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Prevalence, attitudes, and knowledge of in-vehicle technologies and vehicle adaptations among older drivers

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ABSTRACT

The purpose of the present study was to gain a better understanding of the types of in-vehicle technologies being used by older drivers as well as older drivers' use, learning, and perceptions of safety related to these technologies among a large cohort of older drivers at multiple sites in the United States. A secondary purpose was to explore the prevalence of aftermarket vehicle adaptations and how older adults go about making adaptations and how they learn to use them. The study utilized baseline questionnaire data from 2990 participants from the Longitudinal Research on Aging Drivers (LongROAD) study. Fifteen in-vehicle technologies and 12 aftermarket vehicle adaptations were investigated. Overall, 57.2% of participants had at least one advanced technology in their primary vehicle. The number of technologies in a vehicle was significantly related to being male, having a higher income, and having a higher education level. The majority of respondents learned to use these technologies on their own, with "figured-it-out-myself" being reported by 25%–75% of respondents across the technologies. Overall, technologies were always used about 43% of the time, with wide variability among the technologies. Across all technologies, nearly 70% of respondents who had these technologies believed that they made them a safer driver. With regard to vehicle adaptations, less than 9% of respondents had at least one vehicle adaptation present, with the number of adaptations per vehicle ranging from 0 to 4. A large majority did not work with a professional to make or learn about the aftermarket vehicle adaptation.

1. Introduction

The aging of the population is a global phenomenon. According to United States (US) Census Bureau data, 8.5% of the world's population was age 65 or older (hereafter referred to as older adults) in 2015 and projections show that 12% (1 billion people) will be older adults by 2030 (He et al., 2016). These percentages are much higher in developed countries. For example, in 2015, Japan's older adult population was 26.6% and the US older adult population accounted for 14.9% of the total population. Projections show that these percentages will continue to grow in the coming decades. The number of older adults who are driving is also increasing. Results from an analysis by the National Center for Statistics and Analysis (NCSA, 2017) indicated a 33% increase in the number of licensed older drivers in the US between 2006 and 2015, with 40.1 million licensed older drivers in the US in 2015. Despite the downward trend in older driver fatal crash rates, older drivers still have significantly higher fatal crash rates per mile driven than all but the youngest drivers (Insurance Institute for Highway

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Table 1
Questionnaire text used to describe technologies.

Technology	Text Used in Questionnaire to Describe the Technology
Adaptive cruise control	Conventional cruise control systems allow you to maintain a constant vehicle speed without keeping your foot on the accelerator pedal. Some vehicles also have adaptive cruise control; adaptive cruise control adjusts your vehicle speed automatically to maintain a constant gap or headway between your vehicle and the vehicle ahead.
Adaptive headlights	Adaptive (or "active") headlights can automatically change the direction of the light beam when you steer left or right on curved roads. On your vehicle, these headlights may be called "steerable headlights" or something similar.
Backup/parking assist	A backup/parking assist system helps the driver back up/park by either providing audible proximity alerts that sound to warn the driver when the front or rear of the vehicle is near an object, or by providing a rear-view camera with a grid, sounds, lights, or symbols to assist the driver in avoiding obstacles while reversing.
Blind spot warning	A blind spot warning system uses sensors to detect objects, such as other vehicles, that are to the left and right of the lane in which you are driving. The system can provide a warning when you are changing lanes or parking that there is a vehicle or other object next to your vehicle that you may not be able to see.
Cross traffic detection	A cross traffic detection system helps the driver back up by detecting traffic coming from the left or right and providing a warning and/or automatically stopping the vehicle if traffic is detected.
Emergency response	An emergency response system automatically calls emergency personnel when your vehicle is involved in a crash. Other systems will try to contact you first before calling emergency personnel.
Fatigue/drowsy driver alert	A fatigue/drowsy driver alert system uses various technologies to determine if you are getting fatigued or drowsy while driving and provides an alert to you that you may be getting too tired to drive safely.
Forward collision warning	A forward collision warning system uses sensors to detect objects, such as other vehicles, that are in front of your vehicle when you are driving. The system can provide a warning when you are about to collide with an object and, in some systems, apply the brake for you so that you do not hit the object.
In-vehicle concierge	An in-vehicle concierge system allows you to press a dashboard control button and connect with a person who can answer your questions, provide information, and provide other services while you are in your vehicle.
Integrated Bluetooth cell phone	An integrated Bluetooth cell phone system automatically connects with your cell phone and allows you to make and receive phone calls using the vehicle's speakers and dashboard interface without having to handle your cell phone.
Lane departure warning	A lane departure warning system uses sensors to detect your vehicle's position in the lane and provides a warning to you if you drift out of your lane.
Navigation assistance	A navigation system shows maps on a screen and/or provides step by step driving directions to help the driver get to a chosen destination.
Night vision enhancement	A night vision enhancement system uses infrared sensors to "see" objects such as people and animals at night and displays this information to the driver on a video screen in the vehicle.
Semi-autonomous parking assist	A semi-autonomous assistive parking system can steer the vehicle into a parking space by itself with little input from the driver, and in some cases this system can also detect a parking space automatically before self-parking.
Voice control	A voice control system allows you to control vehicle features such as the radio or navigation system, using commands that you speak out loud.

Safety, 2016). In 2015, 6156 older drivers were killed in traffic crashes and about 240,000 were injured (National Center for Statistics and Analysis, NCSA, 2017).

Automobile driving is a skilled activity that requires sound psychomotor, visual, and cognitive functioning. Because of age-related medical conditions, increased use of medications to treat these conditions, and general age-related declines, driving can become more difficult as individuals age (Dickerson et al., 2007; Eby et al., 2009). In part, because of the well-known negative impacts of driving cessation (see e.g., Chihuri et al., 2015) and in part because older adults' preferred method for mobility is the personal automobile (Kostyniuk and Shope, 2003; Zeitler and Buys, 2015), traffic safety and mobility professionals are interested in developing countermeasures to keep older adults driving for as long as they can safely operate an automobile. Recently, several authors proposed that in-vehicle technologies hold promise for helping older drivers stay on the road by assisting them in areas where they are experiencing functional declines (see e.g., Band & Perel, 2007; Eby and Molnar, 2014; Eby et al., 2015, 2016; Marshall et al., 2014; Meyer, 2009; Paris et al., 2014). The use of advanced, in-vehicle technologies could make driving safer and more enjoyable for older adults.

In addition to in-vehicle technologies, aftermarket automotive vehicle adaptations have been used for decades to assist drivers with functional impairments and make driving more comfortable (Bouman and Pellerito, 2006; Koppa, 2004; Mollenhauer et al., 1995; Mitchell, 1997). As described by Bouman and Pellerito (2006), adaptive devices are available to assist with a number of driving-related activities including ingress and egress (e.g., additional handles), safe and comfortable seating (e.g., seat cushions), steering (e.g., spinner knobs), throttle and braking control (e.g., pedal extension), and operating secondary systems (e.g., convex/multifaceted mirrors). The National Highway Traffic Safety Administration (NHTSA, 2007) recommends that drivers work with occupational therapists who can recommend appropriate vehicle adaptations based on the specific functional declines experienced. However, little formal evaluation has been conducted on the use of vehicle adaptations or how drivers go about getting these adaptations made.

The purpose of the present study was to gain a better understanding of the types of in-vehicle technologies being used by older drivers, as well as older drivers' use, learning, and perceptions of safety related to these technologies among a large cohort of older drivers at multiple sites in the US. A secondary purpose was to explore the prevalence of aftermarket vehicle adaptations, and how older adults go about making adaptations and how they learn to use them.

2. Methods

The study utilized baseline data from the multi-site Longitudinal Research on Aging Drivers (LongROAD) study. The LongROAD study was designed to explore several areas of older driver safety and mobility, including: protective and risk factors; medications; medical conditions; self-regulation; in-vehicle technologies and aftermarket adaptations; and cessation of driving. Study participants were enrolled in and around five cities distributed across the US (Ann Arbor, MI; Baltimore, MD; Cooperstown, NY; Denver, CO; and San Diego, CA). Data include self-reported health (i.e., mental, social, physical, cognitive, behaviors, conditions, and impairments and symptoms) and objectively measured health, functional abilities (i.e., cognition, psychomotor, and perception), and driving behaviors; medical record information; and violation and crash records.

Data for the present study were collected from a vehicle technology questionnaire (VTQ) administered to LongROAD participants at baseline. The list of specific technologies, vehicle adaptations, and topics addressed in the VTQ were developed by the research team, based on recent reviews of the literature and the project team's expertise (Eby and Molnar, 2014; Eby et al., 2011, 2015). The following in-vehicle technologies (i.e., technologies that were installed by the vehicle manufacturer either as standard or optional equipment) were included in the VTQ: adaptive cruise control; adaptive headlights; backup/parking assist; blind spot warning; cross traffic detection; emergency response; fatigue/drowsy driver alert; forward collision warning; in-vehicle concierge; integrated Bluetooth cell phone; lane departure warning; navigation assistance; night vision enhancement; semi-autonomous parking assist; and voice control. Table 1 shows how each of these technologies were described in the questionnaire.

The following vehicle adaptations (i.e., aftermarket modifications or additions made to the vehicle by the owner) were also included in the VTQ: convex/multifaceted mirrors; custom armrests; driver seat cushions; gas pedal block; hand controls; left foot throttle; modified secondary controls (wiper, horn, turn signal, cruise control, headlights); pedal extension; push button ignition (aftermarket); seat belt extension; steering wheel modification; and upper body support. The research team developed the survey questions for each topic, consulting published questionnaires and research on similar topics, technologies, and modifications (Bouman and Pellerito, 2006; Eby and Molnar, 2012; Jenness et al., 2007, 2008a,b,c; LeBlanc et al., 2006; Mehler et al., 2014; The Hartford, 2013; Sayer et al., 2011). The draft VTQ was pilot-tested with 56 respondents recruited in roughly equal numbers from each of the sites (mean age = 71.9 years; 53.4% male). Survey feedback and results were analyzed and minor modifications were made to the VTQ to improve clarity.

LongROAD participants were recruited through primary care clinics associated with the health system at each study site and participants were paid up to $100 per year (depending on the site) for their involvement in the study. Participant inclusion criteria were: age 65–79 years; held a valid driver's license; drove on average at least once per week; had no significant cognitive impairment as determined by a score ≥ 4 on the Six Item Screener (Callahan et al., 2002) and medical record review; drove a primary vehicle (at least 80% of the time) that was model year 1996 or newer; planned to reside in the study area 10 months per year; and had no plans to move outside of study area in next 5 years. Eligible and interested individuals were scheduled for an in-person baseline session. At this session, written informed consent was obtained and data were collected (including a face-to-face administration of the VTQ). Each site received approval for the recruitment and study procedures from a local institutional review board. A complete description of the study methods can be found elsewhere (Li et al., 2017).

3. Analysis

Descriptive data analytic techniques were conducted to examine the prevalence of in-vehicle technologies and vehicle adaptations, how older drivers learned to use the technologies/adaptations, the perceived safety benefits of the in-vehicle technologies, and how participants' responses to those questions related to demographic characteristics (sex, age group, education level, and household income). Spearman correlation analyses were conducted to examine the relationship between technology/adaptation item responses and demographic categories. Frequency distributions were compared by demographic categories using chi-square or Fisher's exact test, as appropriate. The likelihood ratio chi-square statistic was obtained from the chi-square tests where counts were too low in some cells to meet chi-square test assumptions otherwise a Pearson chi-square statistic was obtained. Analyses were conducted in SAS Version 9.4 (SAS Institute Inc., Cary, NC).

Education level was collapsed from nine to four categories (high school graduate or less; vocational/technology/business/trade school or some college but no degree; associates or bachelor degree; master/professional/doctoral degree) for the chi-square testing. The revised categories were determined on an ad-hoc basis and were guided by the frequency distribution across the original nine categories.

4. Results

4.1. Demographics

A total of 2990 respondents completed the VTQ at enrollment between July, 2015 and March, 2017. Of these respondents, the three age group categories were: 65–69 years (41.6%), 70–75 years (34.7%), and 75–79 years (23.7%). About one-half (53%) were female, and most were White and non-Hispanic (87.9%), followed by Black/African American (7.1%) and Asian (2.5%). About two-thirds (62.6%) were currently married, 14.8% were divorced, 12.6% were widowed, 4.4% were never married, and the rest were either living with a partner, separated, or did not provide their marital status. The reported education levels were 11.2% with a high school degree or less, 17.7% with some college but not a degree, 30.0% with an associates or bachelor degree, and 40.8% with an advanced college degree. About one-third (30.2%) reported having done work for pay in the past month and 45.9% reported having done volunteer work in the past month. Reported annual household income levels were: less than $20,000 (4.5%); $20,000–$49,999 (21.4%); $50,000–$79,999 (24.0%); $80,000–$99,999 (14.4%); and $100,000 or more (32.1%).

4.2. Prevalence of in-vehicle technologies

Overall, 57.2% (1713) of participants had at least one advanced technology in their primary vehicle. On average, participants had 1.96 (± 2.52) technologies in their vehicle, with a range of 0–14 (median = 1.0). Spearman correlations showed that the number of technologies in a vehicle was significantly related to being male ($\rho = .0398$, $p = .03$), having a higher income ($\rho = .1139$, $p < .0001$), and having a higher education level ($\rho = .2831$, $p < .0001$). Age group was not significantly correlated with the number of technologies. Fig. 1 shows the prevalence of each technology among LongROAD participants. Integrated Bluetooth cell phone, backup/parking assist, and navigation assistance systems were the most frequently reported advanced in-vehicle technologies, with each being reported by more than one-quarter of participants. Voice control, in-vehicle concierge, and blind spot warning systems were next in frequency, with each being reported by at least 10% of participants.

Fischer's exact tests on the prevalence of in-vehicle technology by sex were conducted and statistically significant differences were found for 10 of the 15 technologies: adaptive headlights (men 4.6%, women 2.8%, $p = 0.03$), emergency response (men 12.2%, women 7.4%, $p < 0.001$), in-vehicle concierge (men 13.4%, women, 7.9%, $p < 0.001$), and voice control (men 22.6%, women 16.9%, $p = 0.0001$). In all cases, men were more likely to report having the technology. Chi-square analyses were conducted by age group on the prevalence of each technology. Results showed significant differences for only two technologies: integrated Bluetooth cell phone (65–69 years 50.7%, 70–74 years 48.8%, 75–79 years 39.7%, $\chi^2[2] = 22.23$, $p < 0.0001$) and voice control (65–69 years 22.4%, 70–74 years 19.6%, 75–79 years 14.6%, $\chi^2[2] = 17.36$, $p = 0.0002$). Tables 2 and 3, show the prevalence of reported technologies and statistical results for each individual technology by participant education level (Table 2) and household income (Table 3). Significant differences are shown in bold font. The reported prevalence of these technologies generally increased with increasing income and education. Education level was significantly associated with prevalence for nine of the 15 technologies. The only technologies that did not differ significantly by income were night vision enhancement and semi-autonomous parking assist systems, both of which had very low overall prevalence.

4.3. Learning to use, frequency of use, and safety perception of technologies

The VTQ included several additional questions about each technology for respondents who indicated that their primary vehicle had

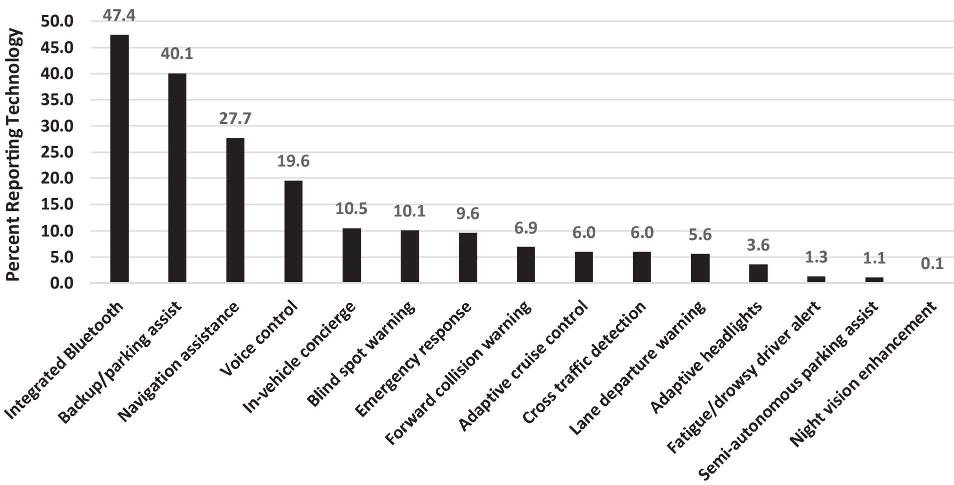

Fig. 1. Advanced in-vehicle technology prevalence among LongROAD participants.

that technology. Three similar questions were asked about the majority of technologies as appropriate: How did you primarily learn to use [technology]? How often do you use [turn on] the [technology] for trips [situations that were appropriate for the technology]? Does having [technology] make you a safer driver? Table 4 shows the primary way that respondents learned to use 12 of the 15 technologies. This question was not asked for adaptive headlights, emergency response, and in-vehicle concierge. How people learned to use technologies clearly varied by the type of technology. For example, nearly one-half of people with semi-autonomous parking assist never learned how to use the technology, whereas less than 1% reported never learning how to use backup/parking assist systems. However, considering the group of technologies as a whole, respondents quite often reported learning to use these technologies on their own, with the percentage of "figured-it-out-myself" ranging from 25%–75% (mean = 48.9%) of the technologies. The second most frequently reported way of learning was the automotive dealer, with percentages ranging from 5%–31%. Analyses were conducted to determine if there were differences in how respondents learned to use the technologies by sex, age group, education level, and income level. These results are shown in the right column of Table 4. There were no differences by age group. For six of the technologies, learning varied by sex. In all cases, women were more likely to report having never learned or to have learned from the dealer and less likely to report having used the owner's manual or figuring it out themselves. Learning varied by income level for three of the technologies. For cross traffic detection, the lowest income group was more likely to report having used an owner's manual and less likely to report having figured it out themselves as compared to the other income groups. For blind spot warning and lane departure warning, the lowest and highest income groups were more likely to report having figured it out themselves and the highest income group was less likely to report having learned from a dealer. Learning about three technologies differed by education level. For navigation assistance systems, respondents with the least education were more likely to report having never learned and less likely to report having used the owner's manual, whereas the most educated group was less likely to report having never learned and more likely to report having learned from the dealer. For adaptive cruise control, respondents with the least education were more likely to report having learned through the dealer and Internet, whereas the most educated group were less likely to report having never learned and more likely to report having figured it out themselves. For voice control, the groups with the least and most education were more likely to have never learned or to report having figured it out themselves as compared to the two middle education groups.

Also of interest in the study was how often technologies were used and/or turned on. This issue was not addressed for adaptive headlights, backup/parking assist, cross traffic detection, or emergency response because these systems are generally always turned on. The question was also *not* asked of participants with forward collision warning (n = 106 of the 206), blind spot warning (n = 173 of 303), lane departure warning (n = 50 of 169), or fatigue/drowsy driver alert (n = 26 of 39) systems that could not be turned off. Those respondents that reported having the other technologies were asked how often they used it. If a technology was designed for use in specific driving situations, such as at night (e.g., night vision enhancement), then the questionnaire asked about use of the technology when driving in that situation. Reported frequency of technology use is shown in Table 5 for the 11 technologies. Overall, these technologies were always used about 43% of the time,

Table 2
Advanced in-vehicle technology prevalence by participant education level.

Technology	HS degree or less% (n)	Trade school/some college% (n)	Associates or Bachelor degree% (n)	Graduate degree% (n)	χ^2 df = 3α (p)
Adaptive cruise control	4.2 (14)	3.8 (20)	5.1 (46)	8.0 (98)	16.92 (0.0007)
Adaptive headlights	2.4 (8)	2.5 (13)	3.7 (33)	4.5 (55)	6.49 (0.0901)
Backup/parking assist	32.1 (108)	35.8 (189)	39.2 (351)	44.8 (547)	24.95 (< 0.0001)
Blind spot warning	5.6 (19)	8.3 (44)	9.7 (87)	12.4 (152)	16.76 (0.0008)
Cross traffic detection	4.5 (15)	4.9 (26)	5.6 (50)	7.0 (85)	5.04 (0.1687)
Emergency response	6.2 (21)	10.4 (55)	9.3 (83)	10.4 (127)	5.95 (0.1142)
Fatigue/drowsy driver alert	0.6 (2)	0.6 (3)	1.1 (10)	2.0 (24)	7.94 (0.0472)
Forward collision warning	2.7 (9)	4.7 (25)	6.4 (57)	9.3 (114)	25.35 (< 0.0001)
In-vehicle concierge	10.4 (35)	12.1 (64)	10.8 (97)	9.4 (115)	2.76 (0.4300)
Integrated Bluetooth cell phone	34.5 (116)	45.6 (241)	46.3 (415)	52.4 (640)	37.26 (< 0.0001)
Lane departure warning	3.6 (12)	3.8 (20)	5.1 (46)	7.4 (90)	13.73 (0.0033)
Navigation assistance	20.2 (68)	21.2 (112)	26.2 (235)	33.9 (414)	44.76 (< .0001)
Night vision enhancement	0.3 (1)	0.8 (4)	0.8 (7)	0.9 (8)	0.92 (0.8214)
Semi-autonomous parking assist	0.3 (1)	0.6 (3)	0.9 (8)	1.6 (20)	7.15 (0.0672)
Voice control	11.0 (37)	16.1 (85)	19.5 (175)	23.3 (285)	32.36 (< 0.0001)

Table 3
Advanced in-vehicle technology prevalence by participant household income.

Technology	$20,000 or less% (n)	$20,000–$49,999% (n)	$50,000–$79,999% (n)	$80,000–$99,999% (n)	$100,000 or more% (n)	χ^2 df = 4α (p)
Adaptive cruise control	2.2 (3)	1.1 (7)	4.6 (33)	7.7 (33)	10.2 (98)	65.62 (< 0.0001)
Adaptive headlights	0.8 (1)	0.6 (4)	3.1 (22)	5.1 (22)	5.8 (56)	37.61 (< 0.0001)
Backup/parking assist	11.9 (16)	27.8 (178)	38.2 (275)	45.0 (194)	51.8 (497)	145.26 (< 0.0001)
Blind spot warning	2.2 (3)	4.2 (27)	8.1 (58)	13.5 (58)	15.2 (146)	69.29 (< 0.0001)
Cross traffic detection	2.2 (3)	1.9 (12)	5.4 (39)	7.9 (34)	8.6 (82)	38.00 (< 0.0001)
Emergency response	3.0 (4)	5.5 (35)	7.8 (56)	10.4 (45)	14.5 (139)	52.63 (< 0.0001)
Fatigue/drowsy driver alert	0.8 (1)	0.5 (3)	0.4 (3)	1.4 (6)	2.4 (23)	18.16 (0.0011)
Forward collision warning	0.8 (1)	2.2 (14)	5.4 (39)	8.1 (35)	11.5 (110)	65.11 (< 0.0001)
In-vehicle concierge	3.7 (5)	8.0 (51)	9.9 (71)	11.6 (50)	13.2 (127)	20.63 (0.0004)
Integrated Bluetooth cell phone	16.4 (22)	33.7 (216)	47.4 (341)	52.0 (224)	60.0 (575)	165.74 (< 0.0001)
Lane departure warning	2.2 (3)	0.9 (6)	4.4 (32)	7.0 (30)	9.5 (91)	60.33 (< 0.0001)
Navigation assistance	4.5 (6)	15.1 (97)	23.1 (166)	31.3 (135)	42.1 (404)	193.68 (< 0.0001)
Night vision enhancement	0.0 (0)	0.5 (3)	0.8 (6)	0.9 (4)	0.7 (7)	1.97 (0.7415)
Semi-autonomous parking assist	0.0 (0)	0.5 (3)	1.0 (7)	1.4 (6)	1.6 (15)	6.34 (0.1752)
Voice control	5.2 (7)	9.8 (63)	17.5 (126)	24.8 (107)	27.2 (261)	106.05 (< 0.0001)

Table 4
Primary way the participant learned to use the technology.

Technology	Never learned % (n)	Dealer% (n)	Owner's manual % (n)	Family/friend % (n)	Internet% (n)	Figured out myself% (n)	Other% (n)	χ^{2a} p
Adaptive cruise control	10.6 (19)	17.2 (31)	12.8 (23)	5.6 (10)	0.6 (1)	48.9 (88)	1.1 (2)	sex: p = .001 education: p = .02
Backup/parking assist	0.7 (8)	17.7 (212)	3.9 (47)	2.0 (24)	0 (0)	75.0 (899)	0.7 (8)	–
Blind spot warning	1.3 (4)	22.4 (68)	6.9 (21)	3.6 (11)	0 (0)	64.4 (195)	1.0 (3)	income: p = .04
Cross traffic detection	1.1 (2)	20.2 (36)	4.5 (8)	1.7 (3)	0 (0)	71.9 (128)	0.6 (1)	income: p = .0001
Fatigue/drowsy driver alert	7.7 (3)	20.5 (8)	10.3 (4)	2.6 (1)	0 (0)	56.4 (22)	0 (0)	–
Forward collision warning	3.9 (8)	23.8 (49)	10.7 (22)	1.9 (4)	0 (0)	58.7 (121)	1.0 (2)	sex: p = .01
Integrated Bluetooth cell phone	18.8 (266)	30.8 (437)	13.4 (190)	10.6 (150)	0.2 (3)	22.8 (323)	1.9 (27)	sex: p < .0001
Lane departure warning	2.4 (4)	23.1 (39)	11.8 (20)	1.8 (3)	0 (0)	56.8 (96)	1.8 (3)	income: p = .05
Navigation assistance	12.1 (101)	20.1 (167)	17.4 (145)	7.0 (58)	0.4 (4)	39.8 (331)	2.8 (23)	sex: p < .0001 education: p = .004
Night vision enhancement	25.0 (5)	5.0 (1)	25.0 (5)	5.0 (1)	0 (0)	40.0 (8)	0 (0)	–
Semi-autonomous parking assist	46.9 (15)	15.6 (5)	9.4 (3)	0 (0)	0 (0)	25.0 (8)	0 (0)	sex: p = .009
Voice control	28.0 (164)	21.2 (124)	15.0 (88)	4.4 (26)	0.2 (1)	27.6 (162)	1.2 (7)	sex: p < .0001 education: p = .04
Average %	13.2	19.8	11.8	3.9	0.1	48.9	1.0	

[a] All statistical analyses were conducted using χ^2 tests separately for sex, age group, education, and income. Empty cells in the rightmost column indicate that there were no significant differences by any of the four demographic variables. Rows may not always add to 100% because of rounding and/or missing data.

Table 5
How often was the technology used/turned on when driving?

Technology	Always% (n)	Often% (n)	Sometimes% (n)	Rarely% (n)	Never% (n)	χ^{2a} p
Adaptive cruise control	18.3 (33)	17.2 (31)	19.4 (35)	19.4 (35)	23.9 (43)	sex: p = .04
Blind spot warning	91.5 (119)	1.5 (2)	1.5 (2)	0 (0)	5.4 (7)	–
Fatigue/drowsy driver alert	92.3 (12)	0 (0)	0 (0)	0 (0)	7.7 (1)	–
Forward collision warning	86.0 (86)	2.0 (2)	2.0 (2)	2.0 (2)	8.0 (8)	–
In-vehicle concierge	2.6 (8)	4.8 (15)	13.4 (42)	24.5 (77)	53.8 (169)	–
Integrated Bluetooth cell phone	36.2 (514)	9.4 (134)	13.4 (190)	13.3 (188)	25.2 (358)	sex: p = .004 age group: p = .01 income: p = .04
Lane departure warning	73.1 (87)	5.9 (7)	8.4 (10)	5.0 (6)	7.6 (9)	income: p = .05
Navigation assistance	33.0 (275)	17.1 (142)	15.4 (128)	13.6 (113)	19.4 (161)	sex: p = .03
Night vision enhancement	30.0 (6)	10.0 (2)	15.0 (3)	20.0 (4)	15.0 (3)	–
Semi-autonomous parking assist	6.2 (2)	3.1 (1)	9.4 (3)	12.5 (4)	68.8 (22)	–
Voice control	8.0 (47)	11.4 (67)	16.6 (97)	22.4 (131)	39.4 (231)	–
Average %	43.4	7.5	10.4	12.1	24.9	

[a] All statistical analyses were conducted using χ^2 tests separately for sex, age group, education, and income. Empty cells in the rightmost column indicate that there were no significant differences by any of the four demographic variables. Rows may not always add to 100% because of rounding and/or missing data.

Table 6
Does having the technology make participant a safer driver?

Technology	Yes	No	Don't know	χ^{2a} p
Adaptive cruise control	61.1 (110)	21.1 (38)	10.0 (18)	education: p = .02
Adaptive headlights	72.5 (79)	16.5 (18)	9.2 (10)	–
Backup/parking assist	84.6 (1014)	14.2 (170)	0.9 (11)	–
Blind spot warning	95.0 (288)	3.6 (11)	1.0 (3)	education: p = .02
Cross traffic detection	96.6 (172)	3.4 (6)	0 (0)	–
Fatigue/drowsy driver alert	69.2 (27)	20.5 (8)	7.7 (3)	–
Forward collision warning	86.9 (179)	9.2 (19)	3.4 (7)	–
Integrated Bluetooth cell phone	62.6 (887)	24.5 (347)	5.2 (783)	sex: p = .02 age group: p = .02
Lane departure warning	87.0 (147)	8.3 (14)	1.8 (3)	–
Navigation assistance	62.4 (519)	27.8 (231)	4.9 (41)	education: p = .01
Night vision enhancement	60.0 (12)	15.0 (3)	15.0 (3)	–
Semi-autonomous parking assist	25.0 (8)	50.0 (16)	12.5 (4)	–
Voice control	43.0 (252)	37.4 (219)	10.1 (59)	income: p = .03
Average %	69.7	19.3	6.3	

[a] All statistical analyses were conducted using χ^2 tests separately for sex, age group, education, and income. Empty cells in the rightmost column indicate that there were no significant differences by any of the four demographic variables. Rows may not always add to 100% because of rounding and/or missing data.

with wide variability among the technologies. Blind spot warning, fatigue/drowsy driver alert, forward collision warning, and lane departure warning were all reported to be used either often or always by 79% or more of respondents. In-vehicle concierge, semi-autonomous parking assist, and voice control were reported to be used rarely or never by more than 60% of respondents. The remaining technologies had a range of frequencies of reported use. Use of adaptive cruise control, integrated Bluetooth cell phone, and navigation assistance varied significantly by sex, with women reporting less use than men. Use of integrated Bluetooth cell phone varied significantly by age group, with frequency of use decreasing with increasing age. Use of integrated Bluetooth cell phone and lane departure warning varied significantly by income level, with use generally increasing with income level.

The study also addressed perceptions of safety related to using in-vehicle technologies by asking respondents if the technology made them a safer driver. This question was not asked for emergency response or in-vehicle concierge because these systems would not be expected to reduce or prevent crashes. Results are shown in Table 6. Across all technologies, nearly 70% of respondents who had these technologies believed that they made them a safer driver. However, for two of the technologies, semi-autonomous parking assist and voice control, less than 50% of respondents reported that they made them feel safer. Safety perceptions for integrated Bluetooth cell phone varied by sex and age group, with reported safety decreasing with increasing age and being female. Reported feelings of safety for voice control varied by income with the middle income level ($50K–$79.9K) less likely to report that the technology made them a safer driver as compared to the other income levels. Perceptions of safety for adaptive cruise control, blind spot warning, and navigation assistance varied significantly by education level, with respondents more likely to report the technology contributing to safety as education level increased.

4.4. Technology-specific questions

In addition to the three general questions asked for most of the technologies, those respondents who indicated that they had certain technologies were also asked questions specific to the functionality of those technologies.

Adaptive cruise control: Respondents were asked if they had ever unintentionally collided with something when adaptive cruise control was being used. Five respondents (2.8%) indicated that they had, with four of these respondents being female ($\chi^2[2] = 8.71$, $p = 0.01$).

Adaptive headlights: Respondents who indicated that their primary vehicle had an adaptive headlights system were asked four follow-up questions on a 5-point scale: How easy is it to see lane lines on curved roads using low beams? How easy is it to read overhead road signs that are not lighted? How easy is it to see pedestrians on or near the road without street lights? How easy is it to see a roadway up a hill ahead when using low beams? Respondents were also asked to indicate their level of agreement with the following two statements on a 5-point scale: I feel less eye strain driving at night with the adaptive headlights system; and I can see better at night with the adaptive headlights system. In general, the majority of respondents reported that adaptive headlights made seeing things at night very or somewhat easy (Table 7, top panel). Respondents were somewhat neutral about the reduction in eye strain while using adaptive headlights, and about one-half agreed or strongly agreed that adaptive headlights helped them see better at night. Responses varied significantly by age group for seeing pedestrians at night, with the oldest age group giving lower ease-ratings as compared to the other two age groups. Responses also varied by income level for less eye strain and seeing better at night, although there was no discernable trend by income.

Backup/parking assist: Respondents who reported having a backup/parking assist system in their primary vehicle were asked: how easy it was to learn to use, how often the system helped them see oncoming traffic from behind, how well the system helped them avoid objects while backing up, and how well the system helped with parallel parking. All questions used a 5-point scale. The middle panel of Table 7 shows respondents' answers to these questions. About 70% reported that backup/parking assist was very easy to learn, about 41% reported that the system helped them a lot to see oncoming traffic and to parallel park, and 76% reported that backup/parking assist helped them a lot to avoid objects when backing up. Men reported significantly higher ratings for avoiding objects and parallel parking, and ratings increased with income level for parallel parking.

Cross traffic detection: Respondents who reported having a cross traffic detection system were asked three follow up questions: how easy was it to learn to use; how well did it help them see oncoming traffic from behind; and how well did it help them to avoid crashes. As shown in the bottom panel of Table 7, a very large majority found the cross traffic detection system easy to learn and thought that the system helped to see oncoming traffic from behind and avoid crashes. There were no differences by any of the demographic variables.

Emergency response: People who reported having this system were asked if they thought the system could help save their life in a crash. A large majority of respondents said yes (88.5%, n = 255), 4.2% (n = 12) said no, and the rest either reported they did not know or did not answer the question. There were no differences by any of the demographic variables.

Table 7
Respondent answers to various questions that were specific to three technologies.

Question	1 % (n)	2% (n)	3% (n)	4% (n)	5% (n)	χ^{2}[a] α (p)
	Adaptive headlight systems					
See lane lines?[b]	72.5 (79)	18.4 (20)	3.7 (4)	3.7 (4)	0 (0)	–
Read overhead signs?[b]	24.8 (27)	39.4 (43)	16.5 (18)	16.5 (18)	0.9 (1)	–
See pedestrians?[b]	31.2 (34)	39.4 (43)	12.8 (14)	12.8 (14)	0.9 (1)	age group: p = .03
See roadway up a hill?[b]	39.4 (43)	40.4 (44)	12.8 (14)	7.3 (8)	0 (0)	–
Less eye strain[c]	14.7 (16)	31.2 (34)	36.7 (40)	2.8 (3)	4.6 (5)	income: p = .005
See better at night[c]	21.1 (23)	35.8 (39)	30.3 (33)	5.5 (6)	1.8 (2)	income: p = .03
	Backup/parking assist systems					
Easy to learn?[b]	69.6 (834)	18.3 (219)	5.2 (63)	5.1 (61)	0.7 (8)	–
See oncoming traffic?[d]	41.0 (492)	7.3 (87)	10.5 (126)	5.0 (60)	31.9 (382)	–
Avoid objects?[d]	76.2 (914)	11.0 (132)	7.4 (89)	2.6 (31)	2.2 (27)	sex: p = .01
Parallel parking?[d]	41.8 (501)	15.5 (186)	13.8 (166)	4.0 (48)	15.7 (188)	sex: p = .02 income: p = .03
	Cross traffic detection systems					
Easy to learn?[b]	82.0 (146)	12.4 (22)	2.2 (4)	2.8 (5)	0 (0)	–
See traffic from behind?[d]	72.5 (129)	7.3 (13)	4.5 (8)	3.4 (6)	9.0 (16)	–
Avoid crashes?[d]	82.6 (147)	7.3 (13)	2.8 (5)	1.1 (2)	3.9 (7)	–

[a] All statistical analyses were conducted using χ^2 tests separately for sex, age group, education, and income. Empty cells in the rightmost column indicate that there were no significant differences by any of the four demographic variables. Rows may not always add to 100% because of rounding and/or missing data.
[b] Scale: 1 = very easy; 5 = very difficult.
[c] Scale: 1 = strongly agree; 5 = strongly disagree.
[d] Scale: 1 = a lot; 5 = not at all.

In-vehicle concierge: Respondents with this technology in their vehicles were asked if the system improved their driving experience and 40.1% (n = 126) responded yes, while 45.2% (n = 142) responded no. The rest either reported that they did not know or did not answer the question. There were no differences by any of the demographic variables of interest.

4.5. Aftermarket vehicle adaptations

Respondents were asked about the presence of several aftermarket adaptations. Overall, 8.96% (n = 268) had at least one vehicle adaptation present, with the number of adaptations per vehicle ranging from 0 to 4 (mean = 0.9 ± 0.34). In order of frequency, the percentages of aftermarket vehicle adaptations among those who reported at least one adaptation were: driver seat cushions (44.8%, n = 120); convex and/or multifaceted mirrors (38.8%, n = 104); safety belt extensions (6.0%, n = 16); upper body support (4.8%, n = 13); aftermarket push button ignition (3.0%, n = 8); steering wheel modification (2.6%, n = 7); custom armrests (1.1%, n = 3); pedal extensions (1.1%, n = 3); hand controls (0.4%, n = 1); left foot throttle (0.4%, n = 1); gas pedal block (0%); and modified controls for wiper, horn, turn signal, cruise control, or headlights (0%). There were no statistically significant differences in these percentages by any of the demographic variables of interest.

For those who reported aftermarket vehicle modifications, three follow-up questions were asked about the respondent's use of a professional in making the modifications. Because seat cushions do not require a professional's input for installing or training for use, we excluded respondents who reported only seat cushions (n = 120) in our analyses of the follow up questions. The questionnaire included an item about whether the respondent worked with a professional to determine the appropriateness of the modification and 87.5% (n = 105) of respondents reported."no." Respondents overwhelmingly reported (95.0%, n = 114) that they did not have the modification made by a professional installer. When asked how they primarily learned to use the modification, 82.5% (n = 99) reported that they taught themselves, with several methods being reported at percentages of less than 5% (occupational therapist, professional installer, manual, Internet, chiropractor, friend, and yoga instructor). There were no differences by any of the demographic variables.

5. Discussion and conclusions

This descriptive study examined in-vehicle technology use and aftermarket vehicle adaptations among a large cohort of older drivers participating in the LongROAD project. The study found that advanced in-vehicle technologies were present in nearly 60% of vehicles driven by LongROAD participants. In order of greatest prevalence, the five most commonly reported technologies were: integrated Bluetooth cell phone, backup/parking assist, navigation assistance, voice control, and blind spot warning. Those with higher income and education levels were more likely to report technologies. This result was not surprising in that the majority of the technologies investigated in this study are available on vehicles at additional cost. Given that education and income levels are highly correlated, those with higher incomes would have more disposable income to purchase vehicles that included advanced technologies and to purchase newer vehicles that may have some of these technologies as standard. Prevalence was also related to being male and not significantly related to age group. These results are in partial agreement with previous research (Jenness et al. 2007, 2008a,b,c) that reported a higher prevalence of five advanced vehicle technologies (high intensity discharge headlights, navigation assistance, adaptive cruise control, backup/parking assist, and rear-view cameras) for men age 65 and older as compared to women in this age group. Prevalence analysis by sex and technology in the current study showed that there were no significant differences by sex in the prevalence of navigation assistance, adaptive cruise control, or backup/parking assist technologies, but differences by sex were found for four other technologies (adaptive headlights, emergency response, in-vehicle concierge, and voice control). Inconsistent results by sex have been found for adoption of other non-driving-related technologies (see e.g., Goswami and Dutta, 2016). Thus, it is not clear without further research what factors might account for this outcome. Finally, prevalence was not related to age group. Although no analyses were conducted between the two older age groups in the Jeness et al. studies (65–74, 75 and older), their results showed little and inconsistent differences in the numbers of older driver respondents reporting having advanced technologies in their vehicle by age group.

The study further examined how older drivers learned to use advanced in-vehicle technologies for the 12 systems that required learning for use. Across these technologies, nearly one-half of older drivers reported that they figured out by themselves how to use the systems, with another 20% reporting that the dealer showed them, 13% reporting that they never learned to use the systems, and only 0.1% reporting that they used the Internet. These results are consistent with other studies. For example, research conducted by the Insurance Institute for Highway Safety, Braitman et al. (2010), Eichelberger and McCartt (2014), found that up to 30% of people whose vehicle had certain technologies reported not knowing that those technologies were present, which suggests that they never received any instruction about how to use the technologies. A summary of several studies sponsored by the AAA Foundation for Traffic Safety (AAAFTS, 2008) found that up to one-half of older adults reported they learned to use in-vehicle technologies through trial-and-error, up to 75% used the owner's manual, and up to 60% learned from the dealer. As stated by several researchers (Coughlin, 2009; Eby and Molnar, 2014; Eby et al., 2015; Reimer, 2014), there is a need for research to better understand the effectiveness of the available strategies and to develop better approaches for teaching older adult drivers (and all drivers) about the capabilities and use of advanced, in-vehicle technologies. One particular approach is to make better use of the Internet, not only by providing additional information to drivers but also by better advertising the sources that are currently available, such as, *Smart Features for Older Drivers* (AAA, 2017) and *My Car Does What* (National Safety Council, 2017). The promotion of these and other resources for older adults will also contribute to reducing the age disparity in access to and utilization of the Internet for improved health and well-being (Perrin and Duggan, 2015; Manganello et al., 2016). Another approach to helping older drivers effectively use advanced technologies might be to promote development of natural systems which improve safety without requiring substantial education of the driver, such as intuitive user interfaces (see e.g., Baerentsen, 2000; Hurtienne and Blessing, 2007). Results from this study also suggest that special efforts should be targeted at women, who were more likely to report never having learned how to use these technologies.

This study addressed how frequently LongROAD participants used technologies. Across all of the technologies studied, more than one-half were always or often used. The most frequently used technologies were blind spot warning, fatigue/drowsy driver alert, and forward collision warning systems. Four technologies by self-report were rarely or never used among 40% or more of LongROAD participants. In order of least frequent use, these technologies were: semi-autonomous parking assist, in-vehicle concierge, voice control, and adaptive cruise control. In general, the high use of most of the technologies is not surprising. One reason for the high use of these technologies is that many manufacturers design these systems to automatically be activated when a vehicle is turned on. Also, as previously discussed, many of the technologies examined in the study are optional at an additional cost and it is reasonable to assume that people would tend to use technologies for which they paid. With the exception of voice control, infrequently used technologies were found in few vehicles. Further research is needed to understand why these technologies are seldom used. The relatively infrequent use of voice control systems is of concern. One explanation for this outcome is that voice control systems are difficult to learn. As stated by Eby et al. (2015), pp 37: "As the number and complexity of advanced in-vehicle systems continue to grow, there will be a need to make interfacing with these systems as intuitive and simple as possible. Voice control systems are a promising method for making interactions with in-vehicle …technologies easier and safer." The present study showed that participants reported a wider range of primary ways for learning how to use voice control systems than the other technologies, suggesting that there may not be a."bes." method for teaching drivers to use voice control systems. It should be noted that the study was not designed to address when and how technologies were used nor did the study address specific design features that might vary among different manufacturers of the same types of technology (such as whether or not the system defaulted to on or off when the vehicle was started). Such information would further our understanding of advanced technology use among older drivers and should be the focus of future research.

In addition, this study investigated perceptions of being a safer driver when using in-vehicle technologies. Averaged across the 13 technologies for which this topic was addressed, about 70% of respondents reported that using the technology made them a safer driver and 19% said the technologies did not make them a safer driver. The five technologies with the highest percentages of people responding "yes" were: navigation assistance, blind spot warning, lane departure warning, forward collision warning, and backup/parking assist, all of which had 84% or more of respondents reporting that the technology made them a safer driver. The two technologies with the lowest safety perceptions were semi-autonomous parking assist and voice control. It can be argued that although semi-autonomous parking assist can help prevent crashes during parallel parking maneuvers, this system is more likely to be considered a system that makes driving (parking) easier rather than safer. On the other hand, voice control systems can have significant safety benefits as compared to manual controls (see e.g., Itoh et al., 2004; Jenness et al., 2002; Maciej and Vollrath, 2009) so the lack of perceived safety with this technology is of concern. It is likely that one factor underlying the safety perception outcome for this technology is related to difficulties in learning to use the system, but other factors, such as perceptual (e.g., hearing difficulties) or cognitive declines (e.g., declining short-term memory), may also play a role.

Finally, addressing aftermarket vehicle adaptations, the study found that less than 9% of participants had made them. Of those vehicles with adaptations, 45% had seat cushions, which are primarily for driving comfort rather than safety. Because of the lack of studies on this topic, it is unknown how this prevalence compares to other populations. However, given that the questionnaire was completed at enrollment and that the study inclusion criteria likely excluded older drivers with significant disabilities, this low prevalence is not surprising. Future papers on the LongROAD study will analyze the presence of vehicle adaptations in relation to functional declines. For respondents who reported vehicle adaptations other than a seat cushion, we analyzed data on how the modification was made and how the participants were trained to use it. Overwhelmingly, respondents did not work with professionals to determine the appropriateness of adaptations or to install/make the adaptations, but rather learned on their own how to use the adaptations. These results show that, at least among the LongROAD participants, older drivers are not following the NHTSA (2007) recommendation to work with occupational therapists who are trained in driver rehabilitation and with other practitioners to make appropriate vehicle adaptations that can help overcome the specific declines being experienced by drivers. Collectively, these results show that there is a need to develop materials and programs promoting awareness of the types of vehicle modifications that are available, as well as the need to utilize professionals for the installation of and training about vehicle adaptations. Further, as stated by other researchers (Dickerson et al., 2007; Silverstein et al., 2005), there is also a need to increase awareness among traffic safety professionals about how vehicle adaptations can help maintain safe driving among older adults. These results add to the sparse literature on the prevalence and use of aftermarket vehicle adaptations among older drivers.

The strengths of this study include: the use of a large sample of older drivers who were recruited at five distinct geographic locations in the US, examination of a wide range of technologies and vehicle adaptations, and the development of the questionnaire that utilized, where possible, items from previously published research. Limitations include the use of self-reported survey data which come with unavoidable reporting biases and potential problems with recall. Data on the self-reported use of technologies may be influenced by some of the drivers not being aware that certain technologies (e.g., forward collision warning systems) are operating in their vehicle unless they have had a situation where the system was activated. Without further information we cannot assess how this might influence results and, therefore, the technology use results should be interpreted with caution. The study also did not address several aspects of technology use that might help explain the results including perceived accuracy and reliability, detailed circumstances for use, and unique design features for technologies. Finally, the LongROAD cohort is relatively well-educated with high incomes and, therefore, not representative of all older adult drivers. As such, these results may not generalize to all older driver populations.

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