Australasian Transport Research Forum 2023 Proceedings
29 November – 1 December, Perth, Australia
Publication website: http://www.atrf.info

Examining older drivers' acceptance of fully automated vehicles by considering their health and driving ability conditions

Ning Liu[1], Xiaomeng Li[1]

Ronald Schroeter[1], Andry Rakotonirainy[1]

[1] Queensland University of Technology, Centre for Accident Research and Road Safety-Queensland, , 130 Victoria Park Road, Kelvin Grove, Qld, 4059, Australia.

Email of corresponding author: n25.liu@hdr.qut.edu.au

1. Introduction

The older population is continuously growing worldwide. Between 2015 and 2050, the proportion of the world's population over 60 years will nearly double from 12% to 22% (WTO). By 2050, the world's population of people aged 60 years and older will be more than 2.1 billion, while the number of people aged 80 years or older is expected to reach 426 million between 2020 and 2050 (WHO, 2021). Compared with the global trend, Australia's population continues to age, with one in every six Australians aged 65 years and over (ABS, 2018).

Older adults face outdoor mobility challenges due to their age-related vision, cognitive and physical changes (Zandieh & Acheampong, 2021). The increasing number of older drivers worldwide has raised safety concerns due to the decline in their functional abilities (Yang & Coughlin, 2014). Ageing, in general, is associated with a functional decline that may have an adverse effect on driving activities (Meng & Siren, 2012), which is a complex task requiring sensory input (e.g., vision and hearing), cognitive function (e.g., attention, comprehension, memory, decision-making, and reaction time), and motor function (e.g., power and coordination) (Wallis et al., 2020). Although many older drivers continue to drive, some gradually decrease their driving frequency or have already ceased driving (Ang et al., 2019).

Declining health might lead to driving cessation, and driving cessation, in turn, may result in adverse health outcomes (Chihuri et al., 2016). The negative impacts of driving cessation include depression, isolation, less social activity, and increased risk of depressive symptoms (Liddle et al., 2014; Qin et al., 2020.). Society is expected to balance concerns with public safety against the possible loss of mobility and other adverse consequences of stopping driving (Dickerson et al., 2019). Intervention programs need to be taken to mitigate the adverse effects of driving cessation on the health and well-being of older drivers (Marottoli et al., 2000).

A number of studies indicated that AVs have the potential to create the basis for future mobility solutions and can benefit older drivers in maintaining their social activities and independence (Zandieh & Acheampong, 2021). The increasing functionalities of automated vehicles can compensate for the deteriorating physical capabilities of old drivers (Li et al., 2018). With the AV technology development, from level 0 to 2, the human driver is entirely responsible for monitoring the road, while the automated driving systems gradually take over the control of the vehicle at higher levels. From level 3 to 5, human drivers' responsibilities for vehicle operation are eventually released to almost zero (SAE J3016). However, these prospective benefits can only come true when older drivers intend to use AVs.

To date, several studies have explored older drivers' acceptance of AV. Faber and van Lierop (2020) indicated that participants have strong interests and positive attitudes toward using AVs in their daily life to overcome current accessibility and mobility difficulties. Haghzare et al. (2021) found that exposing older drivers to an automated simulator or on-road automated shuttle may promote older drivers' acceptance and adoption of AVs. Calssen et al. (2020) found an increase in older drivers' perceptions of safety, trust, and perceived usefulness of AV technology after being exposed to AV technology. Furthermore, Robertson et al. (2019) examined older drivers' knowledge, attitudes, and perceptions toward limited self-driving vehicles (LSDVs) and how these variables can influence their likelihood of relying on this technology. The results demonstrated that feelings of safety and knowledge about LSDVs are positively related to perceived ease of use and adoption of the technology. The positive association between safety and perceived ease of use was further highlighted when comparing the responses of older drivers to those of younger age groups.

1.2 Current study

Compared to studies exploring drivers' acceptance of AVs, Australia's older driver groups were much less studied. Most importantly, the question of how older drivers' day-to-day driving patterns influence their intention to use FAVs is far from satisfactorily answered. The link between psychological factors such as attitudes, subjective norms, perceived behavioural control, and older drivers' intention to use FAV is unclear. Several previous studies have explored older drivers' acceptance of different types of AVs and Advanced Driver Assistant System (ADAS), but less study has thus far explored older drivers' intentions to use AVs by considering their driving-related self-perceptions and current driving patterns. Thus, this study aims to (1) Explore whether and how older drivers' individual characteristics influence their intention to use FAVs; (2) Investigate whether and how older drivers' current driving patterns influence their intention to use FAVs; (3) Identify whether and how older drivers perceived health and driving ability influence their intention to use FAVs.

2. Method

The research was approved by the Ethics Review Committee of Queensland University of Technology (approval number: 5236). The characteristics of the participants, the details of the measures in the survey and the survey procedure are presented in the following.

2.1 Participants

A structured cross-sectional survey was used for data collection from 672 older drivers in Australia. All participants were required to be aged over 50 years old or older and hold or have ever held an Australian driver's license. Table 1 shows the demographic information of the participants.

Table 1: Demographic information

Type	Frequency	Percentage
Age		
50-60	220	33%
61-70	315	47%
71-80	131	20%
81-100	6	1%
Gender		
Male	197	29.3%
Female	475	70.7%
Education level		
Less than Year 12	71	10.6%
Complete Year 12	45	6.7%
Certificate or Diploma	225	33.5%
Bachelor's Degree	201	29.9%
Master's Degree or higher	130	19.3%
Driving frequency		
Frequently (more than 5 times a week)	487	72.5%
Often (3-4 times a week)	143	21.3%
Rarely (less than 3 times a week)	39	5.8%
Ceased driving	3	0.4%
Driving avoidance		
Avoid certain situations	423	63%
Avoid over 10 situations	20	4%

2.2 Measurement

2.2.1 Demographic variables

Participants first completed the demographic items, including age, gender, education level, and ADAS experience. Participants were asked, "Before today, have you heard of the term automated vehicle?" (yes/no). After that, participants were provided with the full definitions of FAVs and drivers' roles.

2.2.2 Perceived driving ability and health

Participants rated aspects of their current driving abilities using the 15-item Perceived Driving Abilities (PDA) scale, which was developed with older drivers and found to have strong psychometric properties (MacDonald et al., 2008). Participants rated their current driving abilities (e.g., road signs recognition at a distance, quick driving decisions) on a 4-point scale (0 = poor to 3 = very good). The result of each survey was designed ranging from 0 to 45, with higher scores indicating more positive perceptions of driving abilities. Furthermore, the same items were used to measure Perceived changes in driving ability (Compared to 10 years ago, how would you rate your own ability to...?). Participants were asked the same 15 questions, with lower scores indicating more decline in changes. Participants were asked questions about their health on a 5-point scale (1-poor to 5-excellent) to evaluate their perceived health (Kostyniuk and Molnar, 2008). The score ranges from 4 to 20, with a higher score indicating a more positive perception.

2.2.3 Current driving patterns

The current driving patterns were divided into driving frequency and driving avoidance. To measure driving frequency, participants were asked, "How often do you drive per week? To measure driving avoidance, participants were asked about avoiding challenging situations. In the survey, there are 20 challenging situations listed for evaluation (MacDonald et al., 2008). Each item is one score if checked, and higher scores indicate more avoidance. For example, participants were asked about options for driving in heavy rain and parking in tight spaces.

2.2.4 The Theory of Planned Behaviour(TPB)

As TPB provides a systematic method to explore the decision-making processes of drivers' AV acceptance, it is widely used in research and studies to examine psychosocial factors influencing drivers' acceptance of AVs. TPB survey items were developed specifically for this study and were largely based on Ajzen (1991) recommended structure for TPB survey design. The TPB questions were adapted from Deb et al. (2017), who focused on pedestrians' acceptance of FAVs. The questions included 11 items focused on behavioural intention, attitudes, subjective norms and perceived behavioural control. A 7-point semantic differential scale measured attitudes using the following word pairs; unpleasant/pleasant, unfavourable/favourable, unsafe/safe, and negative/positive(Cronbach's Alpha=0.968). All other acceptance constructs were measured on a 7-point Likert Scale (1 = strongly disagree, 7 = strongly agree). 3 items measured PBC, such as "I am confident I will be able to drive on roads in the presence of FAVs." (Cronbach's Alpha=0.744), and 2 items measured subjective norms, such as "People who are important to me would not think that I should drive on roads in the presence of FAVs." ($r=0.603$, $p<0.001$). Two items measured intentions, such as "I plan to use FAVs on roads" ($r=0.948$, $p<0.001$). Higher scores on all measures indicated a greater acceptance of FAVs.

2.3 Procedure

An online survey was conducted in this study. Based on the proposed research model and the literature review, the survey was divided into several parts: demographic items, driving-related self-perception items, current driving patterns items, and TPB items. The study was conducted by using an online survey (http://www.qualtrics.com). The survey was disseminated by using social media (Facebook advertisement) and the Queensland University of Technology website research page. Prior to the survey, participants gave their consent to participate in this study. The survey took about 15-20 minutes to complete, and the respondents were assured that their participation was anonymous and voluntary. Participants who joined the study were provided with a chance to win 1 of 8 AUD40 shopping e-gift cards to thank them for their participation.

2.4 Data analysis

In the first step, the descriptive analysis and the bivariate correlation analysis were conducted using the IBM SPSS 28 software. The bivariate correlations were undertaken to assess the relationships between the demographic variables of age, gender, education level and ADAS experiences, driving-related self-perceptions, current driving patterns and the constructs within the TPB.
The SEM path analysis was conducted in the second step. The independent variables were Attitude, Subjective Norms (SN), Perceived Behavioral Control (PBC), Perceived health, Perceived driving ability, Perceived changes in driving ability, driving frequency, driving avoidance and demographic factors. The dependent variable in the model was intentions to use a FAV. The statistical package AMOS 29.0 was used to explore the predictors using path analysis as a particular type of SEM. The fit indices of the measurement are presented in Table 2. The indices meet the recommendation degrees of prior studies.

Table 2: The fit indices.

Fit indices	Measurement model	Recommendations
Chi-square/d.f.	1.776	1-3
GFI	0.993	>0.900
AGFI	0.964	>0.900
TLI	0.970	>0.900

Fit indices	Measurement model	Recommendations
IFI	0.993	>0.900
CFI	0.993	>0.900
SRMR	0.028	<0.050
RMSEA	0.034	<0.080

3. Preliminary findings

3.1 Descriptives and bivariate correlation analysis

Correlation analysis was conducted to investigate the relationship between variables. The TPB constructs of attitudes ($r=0.778$, $p<0.001$), PBC ($r=0.632$, $p<0.001$), and subjective norms ($r=0.420$, $p<0.001$) all have a positive correlation with older drivers' intentions to use FAV, which indicates that high levels of intentions are associated with higher levels of attitude, PBC and SN.

Older drivers' intentions to use FAV has a positive correlation with education level ($r=0.133$, $p<0.001$), crash experience ($r=0.108$, $p<0.005$), ADAS experience ($r=0.192$, $p<0.001$), which indicates that higher intentions are associated with higher levels of education, more crash experience and more ADAS experience.

Older drivers' intentions to use FAV have a negative correlation with age ($r=-0.128$, $p<0.001$), the perceived driving ability ($r=-0.130$, $p<0.001$), which indicates that higher intentions are associated with younger older age and lower perceived driving ability.

3.2 SEM Path coefficient analysis

The structure results are presented in Table 3. The results indicated that eight variables significantly predicted the intentions of using FAVs, and four variables did not. Older drivers' intention to use FAV was significantly influenced by the attitude ($\beta=0.618$, CR=26.072, $p < 0.001$), SN ($\beta=0.372$, CR=10.855, $p < 0.001$), PBC($\beta=0.144$, CR=5.086, $p < 0.001$), perceived driving ability($\beta=-0.020$, CR=-1.988, $p < 0.005$), driving avoidance($\beta=-0.042$, CR=-2-225, $p < 0.005$), age($\beta=-0.031$, CR=-4.570, $p < 0.001$), education level($\beta=0.013$, CR=3.000, $p < 0.005$) and ADAS experience($\beta=0.028$, CR=2.441, $p < 0.005$). However, older drivers' intention to use FAV was not significantly influenced by perceived health, perceived changes in driving ability, driving frequency and gender.

Overall, the results indicate that older drivers with younger ages, higher education levels, lower perceived driving ability, more ADAS experience, and less driving avoidance situations are more likely to use FAV.

Table 3: Path coefficient results; ***p < 0.001; **p < 0.01; *p < 0.05.

Predictor	Estimate	SE	CR	P
Attitudes	0.618	0.024	26.072	***
SN	0.372	0.034	10.855	***
PBC	0.144	0.028	5.086	***
Perceived health	-0.008	0.017	-0.475	0.632
Perceived driving ability	-0.020	0.010	-1.988	0.045
Perceived changes in ability	-0.014	0.116	-0.699	0.325
Driving frequency	0.006	0.084	0.075	0.940
Driving avoidance	-0.042	0.019	-2.225	0.026
Age	-0.031	0.007	-4.570	***
Gender	-0.081	0.116	-0.699	0.484
Education level	0.013	0.043	3.000	0.003
ADAS experience	0.028	0.011	2.441	0.014

4. Discussion and conclusion

The Theory of Planned Behavior (TPB) has been widely used as a systematic framework to predict drivers' acceptance of new products, including the not-yet-available technologies or services when they were studied (Kaye et al., 2020; Lou et al., 2022). The efficacy of TPB in investigating intention-related psychosocial factors has been demonstrated (Rahman et al., 2017; Buckley et al., 2018). The study showed that attitudes, subjective norms and perceived behaviour control were all positive factors in older groups' intention to use FAVs. This implies that to promote the deployment of FAVs among the older generations; more efforts should be engaged to establish a positive perception of AVs among older people and the younger family members and friends around them. Meanwhile, it is also critical for the manufacturers to ensure the technology's operationality and reliabilty to increase older people's confidence in using the technology.

In this study, the lower perceived driving ability was associated with a higher intention to use FAVs. Before the FAV is available in the market, alternative transportation for older adults should be developed and improved to meet current older drivers' travelling demands. Furthermore, it should be further investigated whether current AV technology, such as level 2 and level 3 AVs, can meet older drivers' travel demands and whether semi-AVs can impose higher requirements on driving ability.

Automotive manufacturers and governments need to spend more effort informing older adults about the benefits of vehicles equipped with ADAS and their safety features. The current results found a positive association between ADAS experience and intention to use FAV. A promising approach to promote older drivers' acceptance of future FAVs is to increase their exposure to the current ADAS systems. Industry manufacturers who are working on vehicle automation systems should pay attention to the system's capability in challenging situations.

In this study, people with more driving avoidance situations were less likely to use FAVs. The safety features of AVs in these challenging situations would become an advantage of these vehicles among older groups. Furthermore, drivers receive surrounding information by observing in conventional vehicles, while they are supposed to use the Human Machine Interface (HMI) to obtain information in AVs. An older-driver-centred design of HMI should be applied to facilitate a safe interaction between FAVs and older drivers.

Structural equation modelling will likely be further employed to test the indirect relationship between these variables (perceived health, perceived changes in driving ability and driving frequency) and FAV intention. The exploration of older drivers' FAV acceptance will be conducted when FAVs become market-available.

6. Limitation

The study has several limitations that should be noted. Firstly, for survey studies, the validity of results largely depends on the authenticity of participants when they answer the questions. In this study, participants were made aware that their participation was completely anonymous, and we encouraged them to answer the questions honestly and candidly, with no need to worry about any adverse outcomes from their participation.

Secondly, since FAVs have yet to be available in the market, the lack of interactive experience with FAVs may lead to biases in answering related questions. Therefore, more research is required to examine older drivers' acceptance and subsequent behaviour when these vehicles become available on the roads.

Thirdly, the age distribution of the sample was not representative of the broader age distribution in Australia. The study aims to investigate the relationship between FAV acceptance and age-related declines. However, it is worth noting that based on the literature review, driving-related functional decline typically starts around the age of 50. The participants in this study were required to be 50 years or older, encompassing the age groups from 50-65 and 65 and over; the Australian Bureau of Statistics (ABS) defines 'older people' as those aged 65 and over. Given this distinction, the specific age focus of the study is explicitly specified. Therefore, the educational percentage of the sample in this study may not align with the educational distribution of older adults in Australia. Another contributing factor to the higher education percentage is that this study recruited participants through an online survey. Older drivers who were interested in new AV technology voluntarily participated, which might have attracted relatively highly educated participants. Subsequent research endeavours will explore strategies to achieve a more diverse and representative sample, such as employing stratified sampling techniques or collaborating with organisations that may have access to a broader range of participants.

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Figure 1: Path diagram