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# An Emerging Framework to Inform Effective Design of Human-Machine Interfaces for Older Adults Using Connected Autonomous Vehicles

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**Abstract.** Connected autonomous vehicles (CAVs) represent an exciting opportunity for wider access to mobility; especially for individuals unable to drive manual vehicles. Interaction with CAVs will be through human-machine interfaces (HMIs) providing journey-related and other information with some interactivity. These should be designed with potential users as part of a co-design process to maximize acceptance, engagement, and trust. This paper presents an emerging framework to inform the design of in-vehicle CAV HMIs with a focus on older adults (70-years+). These could be amongst early adopters of CAVs and tend to have the highest level of cognitive, sensory, and physical impairments. Whilst there are numerous principles on HMI design for older adults there are fewer on HMIs for AVs, and a need for research on CAV HMI design principles for older adults. Our emerging framework is novel and important for designers of CAV HMIs for older adults and other potential users.

**Keywords:** Connected Autonomous Vehicle · Human Machine Interface · Older Adults · Design

## 1 Introduction

Connected autonomous vehicle (CAV) technology is developing rapidly. These are referred to as Level 5 AVs in frameworks of vehicle autonomy defined by SAE International [1] as *'the full-time performance by an automated driving system of all aspects of the dynamic driving task under all roadway and environmental conditions that can* *be managed by a human driver'*. There is no fallback of system controls on the person(s) being driven who can have 'mind' as well as 'eyes' off the road during CAV journeys. As such, fully autonomous vehicles may not require manual input devices such as steering wheels which require a requisite level of dexterity. Instead, interaction is likely to be through screen and speech-based human-machine interfaces (HMIs) providing vehicle-related (e.g., speed, time to destination, information about local area) and other information (e.g., in-car entertainment) with perhaps some interactivity capabilities to specify and personalize journeys.

The current paper showcases work from an early phase of an Innovate UK funded project – Flourish – *Empowerment through Trusted Secure Mobility (2016-19)*. The paper is related to one of the key project aims: exploring user interaction by focusing on the needs and experience when using CAV technology. It represents early stages of a larger framework being developed to inform the effective design of HMIs for a population sector likely to benefit from early adoption of CAVs: older adults. Within the emerging framework, older adults are defined as individuals' 70-years or above with normal aging related cognitive, sensory, and/or physical impairments. The key focus is on factors likely to determine user acceptance, engagement, trust, and likely continued usage of CAV HMIs.

## 2 Review Method and Research Questions

Search terms were used to guide the review (with multiple combinations) including: human machine interface, display design, autonomous vehicle, connected, driverless car, automation, elderly and older adults. Key disciplines of interest were: psychology, human factors, ergonomics, aging, gerontology, transport studies, engineering, robotics, and computer science. The search had three stages: (i) *University of the West of England-Bristol* online library database, (ii) general scholarly search engine (*Google Scholar*), and, (iii) general search engine (*Google*). The procedure resulted in multiple references deemed relevant from titles, keywords, and abstracts/summaries that were reviewed thoroughly and scored by members of the research team in terms of relevance to in-vehicle CAV HMI design questions outlined below. This involved a scale ranging from 0 (not relevant) to 5 (very relevant). Those rated 5 were regarded as key references, 3-4 very relevant, and 1-2 lower status (e.g., to support general points). References rated zero were discarded. Our CAV HMI design questions were as follows:

1. What are the leading generic HMI design principles that could inform the development of a CAV in-vehicle HMI for use by older adults?
2. What aging-related impairments should be considered in regards to the accessibility and usability of a CAV in-vehicle HMI?
3. What aging-related impairments should be considered in regards to the functionality and adaptability of a CAV in-vehicle HMI?

# 3 Emerging Principles

## 3.1 Leading Generic HMI Design Principles that Could Inform the Development of a CAV In-Vehicle HMI for Use by Older Adults

Numerous early HMIs seemed to violate many contemporary interface design principles such as providing too many features to perform a similar function(s) (e.g., find, search, locate). However, highly influential frameworks emerged such as those by Shneiderman [2], Nielsen [3], and Wickens, Lee, Liu, and Becker [4] to better guide the design of HMIs and improve human-computer interaction (HCI) by placing user experience, needs and capabilities at the center of the design process. Example principles from Shneiderman's [2] Eight Golden Rule framework include:

- Strive for consistency (e.g., include consistent terminology for menus and prompts);
- Offer informative feedback (e.g., to verify the status of a request);
- Design dialogues to yield closure (e.g., provide feedback when task completed);
- Offer simple error handling (e.g., require the user to go through checking steps that do not simply involve clicking the same button multiple times);
- Reduce short-term memory load (e.g., avoid multiple menus and/or pages).

Nielsen [3] took into consideration factors such as the importance of the match between the system and the real world, establishing and adhering to conventions and standards, maintaining visibility of system status, and simplicity and aesthetic integrity. Together with other interface design principles and frameworks (e.g., [5, 6, 7), Nielsen [3] and Shneiderman and Plaisant [8] continue to lead the way in terms of informing effective generic interface design principles for the majority of knowledgeable to expert frequent HMI users. Wickens et al. [4] developed principles with perhaps even more focus on human cognitive capabilities and limitations. These include:

- Perception (e.g., make displays legible and/or audible);
- Attention (e.g., minimize the cost of accessing important information);
- Memory (e.g., ensure key to-be-remembered information is easily accessible);
- Mental models (e.g., ensure pictorial realism between icons and what they represent);
- Situation awareness (e.g., features to predict/remind of key future and past events).

Many leading generic HMI design principles derived over the past three decades or so can be tentatively applied to the design of in-vehicle HMIs. Some can be directly applied to areas such as: automated system design; spoken input and dialog guidelines; guidelines for visual and auditory displays, and; traffic information guidelines (e.g., [9]). These and other principles will be discussed in more detail below. In terms of specific principles, work by Weir [10] noted that in-vehicle interfaces should be designed to meet requirements related to key factors such as usability, driver comfort, and acceptable levels of attentional demands in dual task conditions. It is also important to aim for optimal functionality and usability in terms of comfort (e.g., climate controls), entertainment (e.g., news links, music), telematics (e.g., network communications), and driver support (e.g., driving condition updates).

Work on HMI design for AVs has begun to increase, particularly during the latter half of the past two decades. Much early work focused on vehicles with one or few automated functions (e.g., Level 1-2). Research involving HMI designs for higher levels of vehicle autonomy (Levels 3-4) has emerged over the past 5-10-years (e.g., [11, 12]). To date, our review has uncovered very little on the design of HMIs for Level 5 fully autonomous vehicles, with a gap on those designed for older adult users.

Over a decade ago, Cuevas [13] suggested that the four most important factors to consider within the design of HMIs for vehicles with high levels of autonomy include:

- Ethnographic/anthromorphic qualities: e.g., attribute human qualities to system displays and functions;
- Cognitive factors: e.g., perception, attention, memory, and mental models;
- Predictive modelling: e.g., step-by-step modelling of interactions with new interfaces informed by established models and architectures;
- Empirical testing: i.e., test with target end-user groups.

More recent work picks-up on the HMI design issues of information overload (e.g., [14]) and situation awareness (e.g., [15]). Essentially, '…design needs to focus on communicating the information needs of drivers in order to give them the best chance of behaving appropriately for the situation' ([9], p. 143) as well as communicating the system limits in a dynamic ongoing (not static) manner [16].

Examples of recent activity on HMI design for AVs has involved 'automation displays' for functions such as adaptive cruise control (ACC) (e.g., [9]). For example, Stanton, Dunoyer, and Leatherland [17] compared three methods of displaying 'stop and go' (S&G-ACC) information to drivers under different driving conditions. Methods involved: a static icon (vehicle ahead, distance lines/arrows), a flashing icon (like static but changed color when close to vehicle ahead), and a radar display (distance ahead, road position). Simple icon-based interfaces did not seem to support driver situation awareness, whereas the more complex radar display helped but increased workload.

Overall, there is much less research on generic HMI design principles for AVs and CAVs (especially Level 5) in comparison to the wealth of literature concerning general HMI design principles that *could* inform the development of in-vehicle CAV HMIs. Many general HMI principles should nevertheless help to inform the design of early generation HMIs for CAVs, including those designed for use by older adults.

### 3.2 Aging-Related Impairments that Should Be Considered in regards to the Usability and Accessibility of a CAV In-Vehicle HMI

Older age is often associated with cognitive, sensory, and mobility impairments (e.g., [18, 19]). CAV HMIs designed for use by older adults with different needs and abilities should match accessibility and usability requirements of this specific population [20, 21]. CAV HMI accessibility for older adults is related to the physical and ergonomic aspects of the in-vehicle environment whereas usability relates to aspects of the HMI including: learnability; efficiency; memorability: error handling; and satisfaction (linked with likelihood of continued use).

Cognitive aging can span multiple areas, but here we focus on attention and memory. Attention is prone to age-associated impairments such as maintaining focus on a stimuli and/or dividing focus between stimuli. General design recommendations have been proposed to increase older adults' usability of a system whilst aiming to alleviate some of the implications of age related decline in attention (e.g., [22, 23]). These include: use of simple displays; differentiating important and relevant information; minimizing screen clutter; and limiting distractor stimuli. Working memory involves trying to retain and manipulate information over short time periods usually not greater that 20-30-seconds [24]. To support age-associated decline in working memory function, recommendations for HMI design have been proposed (e.g., [23, 25]) These include: avoidance of complex long instructions to minimize memory overload; use of graphical aids to support complex tasks; labelling items clearly; and, adopting familiar conceptual models and/or metaphors (e.g., red for 'stop'). Long-term memory (LTM) is also affected by aging (e.g., [21, 23, 26, 27]). LTM is often thought of as capable of holding memories more permanently than working memory for future activation and retrieval [28]. In considering LTM issues related to aging, design should include: using simple, minimal and intuitive steps to perform tasks; offering extra practice to learn procedures; and replacing time-based instructions (e.g., perform x in 60-seconds) with event based instructions involving context specific memory cues to reduce the demands on aspects such as prospective memory.

Visual and auditory sensory impairments are more likely to occur amongst older adults (e.g., [29, 30, 31]). There is a vast amount of previous work on HMI design recommendations taking into account sensory impairments with a key focus on vision (e.g., [23, 32, 33, 34, 35]). Example visual impairment related principles include: using large screens with large buttons (15-20-mm minimum); making information clearly visible using size, enhancing color and contrast features; spacing buttons (3.17-mm minimum); and avoiding dynamic text presentation formats. There has also been a lot of work on HMI design recommendations for auditory impairments (e.g., [21, 36, 37, 38, 39]). Example principles include: ensuring that sound signals are at least 60dB; enhancing discriminability of sounds with a frequency range of at least 500-1000Hz; avoiding synthetic speech; and ensuring that key information is communicate in an auditory as well as a visual format.

Physical usability requirements for older adults often arise due to age-related changes in motor control which can affect fine motor movement and coordination [20]. To improve HMI accessibility and usability amongst older adults, a range of recommendations have been made (e.g., [23, 40, 41, 42, 43, 44]). These include: using haptic displays with touchscreen and voice-command capabilities; avoid simple features that require multiple click actions; avoid pointing and dragging tasks; offering a wide range of different access points within the interface; limiting difficult or long successive actions; and, using light pens for touchscreen interactions. It is also important to provide grip balustrades for support and balance when using HMIs in dynamic situations such as being driven in a car.

Overall, there appears to be a vast range of HMI principles on accessibility and usability that might inform effective design of CAV HMIs for use amongst older adults. Some are quite intuitive yet evidence informed and others are based on tested minimal requirements to ensure that HMIs are accessible and usable.

### 3.3 Aging-Related Impairments Should Be Considered in regards to the Functionality and Adaptability of a CAV In-Vehicle HMI

Availability and usefulness of CAV HMI functions might increase the usability and acceptance of CAVs in general. Having the option to adapt some of these functions to better fit specific user requirements is also likely to be very important.

For AV HMIs, useful functions can increase trust and safety because they provide the user with valid and reliable driving information. Many functions that can maintain and enhance safe in-vehicle mobility have been tested and developed including: navigation aids (e.g., route guidance), visual aids (e.g., night vision enhancement), attentional and cognitive aids (e.g., distraction-management system), and crash avoidant aids (e.g., collision warnings). Common recommendations (see e.g., [28, 45, 46, 47]) include: vehicle speed and journey time information; step-by-step route guidance within navigational systems; and, minimizing complex interface features with multiple functions.

Other in-vehicle HMI functions that might provide a positive experience and keep users engaged with the system have also been recommended by a number of researchers (e.g., [49, 50, 51, 52, 53]). These include: night vision enhancement (NVE); forward collision warnings (FCW); health monitoring capabilities; and infotainment systems.

The usefulness and usability of any function is likely to be dependent on individual user needs and requirements and these may vary considerably amongst older adults; especially those who may have distinct cognitive and/or sensory and/or physical impairments. Also individual aging-related impairments can change, so the system should lend itself to being easily adapted to ensure continued usability.

Some in-vehicle HMIs are now becoming more adaptable (e.g., [54, 55, 56]). According to Lavie and Meyer [57], effective adaptation will involve intermediate levels of adaptation based on task type (e.g., routine vs non-routine), task difficulty, and user requirements (e.g., younger vs older adults). General adaptability recommendations have been proposed by many researchers (e.g., [57, 58, 59, 60, 61, 62, 63]). Examples include: provide text-to-speech/speech-to-text options; provide the option to zoom-in and out; and, use of persona-based user modelling. To support adaptability and personalization, the system needs to have information regarding the user's abilities and limitations which can be captured in a user model and/or through use of a reliable and valid set of tests and measures of factors (see [61, 64]). These include: cognitive (e.g., mental processing speed, attention, working memory), sensory (e.g., vision, hearing), and physical abilities.

Our preliminary review has also revealed that HMI adaptability amongst older adults does not always need to be based on cognitive, sensory and physical impairments. We should also consider driving habits, culture, and preferences. For example, and as posited by Heimgärtner [65], having the ability to control and change things like: preferred route type; preferred speed; default tours; and, preferred HMI interaction styles.

Overall, effective in-vehicle HMI functions for AVs and CAVs are likely to include important in-vehicle information such as vehicle speed and journey time as well as outer-vehicle information such as distance between own and other vehicles and traffic and news updates. Physiological monitoring (particularly for individuals with age related health conditions) is also likely to be important. Adaptability (and ease of adaptability) is also important; particularly for individuals with specific age-related cognitive and/or sensory and/or physical impairments. This likely means that a 'one-size-fits-all'

CAV HMI will not be as effective, especially amongst older users of AVs and CAVs. However, it is noted that there is little research on adaptive in-vehicle HMIs for use amongst older adults in highly and/or fully autonomous CAVs.

## 4 Conclusions and Future Directions

The current paper has focused on a synthesis of principles from an initial literature review conducted to inform the design of effective CAV HMIs for use by older adults above the age of 70-years. This emerging framework represents an important part of our current Innovate UK funded Flourish project that will involve experimental trials with older adults in simulated and road based CAVs in order to test and develop effective in-vehicle HMIs for use amongst this population. There are numerous useful generic HMI and in-vehicle HMI design principles that relate to four general areas: accessibility, usability, functionality, and, adaptability. The review has highlighted that experience and training in the resultant systems, as well as the ability to create bespoke individual user-focused solutions, are likely to play a key role in overcoming many of the possible barriers to adoption, use and continued use.

The review is also very important, because it has identified a major gap in the literature on AV and CAV HMI design principles that consider the needs and requirements of older adults who may be more likely to have cognitive and/or sensory and/or physical mobility impairments. There seems to be little research in this area and thus our short term aim is to further develop the current work into a comprehensive framework to inform effective design of HMIs for older adults using CAVs. This should be informed by requirements and expectations gathered from our target test population (i.e., potential users as part of a co-design process to maximize acceptance, engagement, and trust)

There is a crucial need for more concentrated research on the design and testing of in-vehicle HMIs for CAVs amongst older adults as well as other population sectors. There is a dearth of direct research in this area, and our Flourish project represents a major effort to inform this gap in knowledge and to offer effective design recommendations and solutions.

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