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IN-VEHICLE TECHNOLOGY FOR SELF-DRIVING CARS: ADVANTAGES AND CHALLENGES FOR AGING DRIVERS

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ABSTRACT−The development of self-driving cars or autonomous vehicles has progressed at an unanticipated pace. Ironically, the driver or the driver–vehicle interaction is a largely neglected factor in the development of enabling technologies for autonomous vehicles. Therefore, this paper discusses the advantages and challenges faced by aging drivers with reference to in-vehicle technology for self-driving cars, on the basis of findings of recent studies. We summarize age-related characteristics of sensory, motor, and cognitive functions on the basis of extensive age-related research, which can provide a familiar to better aging drivers. Furthermore, we discuss some key aspects that need to be considered, such as familar to learnability, acceptance, and net effectiveness of new in-vehicle technology, as addressed in relevant studies. In addition, we present research-based examples on aging drivers and advanced technology, including a holistic approach that is being developed by MIT AgeLab, advanced navigation systems, and health monitoring systems. This paper anticipates many questions that may arise owing to the interaction of autonomous technologies with an older driver population. We expect the results of our study to be a foundation for further developments toward the consideration of needs of aging drivers while designing self-driving vehicles.

KEY WORDS : In-vehicle technology, Self-driving cars, Aging drivers, Navigation systems, Health monitoring systems

NOMENCLATURE

AARP	: american association of retired persons
ACC	: adaptive cruise control
ADAS	: advanced driver assistance system
AGNES	: age gain now empathy system
ATIS	: advanced traveler information system
FCW	: forward collision warning
HUD	: head-up display
IEEE	: institute of electrical and electronics engineers
IT	: interaction time
IVNS	: in-vehicle navigation system
LKAS	: lane keeping assistance system
NT	: neglect time
NVE	: night vision enhancement
SPAS	: smart parking assistance system
UAV	: unmanned aerial vehicle

1. INTRODUCTION

The Institute of Electrical and Electronics Engineers (IEEE) predicts that by the year 2040, highways will have designated lanes for autonomous vehicles (Read, 2013). Semi-autonomous features, such as the smart parking assistance system (SPAS), lane keeping assistance system (LKAS), and adaptive cruise control (ACC), have already been commercialized, and fully autonomous vehicles will probably become available within the next 10–20 years. The development of self-driving cars or autonomous vehicles has progressed at an unanticipated pace in recent years. A few years ago, state legislators had not even considered autonomous cars; currently, however, three states have enacted legislation on operating self-driving cars and several more states are considering it. Despite the speed of technological development, people will probably accept and adapt to this new technology in the same manner as they did with other intelligent systems.

Ironically, the driver or the driver–vehicle interaction is a largely neglected factor in the development of enabling technologies for autonomous vehicles. For example, some vehicle automation features cause considerable confusion and frustration in the driver, which is typically associated with poorly integrated systems (Norman, 2003). Despite humans being adaptable, several critical issues related to human–vehicle automation become noticeable with advancements in technology. For example, the term “self-driving” or “autonomous” can easily mislead people into thinking that the driver’s role in vehicle operation will become insignificant with the arrival of advanced vehicles. In fact, the role of humans in driving is changing from conventional manual control to supervisory control with an

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increase in the level of vehicle automation. Several issues pertaining to human–automation interaction are gaining research attention, and autonomous vehicles are no exception.

Researchers have extensively studied human–automation issues in the field of aviation, where automated features such as altitude and speed holds were introduced several decades ago. In aviation, studies on automation and mode selection have focused mainly on problems in pilot–autopilot interaction, such as mode awareness or mode confusion (e.g., Johnson and Pritchett, 1995; Bredereke and Lankenau, 2002).

In the past decade, the military has actively used several different unmanned aerial vehicles (UAVs) such as the ScanEagle and Raven. As the number of issues in human interaction for UAV operation increases, the importance of these issues from the viewpoint of human control of unmanned systems becomes increasingly prominent. For example, mental workload is a limiting factor in deciding the number of UAVs that an operator can control or supervise. Previously, researchers attempted to model the operator capacity for demonstrating the temporal constraints associated with the UAV system. The complexity of such work progressed from measuring the operator capacity in scenarios with homogenous UAVs controlled by one operator (Olsen and Wood, 2004; Cummings and Mitchell, 2008; Crandall and Cummings, 2007; Nehme *et al*., 2008) to scenarios wherein one operator supervised teams of heterogeneous UAVs (Nehme, 2009). The first equation developed to predict operator capacity in homogeneous UAVs suggested that the operator capacity is a function of the neglect time (NT)—which is the duration for which the UAV operates independently—and of the interaction time (IT)—which is the time for which the operator is busy interacting, monitoring, and making decisions with the system (Olsen and Wood, 2004). The mental workload, situational awareness, and human operators' trust in automation differ for different automation levels in human–UAV teams, and selection of appropriate operation modes is a critical factor in the successful and efficient completion of missions.

Similarly, we can benchmark human–automation issues in ground transportation. Aerial and ground transportations are similar in that vehicles are operated in both these domains. However, these domains have several key differences. For example, road traffic has a relatively high hazard density and probability of two-dimensional collisions, whereas aerial traffic has a low hazard density and probability of three-dimensional collisions. The threat response times for road and aerial transportations are on the order of seconds and minutes, respectively. Practically anyone can become a vehicle driver, whereas only highly trained personnel can become pilots, and the latter need to maintain their skill through continuous training. When highly automated systems such as UAVs are introduced into the aviation domain, the operators will most likely be active military officers with sufficient expertise in terms of flight hours, instructor experience, and certified training. In the case of ground vehicles, the elderly will very likely encounter the most advanced functionalities of autonomous vehicles, considering their purchasing power (Coughlin, 2001); in other words, they can afford top-of-the-line and expensive vehicles, which will have the most advanced functionality. Population aging has caused an increase in the number of licensed drivers over the age of 40 (Eby and Molnar, 2012). Nearly 77 million baby boomers in the USA (i.e., people born between the years 1946 and 1964) can be categorized as the automobile generation (Coughlin and Reimer, 2006). With one of these baby boomers turning 68 years old every seven seconds, they encounter new vehicle features that they previously never used or even imagined. Although the common assumption is that older people are reluctant to interact with new technology, research has shown that older adults are actually motivated to use technologically advanced products upon being advised about their benefits (Melenhorst *et al*., 2001). Then, this paper discusses issues with respect to aged drivers in terms of the development and use of in-vehicle technologies in self-driving vehicles, and introduces ongoing research projects in industry and academia. The rest of this paper is organized as follows. Section 2 summarizes the characteristics of aging drivers, and Section 3 discusses key issues in the interaction of aging drivers with in-vehicle technology. Section 4 introduces limited examples of research on the relevant area, and Section 5 provides concluding remarks.

2. CHARACTERISTICS OF AGING DRIVERS

Advanced age obviously distinguishes aging or older drivers from other drivers. Several studies have demonstrated systematic differences between drivers as a function of age, although they are ambiguous about the exact age at which a person becomes an older driver (Meyer, 2004; Coughlin, 2001). For example, Meyer (2004) summarized four reasons for differences between age groups: (a) *cohort effects*, which consider generational effects such as progressive motorization and gender difference; (b) *changing lifestyles*, which acknowledge that aging is also a social process; (c) *disease and medication*, wherein both chronic and acute diseases can impair driving ability; and (d) *age-related changes*, which are due to the physiological aging process itself. The literature on age-related sensory, cognitive, and motor changes is comprehensive and vast. Therefore, in this paper, we cite only some recent works and those that concern driving (e.g., Planek, 1972; Llaneras *et al*., 2000; Hakamies-Blomqvist, 1996; Shaheen and Niemeier, 2001; Meyer, 2004).

In this section, based on the extensive review conducted by Meyer (2004), we briefly discuss some key age-related changes in each of the above-listed four categories that affect driving, in order to gain a better understanding of issues in the interaction of aging drivers with in-vehicle technology.

2.1. Age-related Changes in Sensory and Motor Functions

Vision may be the most important sensory function that affects driving because visual information largely guides driving. In fact, research has suggested that 85%–95% of the sensory cues in driving are visual (Malfetti and Winter, 1986). Through the course of normal aging, all visual functions deteriorate, including static and dynamic visual acuities, contrast sensitivity, night vision, peripheral vision, visual scan, and glare resistance. Regardless of the well-established work done on age-related vision degradation in driving, the exact role of each visual parameter in driving is not very clear (Groeger, 1999).

Another sensory function that declines with age is hearing. The loss of hearing ability is much more marked in the case of high-frequency stimuli (Corso, 1981). Further, older people show lower sensitivity to touch and vibration (Gescheider *et al*., 1994; Harkins and Chapman, 1977). Odor sensitivity also diminishes with age. Although the deterioration of these sensory functions does not necessarily affect driving, designers should consider them when designing new in-vehicle technology, since auditory/haptic/olfactory stimuli can be used for multiple, effective warning modalities.

Muscular strength, speed of muscle contraction, and flexibility also decrease with aging. These changes can result in delayed responses, and hence, they require greater power-assisted braking or steering. Approximately half of the U.S. population over the age of 75 years experiences some degree of arthritis (Blocker, 1972), and in Korea, 36 % of the population over the age of 65 reportedly has arthritis (Statistics Korea, 2004). These statistics are significant because arthritis limits a person's ability to turn the head and trunk, and therefore, it makes vehicle ingress and egress difficult.

2.2. Age-related Changes in Cognitive Function

Cognitive abilities, such as attention, memory, information processing, and decision-making, are critical for safe driving. Several cognitive abilities decline as an individual ages, although the degree of decline varies considerably with advancing age. Research has shown that a correlation exists between selective attention and the accident rates of drivers aged 45–64 years (Mihal and Barrett, 1976) and that older adults have greater difficulty in dividing attention effectively than do younger adults (Brouwer *et al*., 1990). The ability to divide attention declines with age (Ponds *et al*., 1988), and spatial cognition, which affects navigation, also tends to decline with age (Salthouse, 1987). Memory problems can occur at any age, but they become increasingly common in older adults; specifically, older adults encounter problems such as short-term memory, encoding, and retrieval of information from long-term memory (Jacoby and Hay, 1998). Despite the generally held negative view of aging and memory, research has shown that semantic memory (memory for facts or general knowledge) (Cattell, 1963) remains relatively robust during a person's lifetime (Morrow *et al*., 2000).

Fozard *et al*. (1994) showed that simple response times were relatively unaffected by age but choice response times were affected more severely by it. Thus, we can infer a general slowdown of the speed of information processing with aging. Some studies have also shown that executive functioning, or the metacognitive ability that enables a person to effectively plan, organize, strategize, reason, and self-regulate (National Center for Learning Disabilities, 2010) tends to decline in aging adults (Mayr *et al*., 2001; Zelazo *et al*., 2004; Eby and Molnar, 2012). Executive control, which refers to a number of cognitive abilities related to the maintenance and update of cognitive and behavioral goals, planning and sequencing of actions, problem solving, and inhibition of automatic responses (Boot *et al*., 2012), tends to decline substantially with age (Resnick *et al*., 2003). Poor cognitive functions can affect safe driving in several ways, including when a person is engaging in unsafe self-regulated driving, has difficulty in navigating and gets lost, and responds appropriately to quickly changing traffic information (Eby and Molnar, 2012). However, many people begin to adjust their driving as they age: research has shown that elder drivers strategically avoid dangerous driving situations, such as night driving, poor weather, and periods of peak traffic, and they drive more carefully so that they can compensate for their declined sensory, cognitive, and motor functions (Waller, 1991; Rudi and Ingrid, 2000). While many see self-regulation as a success in promoting safety, it could result in lost mobility.

3. KEY ASPECTS TO CONSIDER FOR NEW IN-VEHICLE TECHNOLOGY

3.1. Learnability and Acceptance of New In-vehicle Technology

Older drivers represent an innovation paradox when purchasing vehicles. The majority of new in-vehicle systems are part of the product packaging of higher-end premium vehicles, which older drivers with purchasing power often purchase. Older consumers may be less likely to rapidly learn and use these systems than the natively digital younger generation. Studies have reported that older drivers take much longer to learn how to use new in-vehicle technology (AAA Foundation for Traffic Safety, 2008; Caird, 2004). However, this learnability issue does not mean that older people are reluctant to learn new technology. Instead, research shows that older adults are motivated to use products upon being advised about their benefits (Melenhorst *et al*., 2001). Furthermore, experience with new technologies may increase their willingness to use them (Boot *et al*., 2012). Therefore, it is important to design a method that clearly describes the potential benefits of in-vehicle technology, which would make aging drivers willing to use the new interface or functions. Once older drivers gain knowledge of how to interact with the in-vehicle technology and its benefits, they will be more motivated to use it. This will help the industry to appropriately create a new future for driving that successfully includes their premium customers (Boot *et al.*, 2012).

Older drivers probably have well over 30 years of driving experience, which makes them among the safest and most expert drivers on the road. Ironically, the same experience can make their learning and ability to use the new in-vehicle technology a challenge. Research suggests that younger and older drivers learn to use new technology differently (Coughlin and Reimer, 2006). If the older, more experienced drivers are to use the features of new self-driving or advanced driver assistance systems (ADASs), such as SPAS, LKAS, ACC, head-up display (HUD), and brake assist system, they will have to update their driving skills, after having driven for more than three decades without these automated features. The industry cannot expect older drivers to learn and use the new in-vehicle technology without any training. Lifelong driver education and training may be one approach. For example, technology training can be combined with driver education and training programs, as is done in the American Association of Retired Persons (AARP) Driver Safety Program (Coughlin and Reimer, 2006).

3.2. Net Effectiveness of Use of New In-vehicle Technology

Research has shown that older drivers get distracted from driving when the cause of triggering of a warning system is not evident. Their accumulated expertise and judgment cause them to “second-guess” their trust in the authenticity of the warning, further leading them to look for clear reasons for the triggering of an alarm. In contrast, younger operators, who have less experience by definition, have greater trust in warning systems, often choosing to rely on the system alone, rather than using it as a driver assist system (Yick, 2003; Cottè *et al.*, 2001). When drivers distrust automation, either because of its ambiguity or complexity or because of its true level of reliability, a failure of trust calibration occurs, and such an automated feature will possibly remain unutilized by the drivers (Wickens *et al.*, 2008). The issue of mistrust of automation or false alarms has several solutions. One of them is to allow systems to express their confidence in the signaled warning at more than one level, which creates an increased sensitivity in the driver–vehicle system.

Poorly designed in-vehicle technology could increase distractions and the driving workload for older users, thereby reducing driving safety. A number of studies have shown that older drivers often use new technology differently from younger drivers (Caird, 2004). As summarized by Eby and Molnar (2012), Gish *et al.* (2002) found that older drivers used night vision enhancement (NVE) systems less commonly than did drivers of other ages but the former reported being satisfied with the systems. Older drivers viewed the forward collision warning (FCW) more favorably (Maltz and Shinar, 2004) and used navigation assistance frequently; further, despite reporting some distraction from the system, they experienced increased feelings of safety and confidence (e.g., Vrkljan and Polgar, 2007). Studies also reported that drivers of all ages observed that driver workload and stress reduced when using ACC, and that the drivers trusted the system (Rudin-Brown and Parker, 2004; Stanton and Young, 2005).

Meyer (2004) also provided four reasons why the benefits of advanced technology could be less than expected. First, users may not use the device correctly and may fail to derive safety benefits. Second, drivers may take a greater risk upon the introduction of an advanced technology than they might without the technology, as proposed in Wilde’s (1988) risk homeostasis theory. Third, older drivers, who tend to drive more cautiously than younger drivers, will possibly experience an unacceptably high false alarm rate, which can lead to them rejecting the system. Fourth, drivers may develop new behavioral patterns following the use of the new autonomous technology.

4. SOME RESEARCH-BASED EXAMPLES OF AGING DRIVERS

4.1. Holistic Approach to Designing Vehicles for Older Drivers

The MIT AgeLab introduced a concept vehicle designed to optimize the driving safety and wellness of older adults (Coughlin *et al.*, 2009; Reimer *et al.*, 2009). They realized this concept as the AwareCar, which is based on the idea that crashes can be mitigated by exploiting the interactive and overlapping roles of the vehicle, environment, and drivers. The AwareCar is an instrumented vehicle built for evaluating new models and methods of monitoring driver state through physiology, visual attention, and driving performance in the field. A key feature of the AwareCar is its ability to acquire context-sensitive information on the driver, environment, and vehicle. A variety of studies have used this vehicle to assess hands-free cellular phone usage, provide surrogate measures of visual and cognitive distractions, and improve driver health and wellness. This vehicle has also been used to develop functional methods for assessing age-related changes due to workload, arousal, and stress.

AGNES (Age Gain Now Empathy System) is another tool that has been developed and used to gain a deeper understanding of the friction points in the transportation system for older adults that can help system designers and engineers identify barriers to accessibility for older pedestrians and drivers. Research groups attempted to provide examples of the aging population in the transportation domain. For example, Coughlin and Reimer (2006) presented a modified Haddon matrix (Haddon, 1972) that identified key product development, design, and liability issues challenging the automobile industry and related stakeholders. Further, Reimer *et al.* (2010) evaluated driver reactions to new vehicle parking assist technologies. Mehler *et al.* (2012) assessed the sensitivity of the heart rate and skin conductance level for discriminating between levels of cognitive demand under driving conditions across different age groups. Reimer *et al.* (2013) evaluated the effects of age and cognitive demand on lane choice and lane changing behavior from an on-road study.

4.2. Advanced Navigation Systems for Aging Drivers

Researchers have focused on in-vehicle navigation systems (IVNSs) because these systems are expected to maintain the mobility of older people, for example, by reducing visual processing and attentional demands, reducing navigational errors, and improving overall driving performance (Dingus *et al.*, 1997; Llaneras *et al.*, 2000). Below, we discuss some research-based examples of aging drivers.

Baldwin (2002) applied sensory–cognitive interaction theory and discussed its implications for the design of in-vehicle technologies, such as advanced traveler information systems (ATISs). The sensory–cognitive interaction theory states that sensory abilities account for substantial amounts of variance in cognitive performance among older adults, and can be a better predictor of cognitive performance than age alone (Lindenberger and Baltes, 1994). Baldwin (2002) stated that in-vehicle technologies that provide essential navigational information can greatly improve driver safety among older adults, but stressed that the interaction between sensory and cognitive functions clearly needs to be investigated further, e.g., the potential of sensory augmenting designs.

May *et al.* (2005) described an empirical, road-based investigation of the benefits of providing landmarks within the instructions presented by an IVNS to both older and younger drivers. Their study showed that both younger and older drivers benefited significantly from the incorporation of landmarks in the turn-by-turn instructions provided by the IVNS. The design recommendations regarding future navigation systems that older drivers may possibly use are that they should not rely on distance-to-turn information to locate forthcoming maneuvers. Their study also showed that these systems would be useful for older drivers and received positively if they met a perceived need and were designed effectively.

Kim *et al.* (2010) examined older and younger adults' perceptions regarding a set of 28 motor vehicle features and aspects, to determine the extent to which the participants believed that the individual features might help their safe driving. Their study did not focus on advanced in-vehicle technologies; rather, it examined the potential benefits of existing vehicle features such as dashboard, side-view mirrors, indicators, and controls. Kim *et al.* (2010) compared two different in-vehicle navigation systems, and on the basis of a focus group interview, they proposed a configuration of the navigation menu for the best readability and transmissibility.

Emmerson *et al.* (2012) reported findings of six focus groups with older drivers; the findings revealed that older drivers have a navigation need that is currently not being fulfilled. The majority of older drivers responded positively toward the use of in-vehicle technology; yet, it was evident that they lacked the ability to fully utilize this technology. Even the older drivers who were more traditional in their navigation approach used modern pre-trip planning tools to assist them, indicating an awareness among aging drivers about how the new in-vehicle technology can assist them. Consequently, their subsequent maintained mobility could have far-reaching effects on society upon the removal of known barriers (e.g., a complex screen).

4.3. In-vehicle Health Monitoring Systems

Like the IVNS, in-vehicle health monitoring systems have been developed and studied actively in both academia and industry. For example, Ford has developed a car seat that can check the driver's heart rate and could warn of an impending heart attack, and GM has begun offering emergency healthcare instruction through the OnStar (Naughton, 2011). The Philips Chair of Medical Information Technology, in a cooperation project with the Ford Research Center in Aachen, developed and evaluated a capacitive electrocardiogram measurement system integrated into the driver seat (Eilebrecht *et al.*, 2011). SYNC, the voice-activated technology developed by Ford, allows drivers to access their smartphone applications, and a growing number of those applications are related to healthcare (English, 2013). A steering wheel developed at the Munich Technical University in collaboration with BMW has a built-in sensor and is capable of measuring the heart rate, blood-oxygen level, and blood pressure (Trei, 2011). Long since driver health-monitoring systems received research attention, the integration of advanced collision notification systems (ACNSs) into new cars has undergone substantial development, and this is only the beginning. Current applications use an array of sensors to detect the location of an accident and then notify emergency services. More recently, an extended view of an ACNS includes detection of driver/occupant weight, distance from wheel, and other features that enable the vehicle to play an active role in adjusting the force of airbag deployment (Coughlin and Reimer, 2006). The car, in addition to aiding a rapid deployment of emergency services to the scene, could become a platform for helping organize the emergency room and trauma resources before help arrives.

5. CONCLUSION

Transportation is critical to everyday life, and it involves more than simply getting from point A to point B. The worldwide aging population poses a number of new safety- and technology-based challenges to the automobile industry, as well as to related stakeholders in the government, insurance, and health industries. This paper reviewed the effects of aging on sensory, motor, and cognitive functions, and discussed the learnability, acceptance, and net effectiveness of new in-vehicle technology by aging drivers. Extensive research in this field indicates a potential increasing demand for in-vehicle technology for aging drivers. This paper anticipates many questions that may arise from the interaction of autonomous technologies with an older driver population, and we expect the results of our exploration to be a foundation for further developments toward the consideration of needs of aging drivers while designing self-driving vehicles.

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