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Toward best practice in Human Machine Interface design for older drivers: A review of current design guidelines

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ABSTRACT

Older adults are the fastest growing segment of the driving population. While there is a strong emphasis for older people to maintain their mobility, the safety of older drivers is a serious community concern. Frailty and declines in a range of age-related sensory, cognitive, and physical impairments can place older drivers at an increased risk of crash-related injuries and death. A number of studies have indicated that in-vehicle technologies such as Advanced Driver Assistance Systems (ADAS) and In-Vehicle Information Systems (IVIS) may provide assistance to older drivers. However, these technologies will only benefit older drivers if their design is congruent with the complex needs and diverse abilities of this driving cohort. The design of ADAS and IVIS is largely informed by automotive Human Machine Interface (HMI) guidelines. However, it is unclear to what extent the declining sensory, cognitive and physical capabilities of older drivers are addressed in the current guidelines. This paper provides a review of key current design guidelines for IVIS and ADAS with respect to the extent they address age-related changes in functional capacities. The review revealed that most of the HMI guidelines do not address design issues related to older driver impairments. In fact, in many guidelines driver age and sensory cognitive and physical impairments are not mentioned at all and where reference is made, it is typically very broad. Prescriptive advice on how to actually design a system so that it addresses the needs and limitations of older drivers is not provided. In order for older drivers to reap the full benefits that in-vehicle technology can afford, it is critical that further work establish how older driver limitations and capabilities can be supported by the system design process, including their inclusion into HMI design guidelines.

1. Introduction

Over the next five decades, there will be a substantial increase in both the number and proportion of older people in most industrialised countries as a result of the baby boomers' maturation, lower birth rates and increased longevity (OECD, 2001). With the aging of the population, it is also anticipated that there will be an increase in older drivers' licensing rates (Koppel and Berecki-Gisolf, 2015; Sivak and Schoettle, 2011). Further, the private motor vehicle is likely to remain the principal mode of transport for the emerging cohorts of older drivers who will be more mobile, travel more frequently and travel greater distances compared with earlier cohorts (OECD, 2001). Demographic growth, increased licensing rates, and increased motor vehicle use will combine to produce a marked increase in the number of older drivers on the road (Koppel and Berecki-Gisolf, 2015; Koppel and Charlton, 2013).

While there is strong conceptual support around the world for older people to maintain independent vehicular mobility for as long as possible, their safety is also a serious community concern necessitating development of innovative measures to reduce crash and injury risk (Langford and Koppel, 2006). While current figures show that older drivers are involved in few crashes in terms of absolute numbers, they represent one of the highest risk groups for crashes involving serious injury and death per number of drivers and per distance travelled (Koppel et al., 2011; Langford and Koppel, 2006).

For the most part, older drivers' elevated risk for serious injury and fatal crashes can be explained by their frailty or reduced biomechanical tolerance to crash forces (Li et al., 2003). The energy required to cause injury reduces as a person ages (Augenstein, 2001): older adults' biomechanical tolerances to injury are lower than those of younger persons (Mackay, 1988; Viano et al., 1990), primarily due to reductions in bone and muscular strength and fracture tolerance (Dejeammes and Ramet, 1996; Padmanaban, 2001). Li et al. (2003) used the US Fatality Analysis Reporting System (FARS) and a national probability sample of all crashes (both non-casualty and casualty) to compute the role of frailty in older driver crashes. After statistical correction, the authors reported that older

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drivers' (and especially older female drivers') over representation in fatalities could be explained mainly by frailty, accounting for around 60–90 percent of the fatalities.

In addition, for some older drivers, declines in a range of age-related sensory, cognitive, and physical impairments can also place them at an increased risk of crash-related injuries and/or death, including: a decline in visual acuity and/or contrast sensitivity; visual field loss; reduced dark adaptation and glare recovery; loss of auditory capacity; reduced perceptual performance; reductions in motion perception; a decline in attentional and/or cognitive processing ability; reduced memory functions; musculoskeletal declines and strength loss; postural control and gait changes, and slowed reaction time (Janke, 1994; Stelmach and Nahom, 1992).

If used appropriately, In-Vehicle Information Systems (IVIS) and Advanced Driver Assistance Systems (ADAS) have the potential to assist all drivers with the complex demands associated with the driving task (Vrkljan and Miller-Polgar, 2005). For older drivers in particular, these systems have the potential to assist them to reduce exposure to hazardous driving situations by compensating for age-related sensory, cognitive and physical declines (Caird, 2004; Davidse et al., 2009), while also maintaining mobility (Koppel and Charlton, 2013; Koppel et al., 2009).

For example, Ling Suen and Mitchell (1998) listed the known functional impairments and associated driving problems that drivers tend to develop as they age and identified possible in-vehicle technology or equipment to address these problems (see Table 1 for an updated version of Ling Suen and Mitchell's table).

However, these technologies only have the potential to benefit older drivers if their design is congruent with the complex needs and diverse abilities of this driving cohort (Vrkljan and Miller-Polgar, 2005). For example, as noted by Meyer (2004), lowered acuity and contrast sensitivity are common among older drivers, therefore displays should be at a brightness level that differs as much as possible from the background. Dobres et al. (2016) also found that certain typefaces, colours and styles are less legible across the lifespan and that older people are more strongly affected by suboptimal interface text designs. In addition, intelligent on-board "workload manager" technologies have the potential to determine if a driver is overloaded or distracted, and if so, alter the availability of telematics and the operation. For example, the system may temporarily suppress calls and prevent access to phone functions and controls when distraction potential is estimated to be high (Regan et al., 2001). Several authors (Brennan et al., 1997; Regan et al., 2001; Vrkljan and Miller-Polgar, 2005) have proposed that if the underlying principles of universal design and human factors are integrated from the beginning of the design process for devices, such as IVIS, it may increase the likelihood that drivers of varying abilities, including older drivers, will be able to use the product (Koppel and Charlton, 2013; Koppel et al., 2009).

The design of ADAS and IVIS is largely informed by automotive Human Machine Interface (HMI) design and performance guidelines, of which a number currently exist (e.g., European Statement of Principles (ESoP); Alliance of Automotive Manufacturers (AAM) Statement of Principles, etc). Automotive guidelines are designed to inform the safe design and assessment of in-vehicle systems, particularly in relation to driver workload and distraction. Design guidelines are practices that are desirable to follow, but are not mandatory; as such, they are typically less stringent than standards (Green, 2009). They vary in terms of their level of detail, with principles ranging from broad (e.g., "be consistent") to highly specific (e.g., specific colours to be used). More detailed guidelines precisely state how a product should be designed; however, because of their level of specificity, may be useful for only a small range of technologies. In contrast, broad higher-level guidelines are typically user-centred and 'technologically neutral' meaning they can apply to multiple systems (Stevens, 2009) and remain relevant when technology is changed, advanced or updated. However, they can be written in such a general way that they are open to interpretation and difficult to apply to a given context. The scope of many guidelines are also restricted in terms of the users they target, with many aimed at private (i.e., non-commercial) passenger vehicle drivers and most do not include additional requirements or accommodations for drivers with special needs, disabilities or other impairments.

This paper was stimulated by questions relating to the extent to which potential age-related sensory, cognitive and physical declines of older drivers are addressed in current automotive HMI guidelines. The need for the design of in-vehicle technologies to consider the functional capacities, needs and limitations of older drivers is paramount, as this population is likely to be one of the first to encounter the technology given that systems are typically introduced into the higher-end vehicles often bought by older drivers (Eby and Molnar, 2012; Koppel and Charlton, 2013; Meyer, 2014). This paper provides a review of current guidelines for IVIS and ADAS with respect to how, and to what extent, they address age-related changes in sensory, cognitive and physical abilities. A key focus of the review was on the design guidelines pertaining to visual displays and input controls.

2. Material and methods

2.1. Systematic review of design guidelines

A comprehensive review of the English-language automotive HMI design guidelines was performed covering selected documents published in the period from 2000 to 2015. Design information relating to older persons and the impact of aging on sensory, cognitive and physical functions for use of in-vehicle technologies such as ADAS and IVIS was the focus of the search.

Guidelines selected for inclusion in the review were: European Statement of Principles (ESoP) (European Commission, 2008); Alliance of Automotive Manufacturers (Alliance of Automobile Manufacturers, 2006) Statement of Principles; Japanese Automobile Manufacturers Association Guidelines (JAMA, 2004); Transport Research Laboratory (TRL) Design Guidelines (Stevens et al., 2002); Battelle Crash Warning System (CWS) Interfaces guidelines (Campbell et al., 2007) and NHTSA (2012) Phase 1 Visual-Manual Driver Distraction Guidelines for In-Vehicle Electronic Devices. The guidelines reviewed represent the major automotive design guidelines published or updated since the year 2000.

The guidelines were searched for inclusion of the following key words: *old/older/elderly driver; age, seniors, impairment, sensory, cognitive and physical function and ability, universal design, inclusive design, user-centred design and interaction design*.

The keyword searches revealed limited hits within the selected guidelines, therefore the search was expand to also include two SAE Technical Standards that specifically relate to automotive technology design for older drivers – SAE J2119 (1997) and J2217 (1991). The above keywords were also applied to these technical standards.

2.2. Data abstraction and analysis

Following key word identification, guidelines were appraised by one reviewer in more detail to identify the extent and context in which specific guidelines address the cognitive and physical impairments experienced by older drivers. Included in this appraisal was a count of the outcomes of interest (frequency of key word use), and relevant descriptive content pertaining to each keyword usage.

A second reviewer appraised each set of guidelines independently. When discrepancies arose, these were discussed and the

Table 1
Age-related impairments, driving problems and in-vehicle interventions or equipment assistance.

Age-related Impairments	Driving Problems	In-vehicle interventions or equipment assistance
Reduced vision, including reductions in visual acuity, contrast sensitivity, visual field, dark adaptation and glare recovery	Difficulty seeing other road users (particularly at night); Difficulty reading road and traffic signs	In-vehicle signs (e.g., speed limits) and warnings; Forward collision warning; Night vision enhancement
Reduced motion perception, including difficulty in judging speed and distance of other road users	Failure to perceive conflicting (particularly on-coming) road users at intersections	Forward collision warning; Adaptive cruise control
Reduced reaction time	Slow to respond to road and traffic signs; Slow to respond to hazards	Forward collision warning; Adaptive cruise control; In-vehicle signs and warnings
Reduced attentional and/or cognitive processing ability including difficulty in perceiving and analysing situations	Failure to comply with road and traffic signs; Failure to identify hazards; Difficulty driving in unfamiliar or congested areas; Difficulty completing complex traffic manoeuvres (e.g., turning across traffic, lane changing and merging)	Navigation assistance/Route guidance; Forward collision warning; Adaptive cruise control; In-vehicle signs and warnings
Musculoskeletal declines and strength loss	Difficulty turning head/neck, Reduced peripheral vision; Failure to notice obstacles while manoeuvring/reversing; Lane excursion; Difficulty merging and lane changes	Blind spot/obstacle detection; Rear collision warning; Lane departure warning; Lane change assist/merge warning system
Decreased memory function	Concerns with getting lost	Navigation assistance/Route guidance
Increased susceptibility to fatigue	Concerns over increased susceptibility to become fatigued on long journeys	Driver condition monitoring; Adaptive cruise control; Lane departure warning
General effects of aging	Concerns over inability to cope with a breakdown, driving to unfamiliar places, at night, or in congested areas	Emergency callout (mayday); Vehicle condition monitoring; Navigation assistance/Route guidance
Some functional impairments fluctuate level of severity from day to day	Concern over fitness to drive	Driver condition monitoring
Increased frailty	Reduced tolerance to injury in the event of a crash	Automatic crash notification

guidelines were re-appraised to include additional relevant details from both reviewers.

3. Results

A summary of the outcomes of the keyword searches is contained in Table 2. This table includes, for each keyword hit found in one or more of the guidelines or standards, the page number and section of the guidelines in which each hit appears and briefly notes the context in which the keyword appears. Of the six guidelines and two SAE Technical Standards reviewed, four included reference to older drivers and/or aging issues: the TRL Guidelines, Battelle CWS guidelines and SAE Technical Standards J2119 and J2217. These were grouped for review according to relevance to: (i) a general reference to the aging process, (ii) physical (including sensory) functions and aging; and (iii) cognitive functions and aging.

3.1. Evidence for inclusion of general age-relevant issues

As expected, both SAE Technical Standards make specific reference to older drivers and the impact of the aging process on input control and display design. Both the TRL guidelines (Stevens et al., 2002) and the Battelle CWS guidelines (Campbell et al., 2007) also make specific reference to older drivers and the aging process. These contain a number of broad statements that in-vehicle systems should be designed for all users and that declining sensory, cognitive and physical abilities should be considered. For example, in the section on System Users the TRL guidelines offer the following broad advice: "*Information about which drivers the system is intended to help needs to be taken into account in the design process and the system should ideally be designed with all users in mind, whether male, female, young, old, able bodied, or disabled*".

3.2. Evidence for inclusion of physical (including sensory) functions and aging

Information regarding how to tailor the design of in-vehicle systems for the physical limitations often experienced by older drivers is considered in depth in SAE J2119 and SAE J2217. These standards discuss the glare sensitivity experienced by older drivers and the need to adjust display brightness and colour use accordingly, as well as the age-related physical changes that may affect driver movement and strength and that can make older drivers uncomfortable with controls that are difficult to grasp, have high actuating force levels, a large range of motion, or require small and/or intricate motor adjustments.

The TRL guidelines provides an overarching statement in the introductory section that drivers differ markedly in their physical abilities and systems need to be designed with consideration of user groups that have distinct needs (e.g. elderly drivers). The TRL also offers advice in relation to the design of input controls; however, the reference made is very broad and they do not offer prescriptive advice on how to actually design a system so that it addresses the needs and limitations of older drivers. For example: "*In-vehicle controls should be designed for the intended user group. This requires a clear decision as to who the user group is, together with compatible instructions and publicity to support this decision. The user group may include disabled users, as well as older (and weaker) drivers*". This principle does not specify what types of input controls are or are not suitable for older drivers, nor is the optimal size or placement of these controls for older drivers indicated.

Two specific principles in the Battelle CWS guidelines make reference to the sensory and physical limitations of older drivers (Campbell et al., 2007). The first principle notes that older drivers generally have poorer visual acuity and are less sensitive to luminance contrasts than younger drivers and, as such, the guidance provided on display brightness should accommodate older driver visual limitations. The second principle relates to haptic warnings and, more specifically, states that older drivers are generally less sensitive to vibrations; hence, the strength of seat vibrators needs to be strong enough for older drivers to perceive the warning. However, no specific information is provided on the required strength of the warning for older drivers.

3.3. Evidence for inclusion of cognitive functions and aging

SAE Technical Standard J2119 offers a broad statement that as an individual ages, they experience a gradual decline in their ability to process complex information and, as such, age-related changes in cognitive abilities should be considered in the design of system controls.

Again, the TRL guidelines provide an overarching statement in the introductory section relating to the fact that drivers differ markedly in their perceptual and cognitive abilities and systems need to be designed with consideration to user groups that have distinct needs (e.g. elderly drivers). However, no prescriptive advice is provided regarding what the specific cognitive needs and limitations are, or how HMI design should be modified to accommodate them.

4. Discussion

Vehicle design has the potential to play a major role in the long-term mobility and safety of older road users; however, to date vehicle systems have been largely designed for the 50th percentile 'design driver'—that is, fit and relatively healthy young adults—and therefore make little, if any, allowance for possible diminishing sensory, cognitive, and physical processes brought about by the aging process (Charlton et al., 2002; Morris et al., 2003; OECD, 2001; Waller, 1991).

As the population continues to age, it will become increasingly important to design vehicles that can accommodate the needs and

Table 2
Results of keywords search for each guideline reviewed.

Guideline	Keyword mentions		Keyword context
	Page	Section	
Keyword: Old/Older/Elderly Drivers			
ESoP	–	–	
AAM	–	–	
JAMA	–	–	
TRL	9	2.1.3 System users	The design of systems should take a wide range of users in account, including male, female, young, old, able bodied, or disabled.
	18	5.1 Input controls	In-vehicle controls should be designed with the intended user groups in mind, noting that user groups may include disabled users, as well as older (and weaker) drivers.
NHTSA	–	–	
Battelle	4–11	General Characteristics of Visual ICWs and CCWs	Notes that the design guidelines in relation to ICWs and CCWs accommodate older driver visual limitations, in particular that older drivers typically have poorer visual acuity and are less sensitive to luminance contrasts than younger drivers and thus, displays can become be a source of glare at night.
	5–5	Determining the Appropriate Display Type for Haptic ICWs	Haptic warnings need to be strong enough to be noticed by older drivers who are typically less sensitive to vibrations.
SAE J2217	1	Scope	Notes the document provides information for setting photometric guidelines for instrument panel displays to accommodate older drivers.
	3	3.1 Luminance Contrast	Older drivers are much more sensitive to glare than are younger drivers and require much higher contrast on displays.
	3	3.3 Colour Preference	Spectral purity and intensity are important factors that influence the acceptability of a display colour for older drivers. Older drivers generally prefer the mid-spectrum colours and find yellows and greens easier to focus on than reds and blues.
	3	3.4 Brightness Preference	Older drivers are more sensitive to glare from instrument panel lighting during night driving and may prefer lower brightness levels for display lighting than younger drivers. The instrument panel light levels should be configurable by drivers to avoid glare problems.
SAE J2119	3	3. Changes in Vision Due to Aging	The readability of text and labels can be increased by maximizing their sizes. Recommends following the "James Bond" rule, although suggests changing 0.007–0.008 for older adults if space allows.
Keyword: Age			
ESoP	–	–	
AAM	51 & 52	Apparatus	Discusses the composition of test participants which should include older drivers up to 65 years.
JAMA	–	–	

Table 2 (*Continued*)

Guideline	Keyword mentions		Keyword context
	Page	Section	
TRL	9	2.1.3 System users	System should ideally be designed with all users in mind, including male, female, young, old, able bodied, or disabled.
NHTSA	33	A. Test Participant Recommendations	Discusses the composition of test participants which should include older drivers 55 years old or older.
Battelle	–	–	
SAE J2217	2	3.1 Luminance Contrast	The minimum value of luminance contrast required depends upon, among others, driver age.
SAE J2119	1	Scope	Defines a “mature” driver as over the age of 50 since visual changes become noticeable at about this age. Degenerative cognitive and skeletal changes become more apparent at a later age.
	3	4. Changes in Cognition Due to Aging	The design of controls should consider changes in cognitive ability and the gradual decline in the rate at which complex information is processed as adults age.
Keyword: Cognitive function/ability			
ESoP	42	Recommendations on Safe Use (RSU)	Discusses the need for adequate training on in-vehicle systems due to the different physical and cognitive abilities of drivers and the need to assess if they are capable of using an information or communication system when driving.
AAM	–	–	
JAMA	–	–	
TRL	9	2.1.3 System users	Drivers differ markedly in physical, perceptual and cognitive abilities and systems need to be designed as such. Thus, the guidelines consider user groups that have distinct needs, such as the elderly.
NHTSA	–	–	
Battelle	–	–	
SAE J2217	–	–	
SAE J2119	3	4. Changes in Cognition Due to Aging	The design of controls should consider changes in cognitive ability and the gradual decline in the rate at which complex information is processed as adults age.
Keyword: Physical function/ability			
ESoP	42	Recommendations on Safe Use (RSU)	As above for ‘cognitive function/ability’
AAM	–	–	
JAMA	–	–	
TRL	9	2.1.3 System users	As above for ‘cognitive function/ability’
NHTSA	–	–	
Battelle	–	–	
SAE J2217	–	–	
SAE J2119		5 Physical Changes Due to Aging	Physical changes in mature adults are manyfold and, as a general rule, these impact movement and strength. Mature drivers can be uncomfortable with controls that are difficult to grasp, have high actuating force levels or large ranges of motion, or require small and/or intricate motor adjustments.

Note: The following keywords were not found in any of the guidelines reviewed and have not been included in the table: “seniors”; “impairment”; “universal design”;” inclusive design”; “user-centred design”; and “interaction design.

capabilities of older drivers (Koppel and Charlton, 2013; Koppel et al., 2009). A number of engineering solutions offer the potential for addressing many older driver issues and, as the population ages, should be given high priority in the years ahead. It should also be noted that a safer vehicle for older drivers also means a safer road environment for all-aged road users.

Vehicle designers therefore have a significant role to play in improving the comfort and safety of older drivers. In particular, they need to:

- Be aware of the declining sensory, cognitive and physical abilities of the older driver population;
- Appreciate how these age-related changes may affect the driving task, and
- Modify design and maintenance standards to enable older drivers to cope more easily with the increasingly complex task of driving.

In-vehicle ADAS and IVIS technology, if designed appropriately, has the potential to assist older drivers and make the driving task easier, safer and more comfortable. However, if not designed to accommodate older driver needs and limitations, these systems may present more challenges for the older driver than they solve. It is not necessarily the case that older drivers will require different in-vehicle systems than younger and middle-aged drivers. Rather, well-designed systems should accommodate the needs, preferences and limitations of all drivers, including older drivers. One of the ways to ensure that the design requirements of older drivers are built into in-vehicle systems is to include this information in existing automotive HMI design guidelines.

The outcomes of the review revealed that most of the HMI guidelines do not address design issues related to older driver impairments, either specifically or generally. In fact, in many of the guidelines reviewed, driver age is not mentioned at all and in two guidelines, driver age is only referenced in relation to sample selection for participant testing of various systems and principles. While it is acknowledged that definitive age-based guidelines are not feasible given the diverse sensory, cognitive and physical abilities and limitations found within age groups, including the elderly, more prescriptive guidance on how certain interface designs can accommodate sensory, cognitive and physical limitations on a broad level is indicated. Such guidance is likely to assist a range of driver groups in addition to older drivers, such as novice drivers and drivers with disabilities.

Apart from the two SAE Technical Standards, which specifically target older drivers limitations in display and control design, the only guidelines reviewed that make specific reference to older drivers are the TRL guidelines (Stevens et al., 2002) and the Battelle CWS guidelines (Campbell et al., 2007). These both contain a number of broad statements that in-vehicle systems should be designed for all users and that their sensory, cognitive and physical abilities should be considered. However, the references made are typically general in nature and the individual principles often do not offer prescriptive advice on how to actually design a system so that it addresses the needs and limitations of older drivers.

We have identified a number of key areas where the current HMI guidelines for visual displays and input controls could better address potential age-related sensory cognitive and physical changes.

4.1. Vision and other sensory impairments

As we age, visual abilities decline and older people experience a range of issues with vision including a reduction in their field of view, contrast sensitivity and difficulties with glare (see Eby and Molnar, 2012). Older drivers can therefore experience a number of issues with the use of in-vehicle devices, including difficulty seeing small text and labels, discriminating colours, and display glare, particularly at night. A number of design options should be included in the guidelines to accommodate these issues. These include specifying the use of larger text and labels, reducing the amount of text presented on displays at any one time, and presenting messages and warnings in multiple modalities (visual, auditory and tactile). However, designers should be mindful that older drivers can have hearing impairments and the volume and tone of any audio warnings needs to accommodate potential issues with hearing or discriminating sounds, particularly high-frequency sounds (Corso, 1981). Likewise, older people can display a reduced sensitivity to touch and vibration (Gescheider et al., 1994), which should be considered in the design of tactile warnings.

4.2. Physical impairments

Older people often experience a range of physical or psychomotor impairments that can increase their ability to use vehicle controls and in-vehicle technology (Sivak et al., 1995; Wheatley et al., 2006). Physical issues typically experienced with aging include decreased flexibility, which can affect the ability to easily reach device controls, coordination issues and muscle/hand weakness, which can make it difficult to manipulate certain control types such as small buttons, turn dials, or steering wheel controls. A range of design options should be included in the guidelines to accommodate these issues, including larger controls that do not require physical effort to operate and are located within easy reach of the driver from the normal driving position, and clear feedback for control selection. Older drivers also have slower reaction times resulting from joint stiffness, muscle weakness or slowed cognitive processing (Klavora and Heslegrave, 2002). There is, therefore, a need to factor reduced reaction times for older drivers into the timing and presentation of ADAS warnings.

4.3. Cognitive impairments

As people grow older they experience a range of cognitive declines and a general slowing of processing speed (Eby and Molnar, 2012; Salthouse, 2010; Yang and Coughlin, 2014). This can lead to older drivers experiencing a range of cognitive issues relevant to the design of in-vehicle technology. First, research has shown that older people have a decreased ability to divide attention effectively between multiple tasks, meaning that they can have difficulty focussing on or performing two or more tasks or sources of information (Ponds et al., 1988; Salthouse et al., 1984). Given that in-vehicle technologies often require that drivers divide their attention between information provided by the device and the driving task, this can lead to issues of distraction and cognitive overload in older drivers (Koppel et al., 2009). Declines in the speed at which older people can process information can also lead to issues processing large amounts of text provided by in-vehicle devices or responding quickly to information or traffic warnings (West et al., 1992). It is important that automotive HMI design guidelines address the cognitive limitations of older drivers and make recommendations regarding how the amount, type and timing of information and warnings provided by in-vehicle devices should be modified to accommodate the increased potential for distraction, confusion and overload (Koppel et al., 2009).

Although much research has examined the sensory, physical and cognitive limitations experienced by older people, there are still significant gaps in our knowledge as to how these limitations impact in-vehicle technology use and, thus, how they can best be addressed in system design. A large research effort is required to support the development of prescriptive HMI design principles that address age-related declines adequately and accurately. These principles could range from broader guidelines regarding the optimal amount of text allowed on a display to very specific guidance regarding optimal font size or display luminance.

5. Conclusions

The road transport system is currently facing the confluence of an increasing aged driving population *and* an increase in the number and complexity of in-vehicle technology. The introduction of in-vehicle technology presents a range of challenges for older drivers, as they are forced to adapt life-long skills and practices to accommodate the new systems. As we move towards a more autonomous vehicle fleet, it will therefore become increasingly important that the older driver is considered in technology design and implementation (Yang and Coughlin, 2014).

The review highlights a number of areas where the current in-vehicle technology design guidelines do not adequately account for the potential sensory, cognitive and physical limitations of older drivers. It is recognised that this is likely due to a lack of supporting research data on which to base more specific HMI design guidance for this driving population, as well as due to the lack of a legal and policy framework to guide implementation of HMI design guidelines. It is critical that further work establish how older driver limitations and capabilities can be supported by the system design process, including their inclusion into automotive HMI design guidelines, so that this growing population can reap the full benefits that use of in-vehicle technology and vehicle automation is likely to afford.

The successful introduction of in-vehicle technology for older drivers is, of course, much broader than just getting the design of the systems right. Older drivers will need to learn a new set of skills and ways of performing the driving task in order to interact with the technology. It is acknowledged that with increasing age, learning new skills and changing well-established routines can become more difficult (Craik and Jacoby, 1996). Thus, older drivers are faced with the challenge of learning to use new technology at a time when they are also typically experiencing a decline in driving ability. But older drivers are not adverse to learning new technology, particularly if they are first informed of their benefits (Yang and Coughlin, 2014). Thus, developing appropriate training materials and building awareness among the older driver population about the operation of in-vehicle technologies and their performance limitations also poses a challenge.

Another challenge is establishing how and where HMI design guidance should be implemented. That is, should such guidance be made mandatory through the introduction of design regulations and standards, or should it remain voluntary and adoption be encouraged through mechanisms such as the development of a Memorandum of Understanding between governments and manufacturers? Likewise, it is important to establish at what level such design guidance should be implemented; whether this be at the government level, manufacturer and system developer level, the consumer level, or implemented in various forms across all levels. It is only through the collaboration of system developers, manufacturers, engineers, researchers, governments and road safety agencies, that the challenges associated with successful implementation of in-vehicle technology for older drivers will be met.

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