the UK. To be eligible for the research, each participant was required to be aged 60 years or over, have a valid UK driving licenses and to be an active driver at the time they participated in the study.

When recruiting the participants, they were explained that they are invited to participate in a study aims to investigate older drivers' interactions, opinions and requirements of highly automated vehicles. The study will take place at Newcastle University driving simulator laboratory where they will experience several driving sessions using a simulated HAV, and after that they will be interviewed about their opinions and requirements of HAVs, shopping vouchers will be given to compensate for their time and travel cost for participating the study.

In total, 24 older drivers (mean = 71.50 years, SD = 5.93 years; 12 female, 12 male) who participated in the quantitative driving simulator experiments were interviewed. The sample size was determined by the time when data reached saturation where the data collection completed at the point when no new information was gained from additional interview sessions (Guest, Bunce, & Johnson, 2006; Mason, 2010; O'reilly & Parker, 2013; Saunders et al., 2018). Their annual driving mileages by age group are shown in Table 1.

2.2. Ethical considerations

Before the study, the research team received ethical approval from Newcastle University's ethics committee and performed a risk assessment. At the beginning of the study, a brief safety induction was firstly given to all participants. Next, all the participants were informed that their participation is entirely voluntary and they are free to withdraw from the study at any time for any reason. In addition, they were informed that the data collected from them will be treated with full confidentiality and access to the data is only limited to the researchers involved in this study, if published it will not be identifiable by their names. If a photograph or video clip is used for presentation or in a publication, their name will not be mentioned and their face image will be blanked. After that, the written consent for participation was obtained for all participants.

2.3. Research design and data collection

A previous quantitative study by the authors have provided older drivers with hands-on experience with the HAV and investigated the effect of age on the takeover performance (Li et al., 2018). The present study aims to build a qualitative understanding of older drivers' interaction with HAVs after interacting with a simulated HAV. Among the qualitative research regarding in-vehicle technologies, focus groups and interviews are most common methods of data collection (Buckley et al., 2018; Emmerson et al., 2013; Gesser-Edelsburg & Guttman, 2013; Gill, Stewart, Treasure, & Chadwick, 2008). The data collection of the current research was to be undertaken after each participant had taken part in a quantitative study using a driving simulator (Li et al., 2018), and only one participant could be tested at a time. Therefore, interviews would be more sensible than focus groups for the data collection in the present research. Interviews are known to be an effective method in investigating issues of older drivers' mobility and their reaction to technologies (Buckley et al., 2018; Fofanova & Vollrath, 2012; Gitelman, Pesahov, Carmel, & Chen, 2017; Prat, Gras, Planes, Font-Mayolas, & Sullman, 2017). They enable the participants to fully express their attitudes, experiences, expectations and motivations towards the research topic (DiCicco-Bloom & Crabtree, 2006; Gill et al., 2008).

The research took place in the driving simulator laboratory at Newcastle University. Before the interview, each participant would have experience of a series of HAV driving sessions on the driving simulator (Li et al., 2018), as shown in Fig. 1. The HAV scenario starts with highly automated driving for one minute, and during this period the drivers are allowed to be completely disengaged from driving and to safely perform other non-driving related tasks. After one minute, the system detects a stationary car suddenly block the driving lane, and then it informs the driver by using a takeover request which consists of a visual message, "Take over control" and an audible message, "Attention, please take over the vehicle control". In terms of the lead time available for drivers to take over control, considering previous studies of HAV involving older drivers only used relatively short lead times between 4.5 s and 7.5 s (Clark & Feng, 2017; Körber et al., 2016; Miller et al., 2016; Molnar, 2017), and Clark and Feng (2017) suggested longer duration of lead time could have the potential to benefit the older drivers. Therefore, the HAV of this study provided older drivers with a significant large lead time of 20 s to take over control from the HAV and to react to the stationary car, and it was found to be sufficient for older drivers to successfully take over the control of the HAV (Li et al., 2018). After the driver has passed the stationary car, they are asked to pull over and the scenario ends. The HAV scenario runs on two types of roads: an urban road and a motorway. Each participant had experienced five driving

Table 1
Annual mileage driven by participants.

Annual mileage (miles)	0–3000	3000–6000	6000–10000	10000–15000	15000+	Total
Female	2	4	5	1	0	12
Male	1	1	5	4	1	12
Total	3	5	10	5	1	24

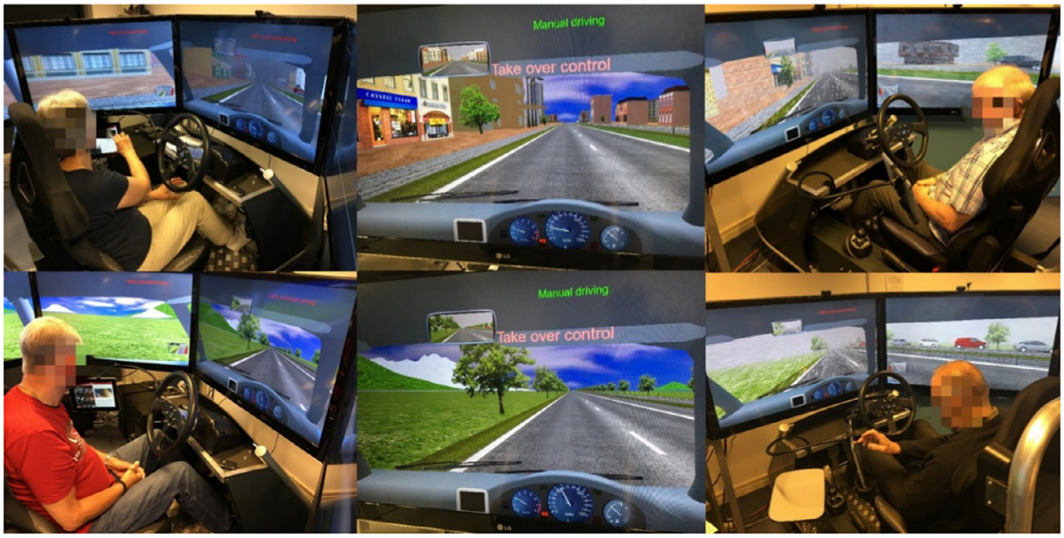

Fig. 1. Highly automated vehicle scenarios on city road (top) and motorway (bottom).

sessions differentiated according to two non-driving related tasks of monitoring driving and reading and four weather conditions of clear weather, rain, snow and fog.

After each participant had finished the driving sessions, which lasted for approximately 45 min for each participant. The data collection for interview investigation started (see Fig. 2). The interview lasted no longer than 30 min in order to restrict the duration of the overall experiment to less than 75 min to prevent the participants from losing attention and becoming fatigued (Purchase, 2012). The interviews were semi-structured which were suitable for this research as they were structured by a group of predetermined open-ended questions and also allowed the researcher to follow up other questions derived from the dialogue between the researcher and participants (DiCicco-Bloom & Crabtree, 2006). The predetermined questions were centred on the new types of human-machine interaction in the HAV highlighted in the literature (DfT, 2015; Gold et al., 2016; SAE, 2014): first, when the HAV is performing automated driving and the drivers are completely disengaged from driving; and second, when drivers are reassuming control of the vehicle back from the HAV. The questions (see the Appendix) were in plain language and cover the following topics: daily driving behaviour, opinions and expectations of HAVs, and advice to HAV manufactures.

Fig. 2. Semi-structured interviews.

2.4. Data analysis

The data collected in the interviews was analysed by inductive thematic analysis, which is a widely-used method used to identify and analyse themes within qualitative data and it is independent of pre-existing theoretical frameworks but allows the interpretation of diverse aspects of a research topic (Boyatzis, 1998; Braun & Clarke, 2006). The thematic analysis was conducted using the computer-assisted qualitative data analysis software NVivo. Using software like this in qualitative research ensures that the data analysis is performed in a continuous and transparent way (Castleberry & Nolen, 2018; Richards & Richards, 1994). The thematic analysis was conducted according to the guidance proposed by Braun and Clarke (2006). Firstly, the interview recordings were transcribed and then the transcripts were read through and the initial thoughts and ideas for the coding of the data were noted. Then, the interview scripts were coded in NVivo, each participants' comment was reviewed, the code was identified inductively based on the semantic features of the data. Then, a label was assigned to the code. The coding process was conducted by one researcher, in order to prevent bias and to ensure the codes are valid and reliable, the codes were verified by two other researchers (Boyatzis, 1998). The next step is to discover themes. Themes are discovered through a process of combining the components of issues, ideas, topics, phenomena or experiences, which may have less meaning or significance if they are inspected individually (Aronson, 1995). An important consideration is what counts as a theme. It is possible to identify a theme based on the number of participants who refer to a topic or the frequency that a topic is mentioned. However, several studies have argued that despite the more times a same code was mentioned by the participants the more likely it could form a theme, the qualitative depth and significance of an issue is much more important than how often this issue is discussed (Braun & Clarke, 2006; Fereday & Muir-Cochrane, 2006; Vaismoradi, Jones, Turunen, & Snelgrove, 2016). Therefore, counts of the frequency or instances of an issue were only used to describe the data rather than to identify themes in this study. Instead of generating themes by counting instance of a topic, previous research pointed out that generating themes should be in accordance with the research questions (Braun & Clarke, 2006; Fereday & Muir-Cochrane, 2006; Musselwhite & Haddad, 2010; Vaismoradi et al., 2016). Thus all codes were reviewed carefully under the context of exploring older drivers' opinions and requirements towards the human-machine interaction of the HAV. By the end of this step, a set of core themes and their sub-themes were carried out. The next step is to review the themes and to check them against the original interview transcripts. Finally, the names and definitions of the core themes were generated. The 24 older drivers' interview transcripts resulted in 62 codes in total, they were grouped into 7 key themes and 20 sub-themes. Table 2 summarises the thematic analysis. The number of participants mentioning a code is reported to describe the qualitative data of this research and it may not be indicative of the frequency that the code would be mentioned in a wider population sample.

3. Findings and discussions

3.1. Self-reported driving behaviour of older drivers

The first themes is about the older drivers' self-reported driving behaviour. In general, older drivers believed that they are safe drivers. More than half of the participants indicated that they drove cautiously and more slowly than others (n = 13, 7 female, 6 male, Table 3, i, ii). Some participants indicated they are good drivers (n = 8, 4 female, 4 male) and they like driving (n = 8, 4 female, 4 male). Example quotes about older drivers' self-reported driving behaviour are outlined in Table 3.

The above findings are in line with previous findings which indicate that the main issue with younger drivers is risk-seeking and lack of skills, but older drivers have the strength of risk aversion (McGwin Jr & Brown, 1999).

3.2. Older drivers' opinions towards the automated vehicles

The second theme was older driver's opinions towards automated vehicles. The themes consists several sub themes including their first-hand experience with the HAV, comparison between the HAV and the FAV (fully automated vehicle), benefits and concerns of the HAV. Example quotes about this theme are outlined in Table 4.

3.2.1. First-hand experience of interaction with the HAV

Participants experienced several HAV driving sessions on the driving simulator prior to the interviews. The driving simulator used in this research has been found to be valid to enable drivers to have an authentic driving experience (Edwards et al., 2016; Guo et al., 2013; Li et al., 2018). Participants (n = 10, 6 female, 4 male, Table 4, a.i) pointed out that the first-hand experience of interaction with the HAV on the simulator is really important for them to build a realistic and spontaneous understanding of HAVs. They stated that it is completely different with the HAV that they imagined when they first heard about it on the news. Also, some participants (n = 9, 4 male and 5 female, Table 4, a.ii) indicated that their trust and confident in HAVs have improved over several driving sessions on the simulator, they believed their trust of automated vehicles could be developed over time.

The abundant information about older drivers' requirements provided by this research may also be credited to the first-hand experience, which has been proven to be effective in helping participants deepen their understanding and develop a more critical perspective of the subject (Davies & Lam, 2009). These findings are in line with those of Eisma et al. (2003),

Table 2
Summary of thematic analysis.

Key themes and sub themes	Codes and frequency of codes
1. Self-reported driving behaviour of older drivers	
	a. I drive cautiously and slowly (n = 13, 7F, 6M)
	b. I am a good driver (n = 8, 4F, 4M)
	c. I like driving (n = 8, 4F, 4M)
2. Older drivers' opinions towards the automated vehicles	
2.1 First-hand experience of interaction with the HAV	a. First-hand experience with the HAV is useful (n = 10, 6F, 4M)
	b. Developing trust of the HAV over time (n = 9, 5F, 4M)
2.2 Perceived benefits of the HAV	a. HAV is good for long journeys (n = 16, 11F, 5M)
	b. HAV is good for motorway driving (n = 5, 2F, 3M)
	c. HAV is suitable for adverse weathers (n = 2, 2F)
	d. HAV is good for unfamiliar roads (n = 3, 2F, 1M)
	e. HAV increases work efficiency (n = 2, 2M)
2.3 HAV vs *FAV*	a. I would like to use a HAV now and to use a FAV when I cease driving (n = 17, 11F, 6M)
2.4 Expectations and Concerns of the HAV	a. Making it simple (n = 4, 2F, 2M)
	b. Making it safe (n = 5, 3F, 2M)
	c. Appearance of HAV (n = 2, 1F, 1M)
	d. Eligibility to use HAV (n = 1, 1M)
	e. Liability insurance of HAV (n = 1, 1F)
3. Physical and potential control of the HAV	
3.1 Physical control of the HAV	a. I would like to retain physical control of the HAV (n = 15, 9F, 6M)
3.2 Potential control of the HAV	a. I would like to have potential control of the HAV (n = 11, 6F, 5M)
4. Non-driving-related tasks in HAV	
4.1 Relaxing tasks	*The relaxing tasks that older drivers would like to perform in the HAV include:*
	a. Relaxing not demanding tasks (n = 10, 5F, 5M)
	b. Listening to radio (n = 8, 4F, 4M)
	c. Reading (n = 16, 10F, 6M)
	d. Looking at scenery (n = 7, 5F, 2M)
	e. Talking to others (n = 4, 3F, 1M)
	f. Using mobile phone (n = 3, 1F, 2M)
	g. Watching TV and films (n = 2, 1F,1M)
	h. Doing exercise (n = 1, 1F)
	i. Thinking (n = 2, 1F, 1M)
	j. Meditation and breathing (n = 1, 1F)
	k. Doing crosswords (n = 2, 1F, 1M)
4.2 Working	a. I would like to work in the HAV (n = 2, 2M)
4.3 Monitoring driving	a. I would like to monitor the HAV system driving (n = 12, 5F, 7M)
4.4 Eating and drinking in the HAV	a. I would like to eat and drink in the HAV (n = 8, 5F, 3M)
	b. I would need a meal table in the HAV (n = 1, 1F)
5. Human-machine interaction during automated driving in HAV	
5.1 Information system in the HAV	a. HAV informs drivers about what's happening (n = 21, 12F, 9M)
	b. HAV informs drivers about journey time (n = 7, 3F, 4M)
	c. HAV informs drivers about vehicle status (n = 7, 2F, 5M)
	d. HAV informs drivers about traffic conditions (n = 4, 1F, 3M)
	e. HAV informs drivers about being in a HAV (n = 3, 2F, 1M)
	f. HAV Informs drivers that it adapts to driving conditions (n = 16, 10F, 6M)
5.2 Monitoring system in the HAV	a. HAV monitors driver status (n = 7, 4F, 3M)
5.3 Form and modality of the feedback	a. Differentiating normal and urgent information (n = 12, 4F, 8M)
	b. Providing helpful but not annoying information (n = 3, 3M)
	c. I would like to customize the voice of the system feedback (n = 9, 2F, 7M)
6. Human-machine interaction during taking over control in HAV	
6.1 Takeover request in the HAV	a. I would like to adjust when and where to receive takeover request (n = 5, 3F, 2M)
	b. I am happy with the existing takeover request (n = 14, 9F, 6M)
	c. Only visual modality of the takeover request is not enough (n = 4, 2F, 2M)
	d. Louder takeover request for drivers with hearing impairment (n = 3, 1F, 2M)
	e. Loud clear but not panicking takeover request (n = 1, 1M)
	f. Providing reasons for takeover in the takeover request (n = 19, 11F, 8M)
	g. Takeover request should inform drivers to take over first then give reasons (n = 3, 2F, 1M)
	h. Hierarchical takeover request (n = 3, 1F, 2M)
	i. Car interiors of HAV correspond with takeover request (n = 1, 1F)
	j. Concerns of sleeping before takeover request (n = 13, 7F, 6M)
	k. Concerns of drinking before takeover request (n = 2, 2F)
	l. Fail safe mode (n = 2, 1F, 1M)
6.2 Lead time for takeover control in HAV	a. 20 s is enough to take over (n = 15, 8F, 7M)
	b. Lead time corresponds non-driving related tasks (n = 5, 2F, 3M)
7. Driving style of HAV	
7.1 Imitative and corrective driving style of HAV	a. HAV adapts to my drive style (n = 11, 4F, 7M)
	b. HAV corrects bad driving style of the drivers (n = 9, 5F, 4M)
7.2 Multiple user mode	a. HAV has multiple user mode of driving styles (n = 2, 2M)
7.3 Remembering journey purpose	a. HAV remembers the trip purpose (n = 1, 1F)
7.4 Optional journey routes of HAV	a. HAV Allows the driver to choose the route (n = 1, 1F)

Note, n = number of participants, F = female, M = male, HAV = highly automated vehicle, FAV = fully automated vehicle.

Table 3
Selected quotes relevant to the theme 1.

Theme 1. Self-reported driving behaviour of older drivers	
Sub themes	Example quotes
–	***i.*** *"When I drive, I am watching what's going on around me, dogs on the pavement, children on the pavement, it's windy, and it's a bit of plastic bags blowing across the road. What's the condition of the road? I am continually scanning everything and thinking about it. I am not doing it for fun, I am doing it because I am going from A to B and I want to get there safely." (No.6, male, age 79)* ***ii.*** *"They say older people are slow, slow still gets you there, you don't break speed limit." (No.18, female, age 81)*

Table 4
Selected quotes relevant to the theme 2.

Theme 2. drivers' opinions towards the automated vehicles	
Sub themes	Example quotes
a. First-hand experience of interaction with the HAV	***i.*** *"Before I came here this afternoon, I thought it would be terrifying to drive an automated car, I'll be frightened to keep my eyes off the road, but now I know I can do it, it's quite smooth." (No.15, female, age 69)* ***ii.*** *"I felt more confident by the end than I did in the first couple, I could see in a day, I would be better." (No. 20, male, age 77)*
b. Perceived benefits of the HAV	***i.*** *"Now I don't do much long-distance driving any more, but I do enjoy it. I think, with the highly automated vehicle, what I would do is I wouldn't get tired as much, cos sometimes it's quite tired driving long-distance. I think that would be a big advantage where you just going down the motorway, you can sit and have a rest. And you won't be that tired when you get there." (No. 13, male, age 64)* ***ii.*** *"When I drive to visit my son, I never really stop going down, I feel fine. But coming back at night is very tiring, that takes more out of you physically, and every other way. So I found on the way back, I need to stop, have a drink, and have a break. This is the time I need an automated car." (No. 12, female, age 73)* ***iii.*** *"Driving in the fog and snow conditions, I would just park and wait until it stops. That appeals to me that the HAV would know better for what speed to drive at when I didn't know what the conditions were like, so that's a big bonus point. (No. 18, female, age 81)* ***iv.*** *"I don't like driving in unknown cities or countries, I don't like planning navigating sort of thing, that would be the time I'll let the car to take over." (No. 23, female, age 72)*
c. HAV vs FAV	***i.*** *"I like driving, I like the abilities to make decisions. So, currently I may choose a highly automated car. But, ten, twenty years from now, I'll be much older, my functionalities will be slower I would imagine, then a fully automated car may benefit me." (No.8, male, age 68)* ***ii.*** *"I would like a highly automated vehicle now. But the fully automated might be useful when as you get older and the DVLA says you shouldn't be driving any more, then you can still have a fully automated car, because taking my car away that would like taking my legs away." (No. 12, female, age 72)*
d. Expectations and Concerns of the HAV	***i.*** *"Older people always have a hard time learning new things, so just make it as easy as possible." (No.24, female, age 73)*

who reported that first-hand experience can enable older people to clearly understand the possibilities of technology more than with a verbal explanation or demonstration. In summary, these findings provide evidence supporting the necessity of providing sufficient 'test-drive' opportunities for the older drivers to help them to gain their first-hand experience towards the HAV.

3.2.2. Perceived benefits of the HAV

Participants also discussed the impact of HAVs on their quality of life, they were generally positive about HAV and believed it would enhance their mobility and help them to stay independent. One common response was that HAV could enable them to drive long journeys confidently and comfortably (n = 16, 11 female, 5 male, Table 4, b.i). In addition, participants perceived that HAV would help them to drive safely and comfortably in situations in which they felt it was difficult to drive, such as motorway driving (n = 5, 2 female, 3 male, Table 4, b. ii), in adverse weather conditions (n = 2, 2 female, Table 4, b.iii) and on unfamiliar roads (n = 3, 2 female, 1 male, Table 4, b.iv).

These findings correspond to the fact that maintaining mobility is a privilege for older drivers, and is invaluable for their independence, quality of life and wellbeing (Charlton et al., 2006; Levasseur et al., 2016). In addition, driving in adverse weathers and on unfamiliar roads are common examples of the challenging situations that older drivers avoid in their driving self-regulation (Charlton et al., 2006). In addition, two male drivers believed HAV would increase work efficiency.

3.2.3. HAV vs FAV

The participants (n = 17, 11 female, 6 male, Table 4, c.i and ii) specified that they currently preferred HAVs as they still allow them to drive manually and have some control over the vehicle. However, they were aware when they become older, their physical, mental and cognitive conditions may not allow them to drive safely. By that time, they would need a fully automated vehicle to enable them to stay mobile and independent. This finding was in accordance with those of Bellet, Paris, and Marin-Lamellet (2018), who reported that older drivers were interested in vehicle automation and would consider using the FAV in the future when they were not able to drive safely anymore. These findings pointed out the importance for the OEMs and policy makers to distinguish the different requirements between those older people who are still active drivers and who have already given up driving. For example, the Level 3 or 4 HAV with good manoeuvrability that still allows the drivers to enjoy the pleasure of manually driving may be more easily adopted by some older active drivers, while for those who have ceased driving, a complete driverless car may appeals to them as it may help them to fulfil their daily travel demands and to maintain mobility.

3.2.4. Expectations and Concerns of the HAV

Moreover, some participants indicated that they expected the HAV to be designed to be simple (n = 4, 2 male, 2 female, Table 4, d.i) and safe (n = 5, 3 females and 2 males). In addition, two participants (1 male, 1 female) exhibited expectations about the appearance of the HAV, they believed it should be designed like the traditional vehicles. However, some participants showed concerns about the eligibility to use the HAV (n = 1, 1 male) and the liability insurance of HAV (n = 1, 1 female).

3.3. Physical and potential control of the HAV

Notwithstanding the positive attitudes towards and the benefits of HAV that the participants perceived, the third theme shows that they would still like to retain certain levels of control of the HAV, both physical and potential. Example quotes about older drivers' self-reported driving behaviour are outlined in Table 5.

3.3.1. Physical control of the HAV

Participants (n = 15, 9 female, 6 male, Table 5, a. i and ii) indicated that they would still like to remain active drivers and be able to control the HAV physically. They stated that it is important for them to retain the ability of manually drive the HAV, as driving is not only a lifelong habit for older people but also creates a sense of control over their lives (Gabriel & Bowling, 2004).

3.3.2. Potential control of the HAV

In addition, some participants (n = 11, 6 female, 5 male, Table 5, b.i and ii) indicated that they needed to perceive themselves as having potential control over the HAV as well. Comparing to the need of having physical control of the HAV, the potential control refers to that older drivers would like to perceive the control of the HAV mentally. They need to perceive that they could intervene the HAV system and take over the control of the vehicle at any time they want even they are not controlling the vehicle in HAV. This need for potential control is very close to the concept of potential travel proposed by Metz (2000), who reported that it is important for older people's mobility that they are aware that a trip could be made even if it is not actually undertaken. Considering the older adults who were active drivers when participated in this study, these findings provide an implication on a suitable way to introduce and explain the HAV to the older drivers. Instead of overemphasizing the 'self-driving' features of the HAV which may result in the misapprehension by some older drivers that their abilities of driving could be taken away, an appropriate standpoint to introduce the HAV to the older drivers may be a new type of vehicle that they can drive it exactly as a conventional vehicle but it can drive for them under the circumstances that they do not feel like to or are not able to drive in.

3.4. Non-driving-related tasks in HAV

The forth theme was regarding the activities older drivers would like to perform instead of driving when the HAV is automated driving. Example quotes about older drivers' self-reported driving behaviour are outlined in Table 6.

Table 5
Selected quotes relevant to the theme 3.

Theme 3. Physical and potential control of the HAV	
Sub themes	Example quotes
a. Physical control of the HAV	***i.*** *"Old habits die hard, our driving habit has been inculcated over 50 years, and it would be very difficult just sort of pretending I was a complete passenger, it's not about not trusting automated cars, but I like to be in control." (No.5, male, age 78)* ***ii.*** *"I think I would like a bit of control, maybe not complete control. If it's on motorway, it drove for you, you can sit there and take a break. Like I was driving up to Edinburgh on A1, I am quite happy to let the car drive. But when I am getting into Newcastle, I need to drive, I want control." (No.16, male, age 73)*
b. Potential control of the HAV	***i.*** *"I like to think I could intervene, if I know I can intervene at any time, then I feel I have some responsibility over this car and I feel control." (No. 15, female, age 65)* ***ii.*** *"I would still prefer to have some control over the car, just don't take it out of the driver's hands totally. The control I mean is more mental, nor physical. I would like to use an automated vehicle, but I need to know I am able to take over it when I feel I want to." (No. 9, male, age 68)*

3.4.1. Relaxing tasks

Some participants indicated that when they are not driving in HAV they would like to do the tasks which are relaxing and do not require massive attention (n = 10, 5 female, 5 male), such tasks may include listening to the radio (n = 8, 4 female, 4 male, Table 6, a.i), reading (n = 16, 10 female, 6 male, Table 6, a.ii and iii), looking at scenery (n = 7, 5 female, 2 male, Table 6, a.iv), talking to others in the car (n = 4, 3 female, 1 male), using mobile phone (n = 3, 1 female, 2 male), watching TV and movies (n = 2, 1 female, 1 male), doing exercise (n = 1, 1 male), thinking (n = 2, 1 female, 1 male) and meditation and breathing (n = 1, 1 female), doing crosswords (n = 2, 1 male, 1 female). Among these activities that older drivers preferred to do in HAVs, reading, communicating with family or friends and listening to the radio are also the most common activities that older people reported as doing in their free time (Seddon, 2011). In addition, previous research into HAVs involving older drivers yielded a similar finding that older drivers tended to spend their time having conversations with other people during automated driving in HAVs (Clark & Feng, 2017).

3.4.2. Working and monitoring driving

Apart from having a desire of performing the above relaxing tasks in HAVs, two male older drivers stated that they would like to work in the HAVs (Table 6, b.i). Moreover, half of the participants (n = 12, 5 female, 7 male, Table 6, c.i and ii) mentioned that they would still like to monitor the HAV system driving to make sure everything is fine, especially in heavy traffic conditions.

3.4.3. Eating and drinking in HAVs

In addition, a large proportion (n = 8, 5 female, 3 male, Table 6, d.i, ii, iii and iv) of older drivers expressed a wish to eat and drink in the HAV. For example: One female older driver mentioned that a meal table would make eating and drinking more convenience in the HAV. In general, the requirement of eating and drinking in HAVs should be taken into account when designing the interior of the HAVs. For example, a compact bookshelf or a tablet dock could be provided for the convenience of those who want to use one, and a rotatable seat may allow older drivers to talk with family and friends without constantly turning their head; A panorama windscreen could also enhance their experience while monitoring driving or looking at the scenery, and a foldable meal table may help them better enjoy their food and drink during automated driving.

3.5. Human-machine interaction during automated driving in HAV

In addition to the non-driving-related activities that older drivers prefer to perform instead of driving in the HAV, the fifth theme was about what they expected the HAV to do in terms of interacting with the driver during automated driving. Generally, their requirements towards the human-machine interaction during automated driving were grouped into two categories. Firstly, they would like an information system in the HAV to keep them updated about what is happening when they are disengaged from driving. Secondly they require the HAV system to be able to monitor on their status to ensure safety. In addition, the type of information they would like the HAV system to inform them, and the preferred form and modality of the feedback were also discussed. Example quotes about older drivers' self-reported driving behaviour are outlined in Table 7.

Table 6
Selected quotes relevant to the theme 4.

Theme 4. Non-driving-related tasks in HAV	
Sub themes	Example quotes
a. Relaxing tasks	***i.*** *"I would listen to music or listen to the radio, but not answering emails, perhaps looking at an iPad a little." (No. 20, male, age 77)* ***ii.*** *"I would read a book perhaps, talk to somebody who is in the car with me, just something not requiring massive attention." (No.8, male, age 68)* ***iii.*** *"I would like to be doing something where I can get relief. Because I need to know a bit of what's happening. It would be OK reading the iPad, reading a bit of news that you didn't have to concentrate on." (No.1, female, age 66)* ***iv.*** *"I'd probably look around me, enjoy the scenery, because you can't really appreciate the scenery around you when you are driving yourself." (No.12, female, age 73)*
b. Working	***i.*** *"If I was going to a business, maybe preparing, I think you could send emails or texts." (No.11, male, age 78)*
c. Monitoring driving	***i.*** *"I would still like to keep an eye on the road, I just think I need to make sure everything is OK." (No.22, female, age 60)* ***ii.*** *"I would probably be watching the car driving at first, and then if it was not busy traffic. I'll probably watch an iPad or read newspaper." (No.14, male, age 65)*
d. Eating and drinking in the HAV	***i.*** *"If it's allowed to eat and drink, that would be brilliant, at the moment it's illegal, isn't it. But if you could actually have a cup of tea or whatever, that would be nice." (No.7, male, age 61)* ***ii.*** *"If I could be having my lunch or a cup of coffee in the car, I don't need to stop at the motorway service station." (No.13, male, age 64)* ***iii.*** *"I may not have lunch in my HAV, cos I don't like my car in a mess, but I would have a piece of food, a chocolate bar, something like that." (No.12, female, age 73)* ***iv.*** *"If I am hungry I may have a slice of bread. I may not drink tea of coffee* cos *I don't want to spill anything on my car, you know I hate cleaning up spills, unless there is a table in my car, like the one on a plane." (No.19, female, age 69)*

3.5.1. Information system in the HAV

A majority of participants (n = 21, 12 female, 9 male, Table 7, a.i) expressed a requirement that they would like the HAV system to inform them about what is happening to keep them updated when the HAV is automated driving. The types of information they would like the HAV to inform them include journey (n = 7, 3 female, 4 male, Table 7, a.i and ii), vehicle status (n = 7, 2 female, 5 male, Table 7, a.iii), traffic conditions (n = 4, 1 female, 3 male). In addition, some participants (n = 3, 2 female, 1 male, Table 7, a.iv) mentioned that some drivers may forget they are in the HAV when they are not driving. Consequently, this may pose a safety threat when it comes to the situations when the drivers' input is required. Therefore, the HAV system should remind the drivers that they are in an automated car when they are not driving. In addition, the majority of participants (n = 16, 10 female, 6 male, Table 7, a. v, vi and vii) stated a strong need that their HAV should inform them that it is adapting the way it drives to suit the conditions it is driving in, especially when driving in adverse weather conditions.

The older drivers' requirement of an information system in HAVs may partially arise because the HAV is a new system which has yet to be introduced in road traffic and older drivers had spent only a limited time interacting with it, and so they may still want to be updated to make sure that everything is fine. From another point of view, this could also be deemed as a need for potential control of the HAV among older drivers, reflecting the fact that they need to know the HAV is doing exactly as they expected and nothing is beyond their mastery even they are not driving the car themselves. This emphasizes the importance of the sense of self-mastery and control over life to older people's wellbeing (Gabriel & Bowling, 2004). In addition, driver information/feedback system has been identified as being useful in improving older drivers' safety in manual driving (Guo et al., 2010), and thus it may also have the potential to enhance older drivers' performance when interacting with the HAV.

3.5.2. Monitoring system in the HAV

Apart from the requirement of needing the HAV to keep the drivers updated, some older drivers (n = 7, 4 female, 3 male, Table 7, b.i) indicated that the HAV should be able to monitor their status and take action accordingly. A common concern was that the driver falls asleep and may not be able to respond to an emergency promptly and effectively, such as to a take-over request. The HAV system, then, should be able to detect this and warn the driver, such as by an additional alert, a higher-volume alert or a vibration alert.

Table 7
Selected quotes relevant to the theme 5.

Theme 5. Human-machine interaction during automated driving in HAV	
Sub themes	Example quotes
a. Information system in the HAV	***i.*** *"I am going to somewhere 150 miles away. I'm reading the morning paper. And time passes, I would love it if the HAV said to me: we'll be there in five minutes, so you can put your tie on, neat and tidy, comb you hair when you get it. I would like to be kept updated on where the car is, how much time we got left before the end of the journey." (No.6, male, age 79)* ***ii.*** *"I need the car to tell me what it is doing if I am not watching it, just basic information would do, like speed, journey time." (No.9, male, age 68)* ***iii.*** *"I presume, for automated vehicles, there will be some sort of alarm or something to say fuel is low, so we are not gonna get there without fuel then so we need to refuel within the next half an hour, which would be great." (No. 13, male, age 64)* ***iv.*** *"It worries me that some people may forget they are sitting in an automated car if it's too cosy, they may think they are in the living room and doze off." (No.8, male, age 68).* ***v.*** *"I want to know that the vehicle knows, and I would like some kind of display that let me know the vehicle knows it is very foggy. So I want to know that the vehicle knows it is the one definite thing." (No. 1, female, age 66)* ***vi.*** *"I would want to be very sure that the car has adapted to the degree of penetration into the bad weather conditions, and was it adjusting its braking for wet and slushing conditions? I want it to say: Hey it is little bit slippery, just gonna slow down a little bit." (No.5, male, age 78)* ***vii.*** *"I suppose the car is advanced far enough to know what to do in situations like snow and fog. I want to know the car knows, the electronic brain knows. If it lets me know, that will make me feel a lot better." (No.16, Male, age 73)*
b. Monitoring system in the HAV	***i.*** *"It could be useful if the system knows what you are doing, for example, if it knows I am going to sleep, maybe then it knows that the volume needs to go up to wake me up, or it gonna to send some vibration to the seat." (No.22, female, age 60)*
c. Form and modality of the feedback	***i.*** *"I think it probably would be a screen showing everything that happens. For the urgent messages, it should be both visual and auditory." (No.2, female, age 71)* ***ii.*** *"For the less important information I would like it to be shown on a display, such as how far is it to the journey destination, or the current speed. But for important information I want it to be audible, for example, for fuel or a take-over request." (No.14, male, age 65)* ***iii.*** *"The sort of messages that are not crucial to the car's safety, such as where you are, how far you are from the destination, why it takes a different route. Pleasant soft voice for that. But if we've got a problem here, it needs to be a loud, clear and straightforward voice. There should be an emergency voice and a routine voice." (No.5, male, age 78)* ***iv.*** *"You got to draw the balance between being over-annoying and being helpful. If it's so annoying, you may not pay enough attention, oh here it goes again, and here it goes again. In England we have thing called 'crying wolf'." (No. 17, male, age 69)* ***v.*** *"It would be good if I can customize the voice, because it might be an irritating voice." (No.8, male, age 68)* ***vi.*** *"I think it is very import to customize the voice of the vehicle because I have a satellite, the voice I could pouch her, I just want her to be somebody else. It is important because if you have all of that, and all sort of messages and things, the voice that you hear has to be friendly and something that you like." (No.1, female, age 66)*

A possible reason for this requirement could because older drivers have a stronger awareness of the danger of the driver's sleepiness and they are less likely to drive while sleepy than younger drivers (Obst, Armstrong, Smith, & Banks, 2011). When monitoring the sleepiness of the driver, the older drivers expected that the HAV should be able to issue an alert with stronger stimuli, such as a voice at higher volume or vibrations in the seat. Also there should be a safe mode if the driver fails to respond appropriately.

3.5.3. Form and modality of the feedback

In terms of the form and modality of the feedback of HAV system, a great number older drivers (n = 12, 4 female, 8 male, Table 7, c.i, ii and iii) indicated that they generally wanted to differentiate between modalities of normal and urgent information.

Some participants (n = 3, 3 male, Table 7, c.iv) also mentioned the form of the driver feedback in the HAV should be able to draw a balance between being annoying and being helpful. And it should minimise false alarms to avoid "crying wolf". Regarding the voice of the HAV system, more than one third of the participants (n = 9, 2 female, 7 male, Table 7, c.v and vi) showed a desire to be able to customize the voice to fit individual requirements.

3.6. Human-machine interaction during taking over control in HAV

The sixth theme focuses on the older drivers' requirements towards the human-machine interaction during taking over control in HAV centred on the takeover request as well as the lead time provided for takeover in the HAV. In general, they would like the takeover request to be adjustable, explanatory and hierarchical. Example quotes about theme 6 are outlined in Table 8.

3.6.1. Takeover request in the HAV

To begin with, some older drivers (n = 5, 3 female, 2 male, Table 8, a.i and ii) expressed a need that, apart from receiving the urgent takeover request which the HAV encounters a system limitation and relies on the drivers to take over control, they

Table 8
Selected quotes relevant to the theme 6.

Theme 6. Human-machine interaction during taking over control in HAV	
Sub themes	Example quotes
a. Takeover request in the HAV	***i.*** *"I am happy to let the car drive on unfamiliar roads, but it should remind me to take over when it drives in the places I'm familiar with." (No.17, male, age 69)* ***ii.*** *"I do want my automated car to tell me when it is the best time for me to drive. Maybe when it detects the weather and traffic is suitable for me." (No.4, female, 70)* ***iii.*** *"I think it would be useful to tell you why you need to take over, then you know you got to be prepared for, because obvious take over control means there is something ahead, which could be bad weather, bad visibility, stationary vehicle, person, it is good if it gives you a hint, because if otherwise you will be thinking I don't know what it is." (No.11, male, age 78)* ***iv.*** *"It says 'please take over' and you look up and you wonder um, boom, you hit something. Because it didn't tell you or indicate the severity of the reason why it wanted you to take over." (No.6, male, age 79)* ***v.*** *"If the car's driving down the road and tells me to take over, my eyes would go everywhere, everywhere at the same time, why did it tell me to do that? If the car said to me I am very tired, please take over, you drive for the next half an hour, now the car has given me a reason for wanting me to take over." (No.20, male, age 77)* ***vi.*** *"The first think I would say is you need to take over the car, then, once the person has taken over, then give the reason, cos you don't need to know the reason immediately, you need to know immediately take over." (No.12, female, age 73)* ***vii.*** *"If it's a predefined one in familiar places, it could be a soft voice. If it is an emergency, like the red car in the front, I would expect a more serious and excited voice "XXX, take over the bloody car now!!!" It would have to be short and clear." (No.6, male, age 75)* ***viii.*** *"It could be a hierarchical thing, it could be a message come up in red, yellow or green to give you an idea how serious it is, if it comes up in red, you got to do something now. If it comes up in green, you know it's not very urgent." (No.1, female, age 66)* ***ix.*** *"When you are going to take control, you know sometimes it is quite difficult to staring yourself, if you are going into a deep sleep. Would it be a failsafe mechanism? " (No.18 female, age 81)* ***x.*** *"But in a highly automated car, it worries me that people who think they can drink and drive, because they can't they still may have to take over." (No. 19 female, age 69)*
b. Lead time for takeover control in HAV	***i.*** *"20 s is quite a long time, better than 10 s. I mean 20 s gives you the time to feel the car. I think 10 s may give you enough time to get the hold of the wheel, but not feel the car." (No.9, male, age 68)* ***ii.*** *"I found the 20 s is an adequate time, it was only once when in the fog, it just seemed to be hard, but for the rest of the times, I felt pretty comfortable with it.": (No.11, male, age 78)* ***iii.*** *"20 s might be enough. But it depends on what the person's doing, if they are sitting there, reading a book, chatting on Facebook, then 20 s is long enough. But if they are doing something more complicated and personal, such as dozing or sleeping, 20 s might not be long enough." (No.6, male, age 79)* ***iv.*** *"20 s is enough unless you got a hot cup of tea and sandwich in your hand. It depends on what you're doing. Even 10 s is fine if you're only sort of sitting and watching scenery. But 10 s isn't fine if you got a hot cup of coffee in one hand and a bite and pint in another." (No.7, male, age 61)*

would need to be able to adjust when and where the HAV sends them take over request according to their preferences. For example, to enable the HAV to always send drivers takeover requests when driving on familiar routes, or when it comes to the pre-defined situations that the HAV detects the traffic and weather conditions are suitable to drive manually for the drivers. The majority of the participants (n = 14, 9 female, 6 male) evaluated the existing visual and audible takeover request in the current research as nice and effective. Some participants (n = 4, 2 female, 2 male) indicated that if the takeover request only has the visual message, that would not be considered as satisfactory. It should include a loud and clear but not panicking audible message. In addition, three participants mentioned that a louder takeover request would benefit the older drivers who suffers hearing impairments.

These findings are generally in line with those of previous research that has reported that visual combined with audio modality is recommended when designing in-vehicle systems for older drivers (Edwards et al., 2016).

Moreover, the majority of the older drivers (n = 19, 11 female, 8 male, Table 8, a.iii, iv and v) showed a strong requirement for including the reason for taking over in the takeover request itself. This requirement could possibly explained as engaging in non-driving related tasks may result in the driver's complete disengagement from driving , which would lead to a longer takeover time being needed and possibly worse takeover quality among drivers (Eriksson & Stanton, 2017; Li et al., 2018; Zeeb, Härtel, Buchner, & Schrauf, 2017). Therefore an explanation of the reason for taking over control may have the potential to facilitate a quicker and more effective takeover.

In addition, some older drivers (n = 3, 2 female, 1 male, Table 8, a.vi) also emphasized that the sequence is important, where the takeover request should inform the driver about taking over control first and then explaining the reason. Another need concerning the takeover request that older drivers expressed (n = 3, 1 female, 2 male, Table 8, a.vii and viii) was that the HAV should adopt a hierarchical take over request mechanism based on how urgent their input is needed. For an urgent takeover request, such as when encountering a system limitation, the visual message could be in red, and the voice message should be clear, serious and straightforward. For non-urgent takeover requests, such as a user's predefined takeover request on familiar routes, the visual message could be in green and the voice message could be relaxed and soft.

One older driver indicated that the screen for performing non-driving related tasks, should be shut down or moved away from the driver automatically following an urgent takeover request. More than half of the older drivers (n = 13, 7 female, 6 male, Table 8, a.ix) showed a concern that if the drivers fall asleep they may not be able to respond to the takeover request safely and effectively. Two female drivers showed concerns that people may think they can drink and drive in HAVs (Table 8, a.x). And two participants (1 female and 1 male) indicated that HAV should adopts a fail-safe mode to ensure safety when the driver fails to take over the vehicle control effectively. For example:

The above rich requirements of older drivers in terms of the takeover request in HAVs may suggested that older drivers treat that taking over control in the HAV as an advantage rather than a drawback, as it would still allow them to manually drive the vehicle and remain active drivers while enjoying automated driving when needed. This could be explained as that older people prefer to receive support and assistance without compromising their control over their lives (Burton, 2012).

3.6.2. Lead time for takeover control in HAV

In regard to the time needed to take over control, older people in general, believed it varies between individuals. The majority of the participants (n = 15, 8 female, 7 male, Table 8, b.i and ii) thought that the 20 s used in the current research was generally adequate and comfortable for taking over the control of the vehicle. In foggy situations, a longer time than 20 s could be better for them.

In addition, some older drivers (n = 5, 2 female, 3 male, Table 8, b.iii and iv) believed that the lead time needed depends on the non-driving related tasks the drivers were doing. And they indicated the requirement that the HAV should monitor what the drivers were doing during automated driving and adapt the lead time to take over control accordingly. They suggested that a longer lead time to take over control would be necessary if the driver had fallen asleep or their hands were occupied.

3.7. Driving style of HAV

The last theme of older drivers' requirements towards the human-machine interaction of HAV focuses on the driving styles of the highly automated vehicles. Example quotes about theme 7 are outlined in Table 9.

3.7.1. Imitative and corrective driving style of HAV

Nearly half of the older drivers (n = 11, 4 female, 7 male, Table 9, a.i and ii) in this study indicated that their HAVs should be able to adapt their driving style to "drive like them", which would make them feel more assured and comfortable. Some other participants (n = 9, 5 female, 4 male, Table 9, a.iii and iv) realized that they have poor driving habits, and were concerned that these bad habits maybe copied by their HAV. But they still liked the idea of their HAV driving like them. Therefore, they pointed out that their HAV should be able to adapt to their driving style as much as possible but correct the bad driving habits. Such a requirement could be a reflection of one of the older drivers' strengths of being cautious divers (McGwin Jr & Brown, 1999).

3.7.2. Multiple user mode, remembering journey purpose and optional journey routes in HAVs

Additionally, two male drivers indicated that the HAV should have multiple user accounts as to accommodate different people's driving styles and preferences (Table 9, b.i). In addition, one male older driver also stated that they would like the

Table 9
Selected quotes relevant to the theme 7.

Theme 7. Driving style of HAV	
Sub themes	Example quotes
a. Imitative and corrective driving style of HAV	***i.*** *"If the computer can learn from me, in the way I normally think under varying road conditions and re-adjust itself, which would be brilliant." (No.6, male, age 79)* ***ii.*** *"It would great if it's driving like you're driving, it's imitating you. Adapting to my driving style." (No.12, female, age 73)* ***iii.*** *"The HAV system might have to be able to differentiate between good and bad. For example, if it realizes that I tend to brake more gently and a little earlier, it would be good if it adapted to that habit. It wouldn't be good if I drove right up to the car in front and slammed down the brakes. So it needs to be able to make a judgement on what is better than the standard and adjust it that way." (No. 5, male, age 78)* ***iv.*** *"I've got bad driving habits same as everybody else. That would be brilliant if my automated vehicle drives like me but corrects the bad habits, I wish it could." (No.9, male, age 68)*
b. Multiple user mode	***i.*** *"If you had a highly automated car, then anyone could drive it, so how would it adapt to different drivers? If it drove like you. And I got into your car, and it drove like you, would I be happy? So it should have a 'host mode' which is your mode, 'guest mode' would be someone else's mode. (No. 14, male, age 65)*
c. Remembering journey purpose	***i.*** *"It would be brilliant if the AV can remember the purposes of the trip, for example, if it can remember every Monday I am going for shopping, it could remind me of buying something that would make me feel more independent." (No.5, male, age 78)*
d. Optional journey routes of HAV	***i.*** *"When you get into an automated car. You will say: right, I am going somewhere, and you put in the postcode, so whatever it is where you going. Then the car asks you that we will go the pretty way, will go the fast way, will go whichever the way it is, and it will take us extra number of minutes, have a nice day kind of thing." (No.19, female, age 69).*

HAV to remember the purpose of the trip (Table 9, c.i). Finally, one female older driver mentioned that she would like to be able to choose the route of the journey (Table 9, d.i).

4. Recommendations

The findings of this study provided several important recommendations to facilitate safe and comfortable human-machine interactions in HAVs for older drivers. These recommendations will be explored in the following sections.

4.1. Appropriate introduction strategies of HAVs to older drivers

This study found that older drivers prefer to remain active drivers, and they required to maintain the ability to manually drive the HAV and they also need to perceive the potential control of the HAV this entails knowing that they could intervene to control the vehicle at any time even though they are not at present having the manual control in HAV.

A recommendation could follow from this finding indicating a suitable way to introduce and explain the HAV to older drivers. The introduction strategies or promotional plans concerning the HAV for active older drivers should fully consider the importance of allowing older drivers to be aware that they can still have the physical and potential control over the HAV. The instructions describing the HAV and its functionality should have a section that clearly explains to the user or potential purchaser that the driver can retake manual driving control at any time they wish and may be requested by the HAV to take over driving control from the automated driving state. Instead of overemphasizing the 'self-driving' or 'automated driving' features of the HAV, which may result in the misapprehension by some older drivers that their driving abilities could potentially be taken away from them by the HAV and thus causing anxiety about losing control over their lives, an appropriate standpoint to introduce the HAV to older drivers could be, for example, that the 'HAV is a new type of vehicle that drivers can drive exactly as with a conventional vehicle; however, under circumstances where the driver does not feel like driving in, such as when driving on a motorway, or they feel it is difficult to drive, such as when driving long journeys, they can give control over the vehicle to the HAV and can then safely performing other activities such as reading, although the driver can take back control of driving at any time they want. In addition, for those older people who have given up driving, a fully automated vehicle would be beneficial for them to stay mobile and independent.

4.2. Providing hands-on opportunities in HAVs for older drivers

This study found that first-hand experience with the HAV on the driving simulator helped older drivers to develop a realistic understanding of HAVs and to improve their trust and confidence in HAVs. Therefore, another recommendation is to provide more hands-on opportunities for older drivers to enable them to gain first-hand experience of the HAV. This research provides evidence indicating that hands-on experience on the driving simulator is beneficial for older drivers to gain a better understanding of the HAV, and it is necessary for the manufactures of HAVs to examine the effect of experiencing genuine HAVs on real roads on the attitudes and performance of older drivers.

4.3. Specially designed car interiors in HAVs to support older drivers

This study found that older drivers expressed requirements to perform a variety of non-driving related tasks when disengaging from driving in the HAV, including reading, talking with family or friends in the car, listening to the radio, looking at the scenery and monitoring the system driving, using a mobile phone, watching TV or films, doing exercises, thinking, meditation and breathing, working, doing crosswords, monitoring the HAV driving, and eating and drinking tea or coffee. Therefore, the interior of the HAVs should be designed to support these preferences of older drivers so as to enhance the comfort of their experience in the HAV. For example, a compact bookshelf and a tablet dock could be provided for the convenience of those who would like to read; and adjustable and rotatable driver's seats could provide more space for those older drivers who want to do exercises and also to allow older drivers to better enjoying their conversations with other people sitting in the back of the vehicle without constantly having to turn their head. A mobile phone holder would benefit those who want to use their phone; a large in-vehicle screen would allow them to better enjoying TV and film; a panoramic windscreen could also enhance their experience while monitoring driving or looking at the scenery, a foldable table would benefit those who preferred to work or do crosswords and would enable them to better enjoy their food and drink during automated driving; a water boiler could be provided to help them make coffee and tea and a cup holder may prevent the drink from spilling. Further research should examine the effects of these aspects of interior design on drivers' performance.

4.4. Information systems and driver monitoring systems in HAVs

This study found that older drivers need an information system to keep them updated about what is happening and to inform them about their journey, vehicle status and road conditions. Essentially, it should inform them that the HAV was adapted its driving to suit the conditions it is driving in. Additionally, older drivers need a driver monitor system in HAVs to enable the HAV system to keep an eye on the driver's status and to take action accordingly. The modalities of system feedback of the information and monitoring systems to differentiate between routine and urgent information. This indicates that the actions of these systems should adapt to the urgency of information. For advisory information, such as concerning the journey, vehicle status, traffic conditions and road conditions, information could be presented in a visual modality, or visual combined with a voice modality. The voice could be a soft voice. For urgent and safety critical information, such as concerning fuel status or takeover requests, a visual combined with a voice modality could be used. The voice should be loud and clear enough to interrupt the non-driving related tasks drivers were performing and to attract their attention quickly and effectively.

4.5. Adjustable, hierarchical and explanatory takeover request in HAVs

Older drivers expressed a requirement to be able to adjust when and where they would receive a takeover request from the HAV, such as on familiar roads or when driving conditions are evaluated to be suitable for them to drive manually. In addition, they would like a hierarchical structure of takeover requests that would differentiate between urgent and non-urgent takeover situations. For example, for an urgent takeover request, such as when the HAV systems encounter a system limitation, the visual message could be in red, and the voice message should be clear, serious and straightforward. For non-urgent takeover requests, such as a user's predefined takeover request on familiar routes, the visual message could be in green and the voice message could be relaxed and soft. In addition, the takeover request should include a description of the reasons for takeover. Twenty second is considered a long enough lead time for older drivers to take over control of the HAV, but it should be adapted to weather conditions and the driver's status.

4.6. Specially designed car interiors coordinating with takeover request.

As suggested above in Section 4.3, the findings of this study suggested several specially designed car interior features for older drivers. However, for an urgent takeover request, some non-driving related tasks may pose a threat to the safe and effective takeover of control; for example, if drivers are too involved in the film they are watching or book they are reading, or both their hands are fully occupied due to holding a tea cup in one hand and a book in the other. In this case, there is a need for specially designed car interior features to be suitable for the system takeover request in order to ensure the safety and efficiency of takeover. For example, following an urgent takeover request, the tablet should be turned off or moved away from the driver automatically; or the rotatable seat should turn back to the driving direction if the driver was facing the back talking to other people in the car. Also the cup holder or bookshelf should be close enough for the drivers to put down their cup or book promptly so as to switch back to the driving position and to take over control of the vehicle.

4.7. Driving style of HAVs

The HAV could be designed to be able to analyse the drivers' driving style, and then adjust itself to drive like them but to correct all the bad aspects of driving style. If the HAV system detects any potentially dangerous driving habits when drivers are driving manually, it could also send a reminder to help the driver to correct them and drive more safely. Also, the HAV could be designed to have multiple-user modes in terms the driving style, so that every time it detects that a different driver is using it, it could automatically switch to the corresponding user mode to fit individual requirements. Finally, the HAV should allow the drivers to choose the routes and remember the purpose of the trips.

5. Conclusion

The ageing segment of the population is increasing quickly across the world and in the UK. Driving is crucial for older people to maintain mobility and stay independent (Metz, 2000). The rapid development of highly automated vehicles may hold promise for older drivers by introducing a new form of human-machine interaction as well as a safer and more comfortable driving experience. Therefore, it is critical to investigate older drivers' opinion and requirements concerning the human-machine interaction in HAVs to ensure that the design fully meets their needs so that they benefit from the HAV. The present study has provided new knowledge and ideas to inform designers and OEMs of the requirements for older drivers in relation to forthcoming roll-out of highly automated vehicles.

This research has shown that first-hand experience is useful to help older people to build in-depth understanding about the HAVs, and to enhance their trust and confidence. The semi-structured interviews have been an effective way to collect information of the requirements of HAVs from end-users. In general, older drivers had positive opinions towards the HAV. They were able to perceive the potential benefits of HAV in enhancing their mobility, especially when driving on long journeys, at night and in adverse weather conditions. In the meantime, older drivers showed a strong requirement to maintain their ability of driving in HAV. Even they are not driving, they still needed to perceive that control of the vehicle was able to be taken over at any time they wanted. In terms of human-machine interaction in the HAV, older drivers expressed a range of needs and requirements towards it. In general, they believed it should be designed to be friendly and helpful. Most significantly, it should be designed to be smart and adaptive to offer tailored solutions based on various traffic, road and weather conditions as well as driver status. Above all, the HAVs that older people required would be a 'driving companion' that could provide automated driving support when they require and enable them to drive safely for longer, facilitate comfortable driving, and ultimately maximise their independence and mobility, rather than just being an automated vehicle that simply took away their ability to drive. Finally, the findings of this research emphasize the necessity to consider the needs and requirements of the ageing population during the design process of new in-vehicle technologies and vehicle automation systems (Guo et al., 2013). If the HAV can be designed to be age-friendly, then the potential advantages to older drivers and their subsequent enhanced mobility, independence and freedom could have profoundly positive effects and implications for society and the economy.

The current research has yielded many useful findings, but the study still has limitations. Firstly, the present research focused on exploring the older drivers' opinions and requirements towards the human-machine interactions in HAVs, future research could include younger drivers and compare their opinions and requirements of HAVs with the findings of this study. Such a comparison of the opinions and requirements between younger and older drivers could be useful and potentially enhance the knowledge of HAV interactions for the whole of the driving population. Secondly, the data for this research were collected by semi-structured interviews that are not focusing on generalization but attempted to yield a rich, contextualized understanding of human experience (Polit & Beck, 2010). Therefore, further research in testing the results of interviews is underway to more broadly generalize the current findings. Thirdly, participants in the current research only experienced a simulated HAV, although they perceived 20 s is a comfortable lead time for taking over control from HAVs in this study, this finding should be further validated investigated in a real-world situation using authentic fully-scale HAVs. Also, future research could investigate the opinions and requirements of older people after experiencing a full scale HAV in real life. In addition, the current research focused on the opinions and needs of older people who were active drivers, and thus future study could explore what an automated vehicle might mean for older people who have given up driving. Moreover, this study mainly focused on investigating older drivers' opinions and requirements towards the human-machine interactions in HAVs, their perceptions and opinions towards other factors of HAVs, such as the cost, uptake, ownership as well as long-term usage of HAVs should be explored by future research. Also, this study did not directly measure the level of using technologies in daily life among the participants, future research could investigate the impact of the usage of technologies in daily life on older drivers' opinions and requirements of HAVs. Furthermore, the participants of this research represent the current generation of older drivers in the UK, it would be important for the future research to explore the opinions and requirements of automated vehicles for the next generation of older drivers as well as those of different countries and cultures.

Finally, the findings of this research provide an important indication of the significance of involving older drivers in the design process of HAVs. It is thus imperative that the ageing and vehicle automation research community and car manufacturers (OEMs) to work closely together to ensure that HAV design takes into account the roles, capabilities and requirements of older driver coherent.

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Declaration of interest

The authors report no conflicts of interest.

Appendix A. Supplementary material

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