Age-Related Differences in the Cognitive, Visual and Temporal Demands of In-Vehicle Information Systems

July 2019

607 14th Street, NW, Suite 201 | Washington, DC 20005 | 202-638-5944

AAA Foundation for Traffic Safety

Title

Age-Related Differences in the Cognitive, Visual and Temporal Demands of In-Vehicle Information Systems

(July 2019)

Authors

Joel M. Cooper, Camille L. Wheatley, Madeleine M. McCarty, Conner J. Motzkus, Clara L. Lopes, Gus G. Erickson, Brian R. W. Baucom and David L. Strayer

University of Utah

Foreword

Globally, the number and proportion of older drivers is on the rise. At the same time, there has been an expansion of new infotainment and In-Vehicle Information Systems (IVIS) into vehicles in recent years. While these systems have afforded drivers new activities and connectivity, there are potential safety concerns. Moreover, it is important to understand how these new technologies impact older drivers' workload and performance.

Recent work sponsored by the AAA Foundation for Traffic Safety led to the development of new methods for measuring the visual and cognitive demands associated with different in-vehicle systems. This report expands on these earlier efforts, describing the results of an on-road study looking at the visual and cognitive demands associated with a variety of infotainment tasks and interaction methods in samples of younger and older drivers. This report and its outcomes should be an interesting and useful reference for OEMs, developers of advanced IVIS, public agencies and researchers, as well as the general driving population.

C. Y. David Yang, Ph.D.

Executive Director
AAA Foundation for Traffic Safety

About the Sponsor

AAA Foundation for Traffic Safety
607 14th Street, NW, Suite 201
Washington, D.C. 20005
202-638-5944
www.aaafoundation.org

Founded in 1947, the AAA Foundation for Traffic Safety in Washington, D.C., is a nonprofit, publicly supported charitable research and education organization dedicated to saving lives by preventing traffic crashes and reducing injuries when crashes occur. Funding for this report was provided by voluntary contributions from AAA/CAA and their affiliated motor clubs, individual members, AAA-affiliated insurance companies, and other organizations or sources.

Table of Contents

List of Figures

List of Tables

Terms and Definitions[1]

Center Console	The center console is located between the driver and passenger front seats. Examples of center console interactions include a rotary dial that allows drivers to scroll through menu items and a touch sensitive pad where drivers use their finger to write out commands. The center console is one of the three modes of interaction that were evaluated in this research.
Center Stack	The center stack is in the center of the dash to the right of the driver. An LCD display is used to present textual and/or graphical information. Center stack systems often include a touch-screen interface to support visual/manual interactions so that drivers can select an option and navigate menus by touch and/or use slider bars to scroll through options displayed on the screen. With some vehicles, the selection of options may be made with manual buttons surrounding the touch screen. The center stack is one of the three modes of interaction evaluated in this research.
Cognitive Demand	The cognitive workload associated with the performance of a task. This would include perception, attention, memory and decision-making processes. In this report, we refer to the cognitive demand associated with performing IVIS task types with different modes of interaction when the vehicle is in motion.
Cognitive Reference Task	The N-back task (see below) served as the cognitive reference task in the current research.
Distraction Potential	The potential distraction associated with secondary-task engagement. This potential may not be realized if drivers regulate their secondary-task interactions to periods when the vehicle is not in motion.
Driver Distraction	The diversion of attention away from activities critical for safe driving toward a competing activity, which may result in insufficient or no attention to activities critical for safe driving.
Detection Response Task (DRT)	The DRT is an International Standards Organization protocol (ISO 17488, 2015) for measuring attentional effects of cognitive demand in driving. In this research, a vibrotactile device emitted a small vibration stimulus, similar to a vibrating cellphone or an LED light stimulus changing color from orange to red. These changes cued the participant to respond as quickly as possible by pressing the microswitch attached to a finger against the steering wheel. DRT reaction time increases and hit rate decreases as the workload of the driver increases.

[1] Some of these terms, definitions and abbreviations were taken directly from ISO/TS 14198 (ISO, 2012); Regan, Hallett and Gordon (2011); and NHTSA (2013).

In-Vehicle Information System (IVIS)	The collection of features and functions in vehicles that allow motorists to complete tasks unrelated to driving while operating the vehicle. In this report, the terms IVIS and system are used interchangeably. The IVIS features we tested involved up to four task types (see below) and up to three modes of interaction (see below).
Linear Mixed Effects Model	We compared the likelihood ratio of the full linear mixed effects model to a partial linear mixed effects model without the effect (e.g., Age, Task Type, Mode of Interaction, Vehicle, Age by Task Type, Age by Mode of Interaction) to determine if the effect in question accounted for a significant proportion of variance.
Modes of Interaction	The way a user interacts with an IVIS to perform a task. Modes of Interaction were categorized into three types: voice commands, center stack and center console. In this report, mode and mode of interaction are used interchangeably.
N-back Task	The N-back task presented a prerecorded series of numbers ranging from 0 to 9 at a rate of one digit every 2.25 seconds. Participants were instructed to say out loud the number that was presented two trials earlier in the sequence. The N-back task places a high level of cognitive demand on the driver without imposing any visual/manual demands and was used as a high workload reference task.
Primary Driving Task	Activities that the driver must undertake while driving, including navigating, path following, maneuvering and avoiding obstacles.
Reference Task	A task used for the purpose of comparing different tests or test results across vehicles or systems.
Single-Task Baseline	When the driver is performing the primary driving task (i.e., driving) without the addition of workload imposed by IVIS interactions.
SuRT Task	The variant of the Surrogate Reference Task (SuRT, ISO TS 14198) used in this report required participants to use their finger to touch the location of target items (larger circles) presented in a field of distractors (smaller circles) on an iPad mini tablet computer that was mounted in a similar position in all the vehicles. The SuRT task places a high level of visual/manual demand on the drivers because they must look at and touch the display to perform the task. The SuRT task served as a reference for the visual/manual demands associated with performing IVIS interactions.
Task Completion Time	The time to complete a task. Task completion time was defined as the time from the moment participants first initiated an action to the time when that action had terminated, and the participant said, "done." When assessed using the visual occlusion methodology, the NHTSA guidelines provide an implicit upper limit of 24 seconds of total task time. While originally intended for visual/manual tasks, these guidelines provide a reasonable upper limit for task durations of any mode or task type.

Task Type	Tasks were categorized into one of four Task Types: audio entertainment, calling and dialing, text messaging, and navigation, depending on vehicle capabilities. These task types were completed via different modes equipped in each vehicle for each interaction.
Visual Demand	The visual workload associated with the performance of a task. This would include the structural interference associated with taking the eyes off the forward roadway as well as the central interference in visual processing that arises from cognitive demand. In this report, we refer to the visual demand associated with performing IVIS tasks with different modes of interaction when the vehicle is in motion.
Visual Reference Task	A variant of the SuRT task (see above) served as the visual reference task in the current research.
Voice Commands	The voice commands method in which users communicate with the IVIS via voice recognition and structured commands. Voice commands are aimed toward hands-free interactions but may incorporate some visual manual interactions such as using steering wheel controls for activation. Voice commands are one of the three modes of interaction evaluated in this research.

Abbreviated Terms

DRT	Detection Response Task
HMI	Human-Machine Interface
IRB	Institutional Review Board
ISO	International Organization for Standardization
IVIS	In-Vehicle Information System
LCD	Liquid-Crystal Display
LED	Light-Emitting Diode
NHTSA	National Highway Traffic Safety Administration
OEM	Original Equipment Manufacturer
PFC	Prefrontal Cortex
SuRT	Surrogate Reference Task
USB	Universal Serial Bus

Executive Summary

Many of the challenges faced by older drivers stem from the natural decline in cognitive and physical abilities associated with aging. Critical processes such as reaction time, memory, reasoning and spatial orientation may all be affected. In-vehicle information systems (IVIS) refer to a collection of features and functions in vehicles that allow motorists to complete tasks (often unrelated to driving) while operating the vehicle. Though these systems have the potential to increase mobility of drivers, their complexity may place undue demand on both older and younger drivers. In particular, in-vehicle information systems (IVIS) may interfere, to a greater extent, with older drivers' ability to attend to the visual and cognitive demands of the driving environment. Importantly, the extent of the interference could be exacerbated depending on the type of interface and mode of interaction.

The current study sought to examine age-related differences in the visual, cognitive and temporal demands associated with IVIS interactions. Older and younger drivers completed a set of common tasks using the IVIS of six different vehicles while they drove along a low-density residential street. Evaluation measures included a Detection Response Task (DRT), to assess both cognitive and visual attention; subjective measures following each condition using the NASA Task Load Index (TLX) and video footage of the driving environment during data collection. Two age cohorts were evaluated: younger drivers, between 21-36 years of age, and older drivers, between 55-75 years of age. Participants completed experimental tasks involving interactions with the IVIS to achieve a specific goal (i.e., using the touch screen to tune the radio to a station; using voice commands to find a specified navigation destination, etc.). Tasks performed while driving were the following: audio entertainment, calling and dialing, text messaging, and navigation. Performance of these tasks was also varied according to different modes of interaction available in the vehicles: center stack, center console and voice commands.

As noted, cognitive demand, visual attention, subjective workload and task completion time were assessed. Participants also provided open-ended responses regarding their experiences with the systems. Participant comments were coded using an inductive thematic analysis. These comments captured the similarities and differences in task types and driving experiences between the age cohorts.

In general, older drivers took longer to complete tasks, were slower to react to stimuli and reported higher task demand when interacting with IVIS. Results from older drivers' comments and performance across task types indicate that new IVIS interfaces may be especially demanding for older drivers. Our analysis shows that drivers' comments could help with design requirements for future interfaces and help to maximize driver attention to the roadway. A well-designed IVIS could support older and younger drivers' attention and positively impact their driving performance. Older drivers stand to benefit the most from these advancements of in-vehicle technology but ironically may struggle the most to use them. Ultimately, the results of this study suggest significant age-related costs in the distraction potential of IVIS on the road. By making the driving environment easier and safer for older adults, all drivers on the road may benefit.

Introduction

Operating an automobile is one of the riskiest activities that adults engage in on a regular basis. In fact, motor vehicle crashes are one of the leading causes of unintentional injury and death in the United States (NSC, 2017) and a significant percentage of crashes involve some form of distraction or inattention (e.g., Dingus et al., 2016). To safely operate a motor vehicle, drivers must maintain their eyes on the forward roadway and keep their mind focused on the drive. This becomes increasingly difficult with the prevalence of in-vehicle electronics. These systems change the way that drivers manage their attention behind the wheel, potentially leading to increases in driver distraction — especially as systems provide more information, functions and features to drivers.

Driver interactions with current and emerging in-vehicle information systems (IVIS) are characterized by complex visual-manual and auditory-vocal action sequences. Tasks such as entering a destination into a GPS system can require several steps. For example, a driver may initiate a destination entry sequence with the press of a button on the steering wheel, followed by a verbal address entry and ending with the use of the touch screen. Led by Strayer and Cooper, researchers at the University of Utah have completed a series of systematic research projects to better understand driver distraction arising from commonly performed in-vehicle tasks (Strayer et al., 2013; 2014; 2017; 2018; Cooper et al., 2014).

Recent work has led to the development of a multimodal evaluation technique that assesses the cognitive, visual and time demands of these complex interactions with IVIS (see Strayer et al., 2017). Overall, results from this effort suggest a large variation in the distraction potential of different IVIS systems across Vehicle Type, Tasks Types (e.g., programming navigation; text messaging), and Modes of Interaction (e.g., center stack touch screen; voice commands).

Importantly, new in-vehicle systems and related tasks may be especially problematic for older drivers (Albert et al., 2018). Ongoing research seeks to understand how the aging process impacts multitasking among older drivers (Clapp et al., 2011) and the technology barriers they encounter (Vaportzis et al., 2017). However, little is known about the way in which senior drivers interact with multimodal In-Vehicle Information Systems (IVIS). These technologies have the potential to prolong safe and enjoyable driving for older adults. If they are not carefully implemented, however, they will decrease attention to the road.

Many of the challenges faced by older drivers stem from the natural decline in cognitive and physical abilities associated with senescence. Much of the existing research related to older drivers focuses on the relationship between age-related co-morbidities and on-road safety risks (e.g., Albert et al., 2018; Cummings et al., 2007; Huisingh et al., 2018; Kelley-Baker et al., 2017). Aging is associated with declines in psychomotor performance that can affect safe driving. These include range-of-motion restriction, which may limit visual scanning in the periphery for potential hazards (Swinkels & Swinkels-Meewisse, 2014), and reduced visual acuity, which can lead to lower quality information sampling (Owsley 2010). Increased glare sensitivity and reduced light sensitivity are also more prevalent in older populations (Wood et al., 2009). Other progressive neurological diseases such as mild cognitive impairment, Parkinson's or Alzheimer's/dementia may present with symptoms that could negatively impact driving ability (e.g., Breen et al., 2007; Ott et al., 2008; Ott & Daiello, 2010). Critical processes such as perception, memory, reasoning and spatial orientation may all be affected.

As visual health declines, the quality of information transmitted to the visual cortex is degraded. Coupled with neurological impairments, many older drivers experience a reduction in overall visual attention (Bédard et al., 2006; Brouwer et al., 1991; Thompson et al., 2012). In practice, this might contribute to the increased crash risk experienced by older drivers (Chandraratna & Stamatiadis, 2003; Bellet et al., 2018), especially for aspects of driving that demand high-level visual processing such as making a left turn across traffic and driving in low-light conditions (Barhorst-Cates et al., 2016; 2017).

Completing IVIS tasks requires that the driver extract actionable information from an electronic display, while integrating environmental driving information through quick shifts in visual attention. These behaviors are supported by physical and cognitive mechanisms that are affected by the aging process (Clapp et al., 2011).

Watson et al. (2011) suggested that the latter half of the U-shaped function depicting crash rates and age is closely aligned with the decline in prefrontal cortical (PFC) regions of the brain (e.g., an inverted U-shaped function across the life span that reaches apex around 30 years of age). The PFC regions are involved in a wide variety of higher-level cognitive functions that support driving-related attention (e.g., lane position, speed management, relation to other vehicles, status of traffic lights, acceptable gap for making a left-hand turn, etc.). Drivers must also juggle other task-irrelevant interactions (e.g., interacting with digital voice assistant or the center-stack display). The added requirement of IVIS interactions increases the perceptual workload of drivers (e.g., Strayer et al., 2003). Strayer et al. (2015) have also shown that older drivers experienced greater cognitive demand than younger drivers when using voice to control IVIS systems. Consistent with these findings, multiple studies have found age-related declines in dual-task processing (e.g., Craik, 1977; Hartley, 1992; Hartley & Little, 1999; Kramer & Larish, 1996; McDowd & Shaw, 2000).

Current Research

This study examined measures of visual and cognitive workload among younger and older drivers as they performed specified tasks on In-Vehicle Information Systems (IVIS) while driving a vehicle on a fixed route. Workload measures were compared across two age groups and six different vehicles with different IVIS. Thus, the current research aims to address a set of questions related to older drivers and their use of modern IVIS, including a variety of task types and modes of interactions. Specifically:

Q1: Do IVIS interaction demands differ for older and younger drivers? If so, how?

Prior research has demonstrated that senescence is associated with physical and cognitive performance declines that can impact safe driving. When older drivers interact with IVIS, they may be more likely to experience cognitive, visual or temporal interference. Furthermore, some types of IVIS interactions may present unique demands on older drivers.

Q2: Are some interfaces more difficult for older drivers to use? If so, why?

Research on IVIS voice interactions has found that older drivers experience higher cognitive demands when completing common tasks (e.g., Strayer et al., 2015). It is not clear, however, whether workload differences exist between older and younger drivers when completing tasks using controls housed in the center stack or when using center console controls. Some of the ways in which older and younger drivers interact with IVIS may change the level of demand that they experience.

Method

Participants

One hundred and twenty-eight participants (52 female) were recruited via flyers, social media posts and local newsprint advertising with approval from the University of Utah Institutional Review Board (IRB). Eligible participants were native English speakers, had normal or corrected-to-normal vision, and held a valid driver's license. Participants were also required to have proof of medical insurance and no accident involvement within the past two years. To ensure participants held a clean driving record, a Motor Vehicle Record report was obtained by the University of Utah's Division of Risk Management.

All participants belonged to one of two age cohorts: younger drivers, between 21-36 years of age (M = 24.8 years, St Dev = 2.97), and older drivers, between 55-75 years of age (M = 65.8 years, St Dev = 5.36). Following University of Utah policy, participants were required to take and pass a 20-minute online defensive driving course and certification test. Compensation was prorated at $20 per hour.

Twenty-four individuals from each age cohort were tested in six unique vehicles, resulting in 48 participants per vehicle (i.e., each cell in the factorial design had 24 participants). The study design allowed participants to drive all six vehicles; however, this was not always possible. Participants were sample-matched by age and number of driving sessions in each of the evaluated vehicles; this was done to ensure that each age cohort was comprised of similar numbers of naïve and repeat participants for the vehicle. The number of exposures was matched across vehicles and age cohorts as closely as possible; however, due to factors such as order of testing and availability of participants, exact matching was not possible. Thus, a planned missing data design was used (e.g., Graham et al., 2006; Little & Rhemtulla, 2013) as only eight individuals drove all six vehicles. Among the younger age cohort, 20 participants drove one vehicle, 16 drove two, 11 drove three, 7 drove four, 2 drove five and 4 drove six. Among the older age cohort, 28 participants drove one vehicle, 14 drove two, 10 drive three, 3 drove four, 6 drove five and 4 drove six. Participants were initially naïve to the specific systems and tasks but were trained until they felt competent and confident performing each type of task while driving.

Stimuli and Apparatus

Vehicles

The vehicles that were used for the study are listed below with the native infotainment system for each shown in parentheses. These cars were selected for inclusion in the study based on market diversity, availability and IVIS functionality. Vehicles were acquired through Enterprise Rent-A-Car or purchased for testing.

- 2018 Audi A6 Premium (Man and Machine Intersect or MMI)
- 2018 Cadillac CT6 Premium Luxury (Custom User Experience or CUE)
- 2018 Lincoln Navigator Select L (SYNC 3)
- 2018 Mazda CX-5 Grand Touring (Mazda Connect)
- 2018 Nissan Pathfinder SL (NissanConnect)
- 2018 Volvo XC90 Momentum – Custom Packages (Sensus Connect)

Equipment

Identical Google Pixel 2 phones on the T-Mobile network were Bluetooth-paired with each vehicle. An iPad mini 4 (20.1 cm diagonal LED-backlit Multi-Touch display) was used to administer a visual-manual reference task (detailed below) and to survey participants on their self-reported measures of workload.

Acer Swift and Dell laptop computers were utilized for data collection in the vehicle. Each vehicle was also equipped with two Garmin VirbXE action cameras, one mounted under the rear-view mirror to capture footage of participants' faces, and an additional camera mounted near the passenger seat shoulder to provide a view of the dash area for infotainment interaction and the forward roadway. Video was recorded at 30 frames per second at 720p resolution.

Task Types and Modes of Interaction

Vehicles were selected for their comprehensive IVIS functionality. Each vehicle utilizes a variety of functions that facilitate interaction with the system such as touch screens, physical buttons, voice commands, touch/trackpads and rotary wheels. Features were grouped into three Modes of Interaction: voice commands, center console and center stack. IVIS functions were grouped into four Task Types: audio entertainment, calling and dialing, text messaging and navigation entry.

Participants completed tasks involving interactions with the IVIS to achieve a goal (i.e., using the touch screen to tune the radio to a station, using voice commands to find a specified navigation destination, etc.) while driving. Tasks were categorized into four Task Types and three Modes of Interaction.

Following Strayer et al. (2017), the possible task types performed by the participant were:

- *Audio Entertainment*: Participants tuned the radio to specific AM and FM frequencies and selected music from a USB connected iPad mini, using designated categories such as song titles, music genres, artist names and album titles.
- *Calling and Dialing*: A list of 91 contacts with a mobile and/or work number was created for participant testing. Participants were instructed to call designated contacts and the associated number type was specified when applicable. In vehicles capable of dialing phone numbers, participants were instructed to dial the phone number 801-555-1234 as well as their own phone number.
- *Text Messaging*: Participants were provided with hypothetical scenarios in which they received text messages from various contacts and were instructed to interact with the messages using specified modes of interaction. Vehicles varied in their SMS capabilities. A portion of the system/mode of interaction combinations allowed users to listen to messages and reply with predetermined responses, or solely listen to the messages and not respond. Other vehicles and modes of interaction allowed users to respond to text messages using free dictation. Differences between system capabilities for text messaging are outlined in Appendix 1.
- *Navigation Entry*: Participants started and canceled route guidance to different locations based on a hypothetical situation they were given that differed slightly according to the options available in each system.

The Modes of Interaction with each system are described below. Interaction modalities were selected based on compatibility with the specific tasks and systems.

- *Center Stack*: Visual-manual tasks were performed using the center stack interfaces found in the middle of the dash to the right of the driver. Center stack systems generally include a touch screen to integrate visual/manual interactions so that drivers can select options and navigate menus via touch, scroll bars, seek arrows, etc., to complete tasks using options displayed on the screen. Some vehicles provide physical buttons near the touch screen for selection of options.
- *Center Console*: Vehicles utilizing center console controls replace or augment a touch-screen interface or manual center stack controls with an interface, usually consisting of a rotary wheel and manual buttons in the center console to the right of the driver. The center console controls facilitate interactions with the center stack display located in the middle of the dash. The rotary can be spun to scroll through menus and used like a button to make selections. In some cases, the rotary wheel interfaces can be maneuvered in various directions to navigate menus, like a joystick. In the case of the Audi A6, the center console controls also incorporated a touch-sensitive pad that could be used to draw letters and numbers in search functions or select preset radio stations.
- *Auditory Vocal*: The voice-based interaction with each IVIS system is initiated by the press of a physical voice recognition button on the steering wheel. Microphones installed in the vehicle process the driver's verbal commands and assist them while performing tasks in the vehicle. Possible voice command options may be presented audibly or displayed on the vehicle's center stack or instrument cluster to assist users in achieving their goal.

The configuration of Task Types and Modes of Interaction depended on each system's unique capabilities. All vehicles supported voice commands; however, each vehicle differed on visual/manual interaction (e.g., touch screen, manual buttons, center console controls). Furthermore, different systems required specific syntax or commands to be given in a systematic order to accomplish tasks in different interaction modes. Task lists were developed to test the various combinations of features and functions available in each system. Tasks were standardized across systems as much as possible, given the variability in system interactions. The tasks supported for each vehicle system are noted in Table 1 and described in detail in Appendix 1.

Table 1. Modes of Interaction and Tasks Types for the six different vehicles.

Vehicle	Audi A6		Cadillac CT6		Lincoln Navigator		Mazda CX-5		Nissan Pathfinder		Volvo XC90	
Mode of Interaction	CS	VC	CC	VC	CS	VC	CC	VC	CS	VC	CS	VC
Audio Entertainment	A	A	A	A	A	A	A	A	A	A	A	A
Calling and Dialing	B	B	B	B	B	B	B	B	C	B	B	B
Navigation	D	D	D	D	E	D	F	F	G	D	D	D
Text Messaging	H	H	I	-	J	J, K	H	H	H	H	-	H

Note. Mode of interaction: CS = center stack; VC = voice commands, CC = center console. Letters (A-K) refer to specific task instructions described in Appendix 1; letters are mapped to a specific vehicle and mode of interaction (e.g., Task A, for audio entertainment, was used for all vehicle and mode combinations). Empty cells represent tasks that were not available for that vehicle/mode of interaction. Cells with multiple letters indicate that the task could be performed in different ways; each was tested separately.

Detection Response Task (DRT)

Participants were trained to respond to both a vibrotactile stimulus and a remote visual stimulus (cf. ISO, 2015). A vibrotactile stimulus was positioned under the participant's left collarbone, and a remote LED light was placed along a strip of Velcro on the dashboard in such a manner that the participants only saw the reflection of the light as it changed from orange to red in the windshield directly in the forward line of sight (see Castro, Cooper, & Strayer 2016; Cooper et al., 2016). This variant of the standard DRT was used to maximize sensitivity to both cognitive and visual attention. Reaction time to the vibrotactile stimulus was used to assess cognitive workload while hit rate to the forward LED was used as a measure of competing visual demand.

A microswitch (i.e., small button) was attached to either the index or middle finger of the left hand and pressed against the steering wheel by participants when they felt a vibration or saw the light change colors. Each press of the switch was counted and recorded but only the first response was used to determine response time to the stimulus. Millisecond resolution response time to the vibrotactile onset or LED light was recorded using a dedicated microprocessor that passed results over USB connection to the host computer for storage and later analysis.

Following ISO-17488 (ISO, 2015), the vibrotactile device emitted a small vibration stimulus, like a vibrating cellphone. Uniquely, the remote light stimulus consisted of a change in color from orange to red. This color changing LED stimulus differed from the ISO standard (see Castro et al., 2016). The occurrences of these stimuli cued the participant to respond as quickly as possible by pressing the microswitch against the steering wheel. The tactile and light stimuli were equally probably and were programmed to occur every three to five seconds (with a rectangular distribution of inter-stimulus intervals within that range) and lasted for one second or until the participant pressed the microswitch.

Procedure

Driving Route

A suburban residential street with a 25-mph speed limit was used for the on-road driving study (Strayer et al., 2017). The route consisted of a straight road with four stop signs and two speed bumps. Participants were required to follow all traffic laws and adhere to the 25-mph speed limit. The driving route was approximately two miles long one-way with an average drive time of six minutes. A researcher was present in the passenger seat of each vehicle for safety monitoring and data collection. An image of the driving route can be seen in Figure 1.

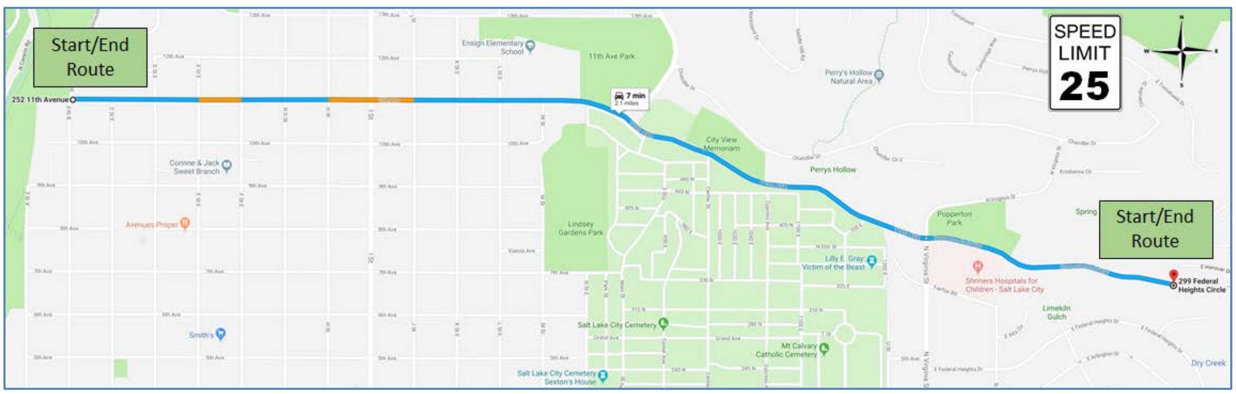

Figure 1. A map image of the designated driving route, a two-mile-long residential roadway in Salt Lake City, Utah.

Training

Prior to the start of the study, participants were provided the time to become accustomed to the vehicle, the route and the DRT. The initial familiarization period is as follows:

- DRT training: Participants were instructed on how to respond to the light and vibration motor using the microswitch. Researchers monitored participants as they practiced responding to 10 stimuli to ensure participants produced response times of less than 500 milliseconds, indicating a competence and understanding of the task. After initial trainings, participants were given the opportunity to practice responding to the DRT while driving during the practice drive described below.
- Practice route: Prior to data collection, participants were instructed to drive the route seen in Figure 1. Researchers pointed out all obvious and identifiable road hazards. This practice drive allowed participants to familiarize themselves with the road as well as the handling of the vehicles.

Participants were trained to interact with and complete tasks using the assigned mode of interaction before each condition began. Participants were required to complete three task trials without error and while simultaneously responding to the DRT prior to starting the driving task for each of the system interactions. Additional practice was provided if participants were not confident in their abilities to interact with the system and required more training or practice. Once participants demonstrated competence in their ability to interact with the system, the experimental run began.

Experimental Blocks

During the experimental blocks, participants were instructed to complete a set of tasks administered by the researcher using an assigned mode of interaction with the infotainment system. Driving the vehicle was emphasized as the priority task through verbal instructions.

Participants were asked to pull over on the side of the road at the termination of one length of the route. The subsequent experimental block, with a new assigned task type and mode of interaction, began in the opposite direction on the same route and concluded in the same manner. This was repeated until all conditions were completed, resulting in alternating travel directions for each experimental block. The order of task types and conditions administered in each vehicle was counterbalanced across 24 participants in each age cohort.

Tasks were only administered in safe and normal driving conditions. Disruptions to the natural driving environment resulted in the researcher instructing the participant to terminate the current task and only administering a new task when it was safe to do so. Tasks were not administered as participants approached intersections or construction zones. Normal behaviors of other vehicles and pedestrians were within the scope of the natural driving environment. Participants could elect to discontinue their participation at any time, particularly if they did not feel comfortable or safe interacting with the IVIS while driving.

Participants were provided with verbal hypothetical situations or commands as cues from the passenger researcher (e.g., "Jack Olsen would like you to call him on his cellphone."). Participants were trained to wait to start each task until the researcher said, "go." After the completion of each task, participants were trained to say, "done." Tasks were delivered with an approximately five second interval following the participants' announcement of completion of the previous task. Researchers denoted each task's start and end time by pressing designated keys on the data collection computer, thus indicating the timing of on-task performance on the driving route. DRT trials were considered valid for inclusion in the statistical analysis if they occurred between these start and end times. Participants were encouraged to complete tasks as efficiently as possible; however, drivers were given as much time as needed to complete each task, unless the end of the route was reached, in which case tasks were terminated prematurely and later omitted from analysis. The total number of tasks administered and completed in each two-mile run varied depending on task completion time.

Participants also performed, separately, three control tasks while driving one length of the designated route per task. These tasks provided a standard set of performance references, which included a single-task baseline, a high cognitive demand reference task (N-back), and a high visual-demand reference task (SuRT).

- Single-task baseline: Participants performed a single-task baseline drive using the vehicle being tested on the designated route, without interacting with the infotainment system. During the single-task baseline, participants interacted solely with the DRT stimuli, responding to both the tactile stimulus and light change as fast as possible, and were asked to remain silent as to minimize distraction.

- Auditory N-back task: The auditory N-back task (Mehler et al., 2011) presented a prerecorded, randomized set of numbers ranging from zero to nine in sequences of 10. In each sequence, numbers were spoken aloud at a rate of one digit every 2.25 seconds. Participants were instructed to verbally repeat the number that was presented two trials earlier as they concurrently listened for the next number in the sequence. Participants were told to respond as accurately as possible to the N-back stimuli while researchers monitored performance in real-time. During the N-back task, participants also responded to the DRT stimuli.
- Surrogate Reference Task (SuRT): A modernized version of the SuRT task (ISO 14198) was presented on an iPad Mini 4 with circles printed in black on a white background. A target was presented on the display amidst 21-27 distractors. The target was an open circle 1.5 cm in diameter and the distractors were open circles 1.2 cm in diameter. Participants were instructed to touch the location of the target. Immediately thereafter, a new display was presented with a different configuration of targets and distractors. The location of targets and distractors was randomized across the trials in the SuRT task. Participants were instructed to continuously perform the SuRT task while giving the driving task highest priority as researchers monitored performance in real-time. Researchers instructed participants to pause the SuRT task at intersections and in the event of potential hazards on the roadway. During the SuRT task, participants also responded to the DRT stimuli.

After the completion of each condition, participants completed the NASA-TLX (Hart & Staveland, 1988) to assess the subjective workload of the system presented on the iPad mini 4. Following this assessment, participants were asked an open-ended question as an opportunity to describe or detail information not captured by the NASA-TLX questions: "Do you have any comments about the task or vehicle after this last run?"

Dependent measures

DRT data were preprocessed following procedures outlined in ISO 17488 (ISO, 2015). All response times faster than 100 milliseconds were considered impossible or inadvertent responses and were not considered valid. Similarly, reaction times slower than 2,500 milliseconds were eliminated from the overall calculation for reaction time. Nonresponses or responses that were made after 2,500 milliseconds from the stimulus onset were coded as a miss. Task start and end times were recorded by the researcher via pressing designated keys on the DRT host computer, allowing the identification of "on-task" and "off-task" segments of driving. Incomplete, interrupted or otherwise invalid tasks were marked with a key-flag and subsequently excluded from the analysis. The primary dependent measures in the study were:

- DRT – Reaction Time: Defined as the sum of all valid reaction times to the DRT task divided by the number of valid reaction times. Reaction time to the DRT was used to calculate cognitive demand during each experimental condition. This was used to gauge the approximate mental workload and allocation of cognitive resources required by the task for each type of IVIS interaction. Reaction times to both stimuli (LED and vibrotactile) were included in analysis.

- DRT – Hit Rate: Defined as the number of valid responses divided by the total number of valid stimuli presented during each condition. Hit rate to the DRT was used to calculate visual demand, or how much visual attention was required by the task during each experimental condition. In order to maximize the sensitivity to divided visual attention effects (e.g., looking away from the forward roadway), analyses were only conducted on responses to the remote LED stimulus.
- Task completion time was defined from the time researchers said “go” and participants first initiated an action to the time when that action was completed and the participant said, “done.” Tasks with irregular occurrences and errors in administration or performance that may have affected task completion time were marked as abnormal during data collection and were not included in subsequent analyses. When assessed using the visual occlusion methodology, the NHTSA guidelines provide an implicit upper limit of 24 seconds of total task time (NHTSA, 2013; see also Strayer et al., 2017). While originally intended for visual/manual tasks, these guidelines provide a reasonable upper limit for task durations of any type.
- The NASA-TLX involved a close-ended questionnaire that forced participants to answer a series of questions on a 21-point numerical scale. Due to high response collinearity, responses across the subscales were averaged together to form a single composite score. Questions were:
    - Mental – How mentally demanding was the task?
    - Physical – How physically demanding was the task?
    - Temporal – How hurried or rushed was the pace of the task?
    - Performance – How successful were you in accomplishing what you were asked to do?
    - Effort – How hard did you have to work to accomplish your level of performance?
    - Frustration – How insecure, discouraged, irritated, stressed and annoyed were you?

Answers to the open-ended question, “Do you have any comments about the task or vehicle after this last run?” were free response and encouraged by researchers. Participant comments were coded using an inductive thematic analysis (Braun & Clarke, 2006) and following steps outlined by Crowe et al. (2015). Comments were first coded for tone and then theme. For example, the comment “I liked the touch screen, but the knobs need getting used to” was identified as *neutral* (consisting of one positive and one negative statement) first, and then themes and weight would be identified. In accordance with Braun and Clarke’s (2006) method for qualitative analysis, researchers completed a multiphase coding process. Comments with multiple units of unique meaning were broken into separate statements and weighted. Full comments from participants were assigned one point. If one comment contained multiple themes, the comment itself was parsed and the weight divided evenly. For example, the comment “I liked the touch screen, but the knobs need some getting used to” was divided into two themes, each receiving a half weighting (.5).

Following Fellbaum (1988), tones were defined as:

- *Positive:* comments with a connotation that valued the presence of certain features/preferences, as opposed to the absence of features/preferences.
- *Neutral:* comments with a connotation that tended to focus on absence of preferred features/design.
- *Negative:* comments with a connotation that did not value or disparage presence/absence of features/preferences, or that were purely descriptive in nature.

Comments marked as neutral due to nested positive and negative statements were split into two separate units and weighted appropriately.

Experimental Design

The experimental design was a 2 (Age Cohort: older or younger drivers) x 6 (Vehicle: Audi A6, Cadillac CT6, Lincoln Navigator, Mazda CX-5, Nissan Pathfinder, Volvo XC90) x 4 (Task Type: audio entertainment, calling and dialing, navigation entry and text messaging) x 3 (Mode of Interaction: auditory/vocal, center stack, center console) factorial with 24 participants evaluated in each cell of the factorial. However, not all system interactions offered the full factorial design (i.e., not all Task Types and Modes of Interaction were available in all vehicles). Moreover, participants were tested in a varying number of vehicles, which was necessary because it was not possible for all participants to drive all cars. Consequently, an unbalanced design was used where some cells in the factorial were missing. Linear mixed models are specifically designed to accommodate this form of missing data (i.e., they are appropriate for unbalanced designs with different numbers of observations for different participants).

Results

Linear mixed effects analyses were performed using R 3.5.1 (R Core Team, 2019) and lme4 version 1.1-18-1 (Bates et al., 2015).

In the analyses reported below, models containing the Age Cohort, Task Type, Mode of Interaction, and Vehicle factors were entered as fixed effects with Participant entered as a random effect. To evaluate main effects, these models were sequentially compared with models where the effect in question was removed. Interactions between conditions were analyzed through the comparison of models where factors were specified as interactive with models where factors were specified as additive. In each case, p-values were obtained by likelihood ratio tests comparing the full linear mixed effects model with the partial linear mixed effects model (see Winter, 2013). This linear mixed modeling analysis has the advantage of analyzing all available data while adjusting fixed effect, random effect and likelihood ratio test estimates for missing data.

Pairwise comparisons for each of the analyses are also provided in a tabular format (see the example Table 2 below). Pairwise comparisons were extracted through the sequential evaluation of each model in question using a factor re-referencing approach. Each table of pairwise comparisons is structured to provide:

1) The means and standard deviations at each factor level by age.
2) The pairwise comparisons for the age contrast, which indicates whether the effect of age was significant at each level of the factor in question.
3) The pairwise comparisons of the effect in questions, which indicates whether factor levels differed from each other.
4) The pairwise comparisons for the effect of age at each level of the factor in question. This indicates whether the age effects at each factor level differed from each other — in essence, an indication of the interaction effect(s) between the variables.

This selective set of pairwise comparisons addresses the core effects and questions of interest.

Table 2. An example of the pairwise comparisons of individual levels of a variable factor and the effects of age cohort.

	Factor	Level A	Level B	Level C	Level D
1) Means (SD)	Ages 21-36	M (SD)	M (SD)	M (SD)	M (SD)
	Ages 55-75	M (SD)	M (SD)	M (SD)	M (SD)
2) Age Cohort Contrasts		t-val	t-val	t-val	t-val
3) Factor Contrasts	Level A				
	Level B	t-val			
	Level C	t-val	t-val		
	Level D	t-val	t-val	t-val	
4) Factor by Age Cohort Contrasts	Level A				
	Level B	t-val			
	Level C	t-val	t-val		
	Level D	t-val	t-val	t-val	

For each independent variable (task completion time, DRT reaction time, DRT hit rate, subjective workload), linear mixed effects models were built to explore the main effects of Age Cohort, Task Type, Mode of Interaction, and Vehicle as well as all two-way interactions with Age Cohort (e.g., Age Cohort by Task Type, Age Cohort by Mode of Interaction and Age Cohort by Vehicle). Given the focus of this report on the effects of Age on IVIS interactions, other higher order interactions were not evaluated. Figures showing the full factorial are provided in Appendix 2.

Where appropriate, results were analyzed and modeled with the inclusion of the baseline conditions (Single-task, SuRT, N-back). Baseline tasks were not included in the analyses of Vehicle, nor were they included in the analysis of task completion time. Results address the question of whether there were significant age differences in the associations of interactions with the vehicle technology with the independent variables.

Mean results for each of the main effects are provided in the units in which they were recorded, along with measures of variability in parentheses. Due to the number of statistical comparisons performed, we used a more conservative $\alpha = .01$ and $\alpha = .001$ to denote varying levels of statistical significance. Effects that reach these levels are flagged with a single `*` and a double `**`, respectively. This more conservative significance level helps to reduce the likelihood of false positives in the statistical analysis.

Task Completion Time

Main Effects

Results indicated that task completion time differed by Age Cohort, $\chi^2(1) = 51.42$, $p < .001$, with older drivers taking significantly longer to complete tasks than younger drivers. Additionally, there were significant main effects of task completion time for Task Type, $\chi^2(3) = 785.85$, $p < .001$, and Mode of Interaction, $\chi^2(2) = 119.56$, $p < .001$. Finally, there was a significant main effect of Vehicle, $\chi^2(5) = 218.32$, $p < .001$. Table 3 summarizes the main effects.

Table 3. Summary of main effects for task completion time (s). Means are shown with standard deviations (SD) in parentheses.

Main Effect						
Age Cohort	Young	Older				
	23.5 (9.8)	30.2 (15.2)				
Task Type	Audio Entertainment	Calling and Dialing	Text Messaging	Navigation Entry		
	21.6 (9.1)	20.0 (5.8)	30.7 (16.9)	35.6 (12.4)		
Mode of Interaction	Auditory Vocal	Center Console	Center Stack			
	29.4 (14.9)	27.4 (11.7)	22.6 (9.6)			
Vehicle	Audi A6	Cadillac CT6	Lincoln Navigator	Mazda CX-5	Nissan Pathfinder	Volvo XC90
	29.64 (0.62)	20.91 (0.67)	19.05 (0.64)	34.35 (0.63)	25.62 (0.64)	25.71 (0.65)

Age Cohort by Task Type

The analysis revealed a significant two-way interaction between Age Cohort and Task Type, $\chi^2(1, 3) = 12.5$, $p = .006$. Age contrasts indicated that the effect of age reached significance at all levels of Task Type and that all levels of Task Type differed from each other (see Table 4). Furthermore, Task Type by Age Cohort contrasts suggests that older drivers had an especially difficult time with the navigation entry task, particularly compared with calling and dialing (see Figure 2). Notably, only the median task completion time for the audio entertainment and calling and dialing tasks came in under the 24-second referent for both age groups (Figure 2; Strayer et al., 2013).

Table 4. Pairwise comparisons for task completion time (s) as a function of Task Type and Age Cohort.

	Task Completion Time by Task Type	Audio Entertainment	Calling and Dialing	Text Messaging	Navigation Entry
Means (SD)	Younger (21-36 yrs)	18.0 (5.0)	17.7 (3.6)	27.7 (11.8)	31.4 (8.6)
	Older (55-75 yrs)	25.4 (10.7)	22.4 (6.5)	33.8 (20.4)	40.0 (14.1)
Age Cohort Contrasts (t-value)		7.00**	4.64**	5.53**	8.00**
Task Type Contrasts (t-value)	Audio Entertainment				
	Calling and Dialing	-2.86*			
	Text Messaging	14.53**	17.25**		
	Navigation Entry	23.86**	26.71**	8.20**	
Task Type by Age Cohort Contrasts (t-value)	Audio Entertainment				
	Calling and Dialing	-2.35			
	Text Messaging	-1.11	1.12		
	Navigation Entry	1.02	3.36**	2.08	

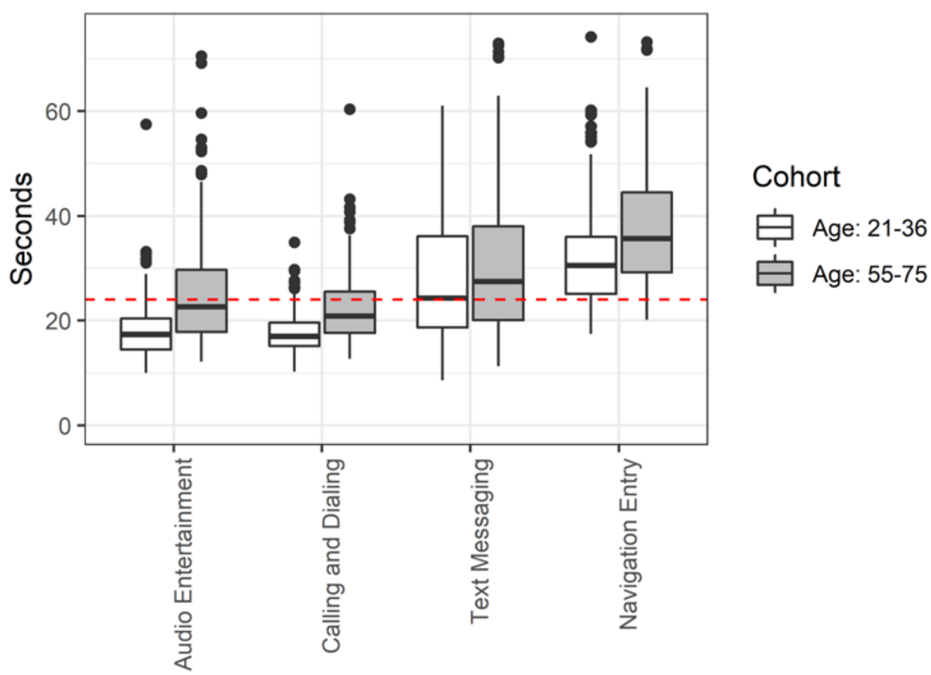

Figure 2. Task completion time as a function of Age Cohort and Task Type. The dashed horizontal red line represents 24 seconds.

Age Cohort by Mode of Interaction

The interaction between Mode of Interaction and Age Cohort was not significant, $\chi^2(1, 2) = 1.09$, $p = 0.57$, suggesting that the increased task completion time for older drivers was similar across all three modes. That is, while Age Cohort and Mode of Interaction both affected task completion time, the impact of each was not dependent on the other (see Figure 3).

As shown in Table 5, age contrasts indicated that the effect of age reached significance for all levels of Mode of Interaction. In addition, Mode of Interaction contrasts indicated that performance differed between each mode (see also Table 3). Mode of Interaction by Age Cohort contrasts suggested that the magnitude of the age effect was not dependent on the specific mode (i.e., there were no significant contrasts).

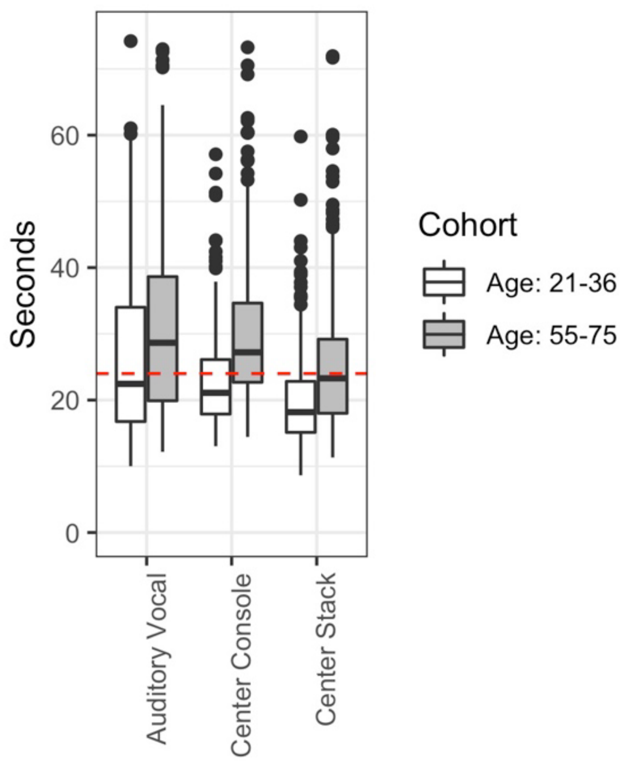

Figure 3. Task completion time as a function of Age Cohort and Mode of Interaction. The dashed horizontal red line represents 24 seconds.

Table 5. Pairwise comparisons for task completion time as a function of Mode of Interaction and Age Cohort.

	Mode of Interaction	Auditory Vocal	Center Console	Center Stack
Means (SD)	Younger (21-36 yrs)	26.2 (11.3)	23.2 (7.9)	19.7 (6.4)
	Older (55-75 yrs)	32.7 (17.2)	31.4 (13.3)	25.7 (11.3)
Age Cohort Contrasts (t-value)		6.98**	5.93**	6.01**
Mode of Interaction Contrasts (t-value)	Auditory Vocal			
	Center Console	-4.10**		
	Center Stack	-11.03**	-4.36**	
Mode of Interaction by Age Cohort Contrasts (t-value)	Auditory Vocal			
	Center Console	-0.95		
	Center Stack	-0.98	-0.98	

Age Cohort by Vehicle

The interaction between Age Cohort and Vehicle was significant, $\chi^2(1, 5) = 23.2$, $p < .001$. As shown in Table 6, age contrasts indicate that the effect of Age Cohort reached significance in each of the six vehicles. Vehicle contrasts indicated that tasks using systems on the Cadillac CT6 and the Lincoln Navigator required the least amount of time to complete; tasks completed using the Audi A6, Nissan Pathfinder and Volvo XC90 took slightly longer; and tasks completed using the Mazda CX-5 took the longest (see also Table 3). Vehicle by Age Cohort contrasts suggested that the effect of age was greater in the Mazda CX-5 than the Cadillac CT6, the Lincoln Navigator, the Nissan Pathfinder, and the Volvo XC90. Other contrasts did not differ. Notably, the median task completion time in the Cadillac CT6 and Lincoln Navigator was less than 24 seconds for both older and younger drivers (see Figure 4).

Table 6. Pairwise comparisons for task completion time as a function of Vehicle and Age Cohort.

	Vehicle	Audi A6	Cadillac CT6	Lincoln Navigator	Mazda CX5	Nissan Pathfinder	Volvo XC90
Means (SD)	Younger (21-36 yrs)	25.4 (9.2)	20.1 (8.3)	18.9 (5.8)	28.0 (11.4)	24.1 (9.6)	24.0 (10.8)
	Older (55-75 yrs)	33.0 (13.4)	24.0 (9.3)	22.8 (8.5)	39.3 (22.0)	30.5 (12.4)	30.5 (14.8)
Age Cohort Contrasts (t-value)		5.79**	2.96*	3.13*	8.69**	5.00*	4.73**
Vehicle Contrasts (t-value)	Audi A6						
	Cadillac CT6	-7.62**					
	Lincoln Navigator	-8.99**	-1.11				
	Mazda CX5	4.86**	11.76**	13.19**			
	Nissan Pathfinder	-1.74	5.52**	6.83**	-6.92**		
	Volvo XC90	-1.80	5.51**	6.77**	-6.55**	-0.05	
Vehicle by Age Cohort Contrasts (t-value)	Audi A6						
	Cadillac CT6	-1.97					
	Lincoln Navigator	-1.99	0.04				
	Mazda CX5	2.30	4.08**	4.16**			
	Nissan Pathfinder	-0.56	1.36	1.37	-2.95*		
	Volvo XC90	-0.59	1.32	1.32	-2.83*	-0.03	

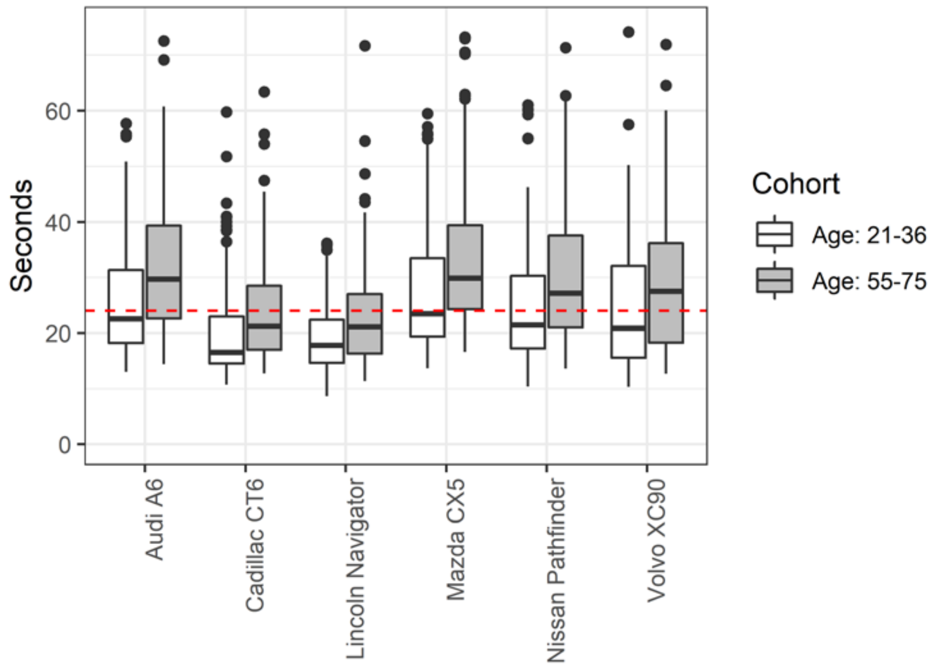

Figure 4. Task completion time as a function of Age Cohort and Vehicle. The dashed horizontal red line represents 24 seconds.

DRT Reaction Time

Main Effects

Results indicated that DRT reaction time differed by Age Cohort, $\chi^2(1) = 49.8$, $p < .001$, with older drivers taking significantly longer, on average, to respond to the DRT than younger drivers. Additionally, there were significant main effects for Task Type, $\chi^2(6) = 1466$, $p < .001$, Mode of Interaction, $\chi^2(5) = 1450$, $p < .001$, and Vehicle, $\chi^2(5) = 44.52$, $p < .001$ (see Table 7 for a summary of the main effects).

Table 7. Summary of main effects for DRT reaction time (ms). Means are shown with SD in parentheses.

Main Effect						
Age Cohort	Young	Older				
	739 (168)	914 (193)				
Task Type	Audio Entertainment	Calling and Dialing	Text Messaging	Navigation Entry		
	870 (194)	848 (180)	856 (191)	863 (189)		
	Single-task	N-Back	SuRT			
	582 (13)	851 (187)	792 (187)			
Mode of Interaction	Auditory Vocal	Center Console	Center Stack			
	858 (199)	868 (179)	856 (177)			
Vehicle	Audi A6	Cadillac CT6	Lincoln Navigator	Mazda CX-5	Nissan Pathfinder	Volvo XC90
	800 (189)	801 (188)	813 (194)	871 (214)	861 (207)	807 (201)

Age Cohort by Task Type

Analysis of the two-way interaction between Age Cohort and Task Type indicated that the interaction reached significance, $\chi^2(1, 6) = 31.6$, $p < .001$. Inspection of the data reveals a highly consistent effect of task engagement and age across each of the four task types (see Figure 5). As shown in Table 8, Age Cohort contrasts indicated that the effect of age reached significance at each level of Task Type. Task Type contrasts suggest that reaction time to the audio entertainment and navigation tasks were slightly more delayed than to the calling and dialing task (see also Table 7). Overall, reaction time in the single task condition was faster than all other tasks. Reaction time to the SuRT task was also faster than to the other tasks (except single task), while reaction time to the N-back task did not differ from the IVIS tasks (see Table 8). Task Type by Age Cohort contrasts suggest that the effect of age was smallest for the single task condition and differed from all other tasks; however, there were no age-related differences between any of the other conditions. Thus, age-related slowing on the DRT task was exacerbated in all task conditions compared to baseline.

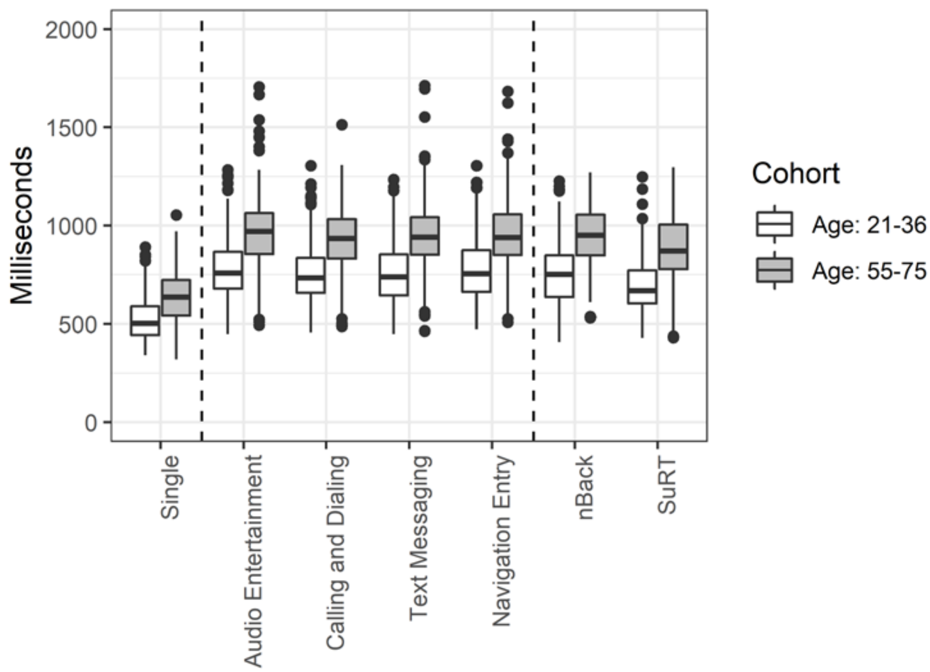

Figure 5. Reaction time as a function of Age Cohort and Task Type. The vertical dashed lines visually separate the baseline and reference tasks.

Table 8. Pairwise comparisons for reaction time as a function of Task Type and Age Cohort.

	Task Type	Single	Audio Entertainment	Calling and Dialing	Text Messaging	Navigation Entry	N-back	SuRT
Means (SD)	Younger (21-36 yrs)	526 (110)	778 (154)	762 (150)	763 (158)	773 (157)	760 (174)	703 (147)
	Older (55-75 yrs)	639 (135)	946 (184)	934 (166)	951 (176)	954 (175)	944 (151)	881 (182)
Age Cohort Contrasts (t-value)		4.50**	7.98**	7.34**	7.91**	7.70**	7.47**	7.16**
Task Type Contrasts (t-value)	Single							
	Audio Entertainment	38.56**						
	Calling and Dialing	35.34**	-3.94**					
	Text Messaging	35.25**	-2.46	1.28				
	Navigation Entry	37.49**	-1.27	2.66*	1.25			
	N-back	31.17**	-2.57	0.65	-0.44	-1.53		
	SuRT	24.33**	-10.53**	-7.31**	-8.14**	-9.48**	-6.89**	
Task Type by Age Cohort Contrasts (t-value)	Single							
	Audio Entertainment	4.99**						
	Calling and Dialing	3.99**	-1.22					
	Text Messaging	4.90**	0.10	1.26				
	Navigation Entry	4.56**	-0.52	0.70	-0.59			
	N-back	4.31**	-0.01	0.99	-0.09	0.42		
	SuRT	3.85**	-0.55	0.45	-0.61	-0.12	-0.46	

Age Cohort by Mode of Interaction

The interaction between Age Cohort and Mode of Interaction also reached significance, $\chi^2(1, 2) = 33.05$, $p > .001$ (see Figure 6). As shown in Table 9, contrasts indicated that the effect of Age Cohort on reaction time reached significance for each Mode of Interaction. Furthermore, Mode of Interaction contrasts indicated that the single task and SuRT tasks differed from all other modes but that none of the other modes differed from one another.

Mode of Interaction by Age Cohort contrasts indicated that the effect of age was smallest in the single task baseline and similar in all other conditions.

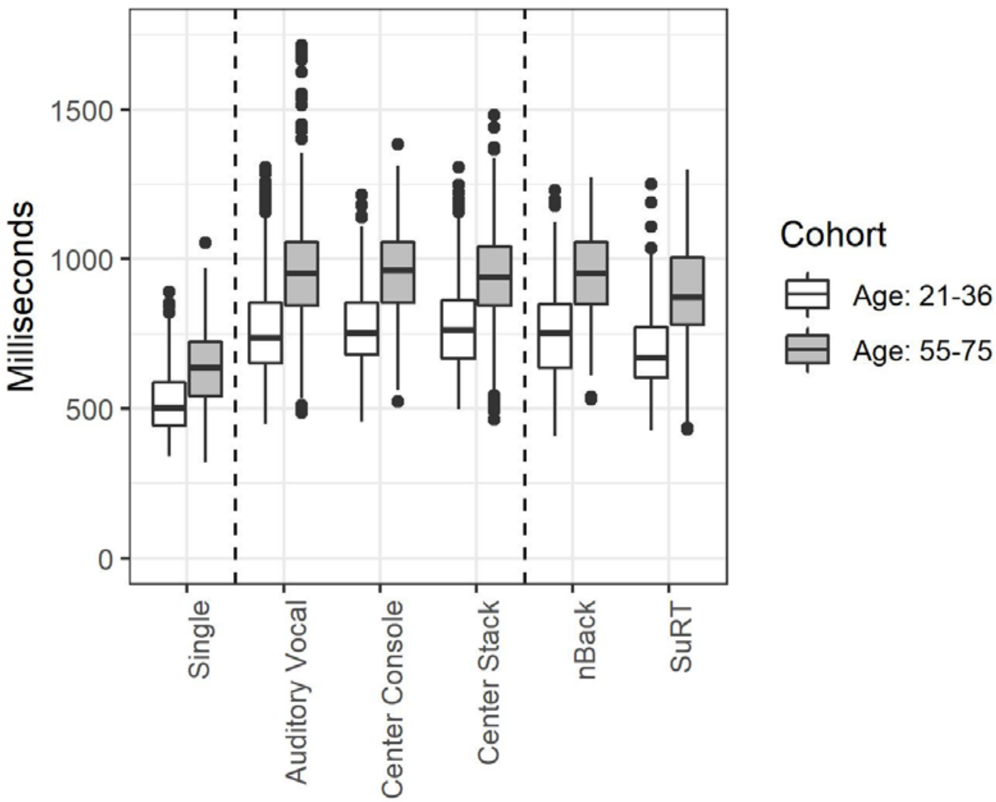

Figure 6. Reaction time as a function of Age Cohort and Mode of Interaction. The vertical dashed lines visually separate the baseline and reference tasks.

Table 9. Pairwise comparisons for reaction time as a function of Mode of Interaction and Age Cohort.

	Mode of Interaction	Single	Auditory Vocal	Center Console	Center Stack	N-back	SuRT
Means (SD)	Younger (21-36 yrs)	526 (110)	764 (161)	775 (147)	775 (148)	760 (174)	703 (147)
	Older (55-75 yrs)	639 (135)	954 (188)	957 (160)	942 (164)	944 (151)	881 (182)
Age Cohort Contrasts (t-value)		4.49**	8.37**	7.34**	7.35**	7.47**	7.16**
Mode of Interaction Contrasts (t-value)	Single						
	Auditory Vocal	40.08**					
	Center Console	34.28**	0.89				
	Center Stack	37.84**	0.04	-0.78			
	N-back	31.09**	-0.94	-1.46	-0.91		
	SuRT	24.27**	-9.60**	-8.72**	-9.08**	-6.87**	
Mode of Interaction by Age Cohort Contrasts (t-value)	Single						
	Auditory Vocal	5.63**					
	Center Console	4.05**	-0.88				
	Center Stack	3.98**	-1.92	-0.61			
	N-back	4.30**	-0.22	0.49	1.13		
	SuRT	3.84**	-0.80	0.00	0.58	-0.46	

Age Cohort by Vehicle

The interaction between Age Cohort and Vehicle was significant, $\chi^2(1, 5) = 44.5$, $p < .001$ (see Figure 7). Following from Table 10, contrasts suggest that the effect of age on reaction time reached significance in all vehicles. Vehicle contrasts suggest that reaction time to the IVIS tasks was somewhat higher in the Mazda CX-5 and the Nissan Pathfinder relative to the other vehicles evaluated, as seen in Figure 7 and Table 10. Vehicle by Age Cohort contrasts suggest that the effect of age on reaction time differed between the Volvo XC90 and the Audi A6, the Mazda CX5, and the Nissan Pathfinder. Generally speaking, however, the effect of age on reaction time appears to be relatively stable across each of the vehicles, with older drivers showing a consistent increase in reaction time relative to younger drivers (see Table 10 and Figure 7).

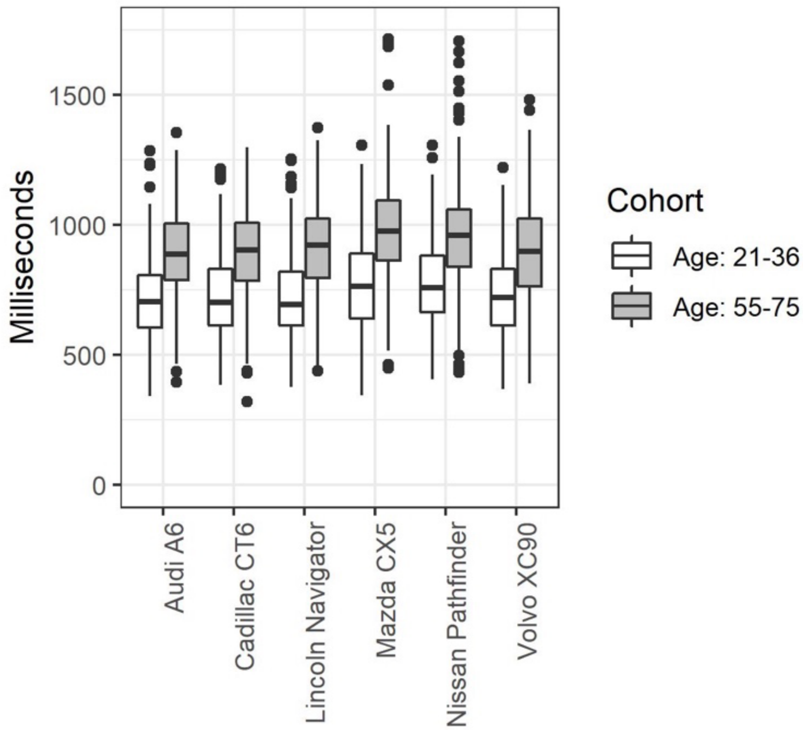

Figure 7. Reaction time as a function of Age Cohort and Vehicle. The vertical dashed lines visually separate the baseline and reference tasks.

Table 10. Pairwise comparisons for reaction time as a function of Vehicle and Age Cohort.

	Vehicle	Audi A6	Cadillac CT6	Lincoln Navigator	Mazda CX5	Nissan Pathfinder	Volvo XC90
Means (SD)	Younger (21-36 yrs)	710 (156)	727 (167)	722 (161)	770 (182)	774 (169)	728 (161)
	Older (55-75 yrs)	883 (178)	881 (176)	903 (181)	974 (195)	954 (204)	889 (205)
Age Cohort Contrasts (t-value)		7.05**	6.21**	6.88**	7.53**	8.27**	4.93**
Vehicle Contrasts (t-value)	Audi A6						
	Cadillac CT6	-0.71					
	Lincoln Navigator	-0.55	0.17				
	Mazda CX5	3.96**	4.42**	4.40**			
	Nissan Pathfinder	4.24**	4.64**	4.67**	0.18		
	Volvo XC90	-0.47	0.23	0.07	-4.47**	-4.80**	
Vehicle Contrasts by Age Cohort (t-value)	Audi A6						
	Cadillac CT6	-0.97					
	Lincoln Navigator	-0.15	0.82				
	Mazda CX5	0.71	1.55	0.83			
	Nissan Pathfinder	1.61	2.41	1.72	0.94		
	Volvo XC90	-2.77*	-1.71	-2.55	-3.36**	-4.37**	

DRT Hit Rate

Main Effects

Results indicated that DRT hit rate differed by Age Cohort, $\chi^2(1) = 70.2$, $p < .001$, with younger drivers detecting and accurately responding to the onset of the forward LED significantly more often than older drivers. Consistently across factors, older drivers failed to respond to the light stimulus more frequently, resulting in lower hit rates. Additionally, there was a significant main effect of Task Type, $\chi^2(6) = 1232$, $p < .001$, and Mode of Interaction, $\chi^2(5) = 1577$, $p < .001$. Finally, there was a significant main effect of Vehicle, $\chi^2(5) = 181$, $p < .001$. Table 11 summarizes the main effects.

Table 11. Summary of main effects for DRT hit rate (proportion correct). Means are shown with SD in parentheses.

Main Effect						
Age Cohort	Young	Older				
	0.67 (0.23)	0.41 (0.28)				
Task Type	Audio Entertainment	Calling and Dialing	Text Messaging	Navigation Entry		
	0.44 (0.28)	0.51 (0.29)	0.50 (0.27)	0.47 (0.27)		
	Single-task	N-Back	SuRT			
	0.85 (0.17)	0.64 (0.25)	0.55 (0.24)			
Mode of Interaction	Auditory Vocal	Center Console	Center Stack			
	0.55 (0.28)	0.38 (0.26)	0.43 (0.26)			
Vehicle	Audi A6	Cadillac CT6	Lincoln Navigator	Mazda CX-5	Nissan Pathfinder	Volvo XC90
	0.51 (0.29)	0.61 (0.26)	0.61 (0.27)	0.49 (0.30)	0.57 (0.29)	0.43 (0.28)

Age Cohort by Task Type

Analysis of the two-way interaction between Age Cohort and Task Type on DRT hit rate indicated that the interaction was significant, $\chi^2(1, 6) = 102$, $p > .001$ (see Figure 8). The age contrasts revealed a significant effect of Age Cohort at each level of Task type (see Table 12). Task Type contrasts indicated that, on average, all task types differed from each other, apart from calling and dialing and text messaging. Task Type by Age Cohort contrasts suggested that the effect of Age Cohort was generally larger in the IVIS task conditions than for the baseline tasks, but that there were no significant differences among the IVIS tasks themselves (see Figure 8).

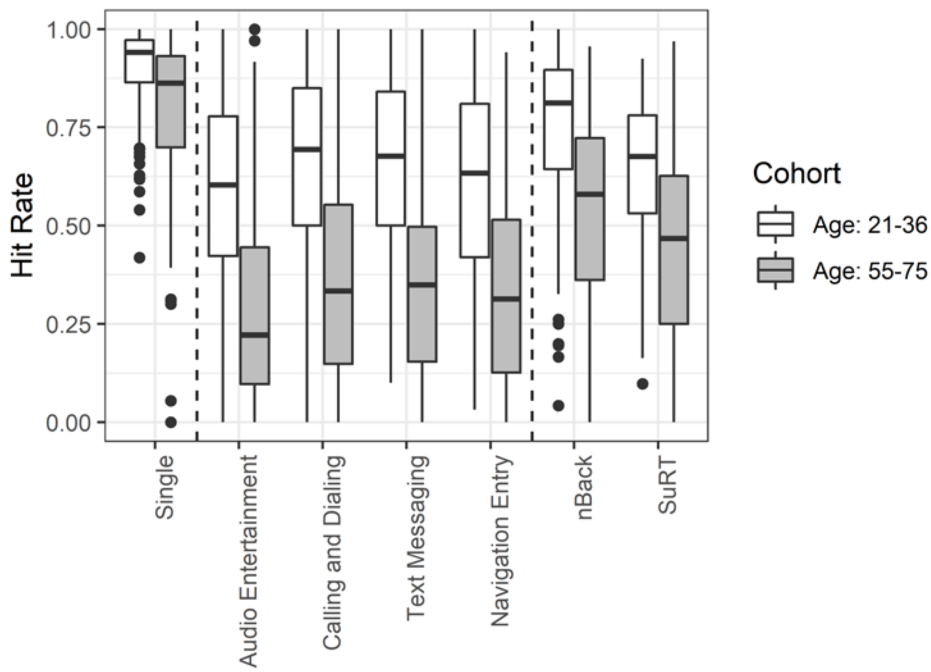

Figure 8. Hit rate as a function of Age Cohort and Task Type. The vertical dashed lines visually separate the baseline and reference tasks.

Table 12. Pairwise comparisons for hit rate as a function of Task Type and Age Cohort.

	Task Type	Single	Audio Entertainment	Calling and Dialing	Text Messaging	Navigation Entry	N-back	SuRT
Means (SD)	Younger (21-36 yrs)	0.90 (0.11)	0.59 (0.24)	0.66 (0.24)	0.66 (0.21)	0.60 (0.24)	0.76 (0.19)	0.65 (0.18)
	Older (55-75 yrs)	0.80 (0.20)	0.29 (0.24)	0.37 (0.26)	0.35 (0.23)	0.33 (0.23)	0.53 (0.25)	0.44 (0.26)
Age Cohort Contrasts (t-value)		-3.79**	-10.34**	-9.78**	-10.01**	-9.29**	-7.26**	-6.67**
Task Type Contrasts (t-value)	Single							
	Audio Entertainment	-34.73**						
	Calling and Dialing	-28.55**	7.56**					
	Text Messaging	-28.47**	6.18**	-1.02				
	Navigation Entry	-32.37**	2.85*	-4.69**	-3.45**			
	N-back	-15.12**	17.27**	11.10**	11.58**	14.92**		
	SuRT	-22.17**	9.19**	3.01*	3.76**	6.85**	-7.02**	
Task Type by Age Cohort Contrasts (t-value)	Single							
	Audio Entertainment	-8.69**						
	Calling and Dialing	-7.92**	0.94					
	Text Messaging	-8.22**	0.22	-0.67				
	Navigation Entry	-7.24**	1.76	0.83	1.46			
	N-back	-4.55**	3.43**	2.66*	3.13**	1.99		
	SuRT	-3.77**	4.35**	3.58**	4.02**	2.90*	0.79	

Age Cohort by Mode of Interaction

The interaction between Age Cohort and Mode of Interaction was also significant, $\chi^2(1, 5) = 116.0$, $p > .01$, suggesting that the effect of age on hit rate depended on the mode of interaction (see Figure 9). Age contrasts indicated that the effect of Age Cohort reached significance at all levels of the mode of interaction (see Table 13). Mode of Interaction contrasts differences between the conditions: that hit rates were highest in the single task condition, followed by the N-back task, then the SuRT and auditory vocal tasks, and lowest in the center stack and center console. Mode of Interaction by Age Cohort contrasts suggested that the effect of age varied by mode. Age-related differences were smallest in the single task condition and largest for each of the modes of interaction, with the N-back and SuRT tasks falling in the middle.

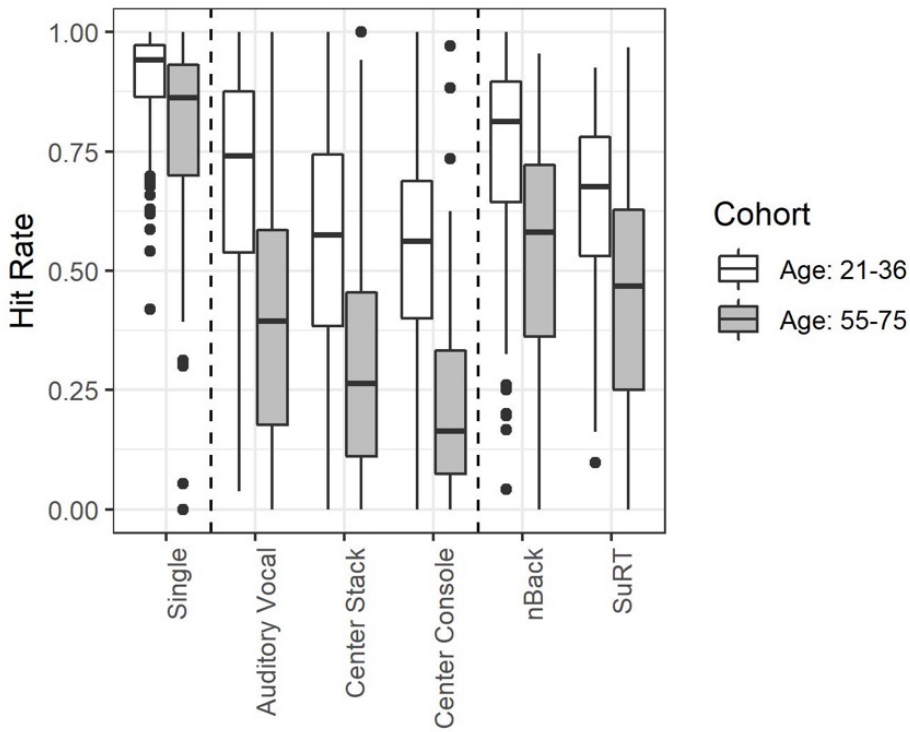

Figure 9. Hit rate as a function of Age Cohort and Mode of Interaction. The vertical dashed lines visually separate the baseline and reference tasks.

Table 13. Pairwise comparisons for hit rate as a function of Mode of Interaction and Age Cohort.

	Mode of Interaction	Single	Auditory Vocal	Center Console	Center Stack	N-back	SuRT
Means (SD)	Younger (21-36 yrs)	0.90 (0.11)	0.70 (0.22)	0.54 (0.23)	0.56 (0.23)	0.76 (0.19)	0.65 (0.18)
	Older (55-75 yrs)	0.80 (0.20)	0.40 (0.25)	0.21 (0.18)	0.30 (0.22)	0.53 (0.25)	0.44 (0.26)
Age Cohort Contrasts (t-value)		-3.85**	-10.53**	-10.26**	-9.42**	-7.38**	-6.77**
Mode of Interaction Contrasts (t-value)	Single						
	Auditory Vocal	-29.47**					
	Center Console	-37.62**	-16.84**				
	Center Stack	-39.48**	-16.84**	3.02*			
	N-back	-16.00**	9.32**	20.72**	20.47**		
	SuRT	-23.46**	-0.01	12.92**	11.68**	-7.42**	
Mode of Interaction by Age Cohort Contrasts (t-value)	Single						
	Auditory Vocal	-9.61**					
	Center Console	-8.82**	-0.99				
	Center Stack	-7.80**	1.84	2.25			
	N-back	-4.83**	3.53**	3.71**	2.05		
	SuRT	-4.00**	4.60**	4.61**	3.06*	0.85	

Age Cohort by Vehicle

The interaction between Age Cohort and Vehicle was significant, $\chi^2(1, 5) = 37.3$, $p < .001$ (see Figure 10). As shown in Table 14, Age Cohort contrasts suggest that the effect of age reached significance in each vehicle. Furthermore, Vehicle contrasts suggested that that overall hit rate while interacting with IVIS resulted in three groupings: the Cadillac CT6, Lincoln Navigator and Nissan Pathfinder each resulted in similar hit rates. Next, the Audi A6 and the Mazda CX-5 resulted in similar hit rates. Finally, overall hit rates in the Volvo XC90 were lower than in the other vehicles. Vehicle by Age Cohort contrasts suggested that the effect of Age Cohort was greater in the Mazda CX-5 than in the Cadillac CT6, the Lincoln Navigator and the Volvo XC90. Likewise, the effect of Age Cohort in the Volvo XC90 was smaller than in the Audi A6 and the Nissan Pathfinder (see Figure 10 and Table 14).

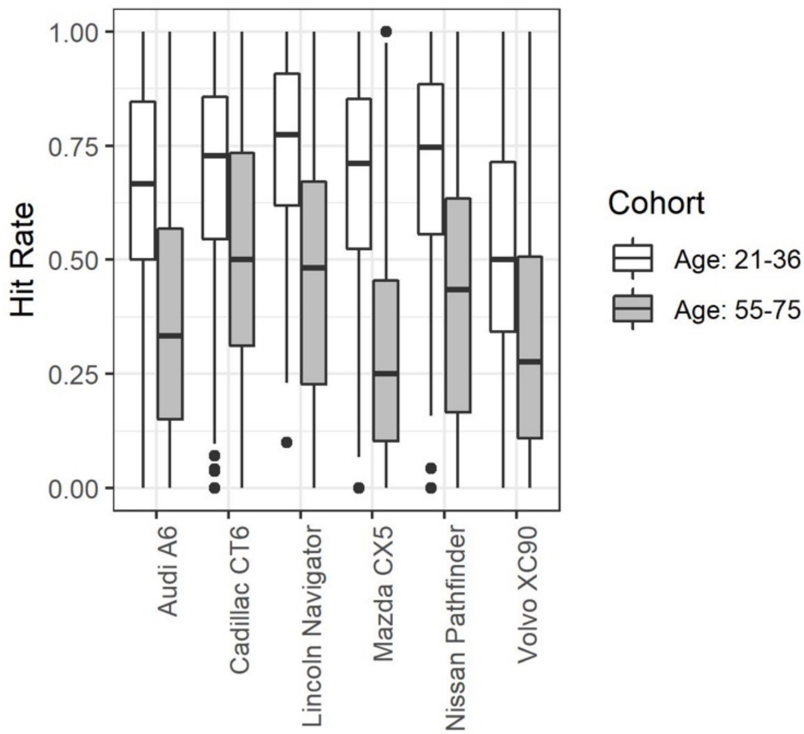

Figure 10. Hit rate as a function of Age Cohort and Vehicle. The vertical dashed lines visually separate the baseline and reference tasks.

Table 14. Pairwise comparisons for hit rate as a function of Vehicle and Age Cohort.

	Vehicle	Audi A6	Cadillac CT6	Lincoln Navigator	Mazda CX5	Nissan Pathfinder	Volvo XC90
Means (SD)	Younger (21-36 yrs)	0.65 (0.24)	0.69 (0.22)	0.74 (0.19)	0.68 (0.22)	0.71 (0.22)	0.53 (0.25)
	Older (55-75 yrs)	0.38 (0.27)	0.52 (0.26)	0.47 (0.28)	0.31 (0.25)	0.43 (0.28)	0.33 (0.27)
Age Cohort Contrasts (t-value)		-8.93**	-6.98**	-7.97**	-10.79**	-9.04**	-5.96**
Vehicle Contrasts (t-value)	Audi A6						
	Cadillac CT6	4.59**					
	Lincoln Navigator	6.44**	1.70				
	Mazda CX5	-0.18	-4.27**	-5.97**			
	Nissan Pathfinder	4.56**	0.16	-1.45	5.02**		
	Volvo XC90	-5.49**	-9.50**	-11.43**	-5.04**	-10.09**	
Vehicle by Age Cohort Contrasts (t-value)	Audi A6						
	Cadillac CT6	2.15					
	Lincoln Navigator	1.07	-1.10				
	Mazda CX5	-2.27	-4.12**	-3.21*			
	Nissan Pathfinder	-0.19	-2.14	-1.18	2.26		
	Volvo XC90	3.51**	1.28	2.39	5.65**	3.64**	

Subjective Workload

Main Effects

Results indicated that the composite TLX scores (average of the 21-point rating across each of the TLX subscales) differed by Age Cohort, $\chi^2(1) = 8.69$, $p = .003$, with older drivers reporting IVIS task interactions to be more difficult than younger drivers (see Table 15). Additionally, there were significant main effects for Task Type, $\chi^2(6) = 789$, $p < .001$, Mode of Interaction, $\chi^2(5) = 958$, $p < .001$, and Vehicle, $\chi^2(5) = 58.2$, $p < .001$.

Table 15. Summary of main effects for composite NASA-TLX scores. Means are shown with SD in parentheses.

Main Effect						
Age Cohort	Young	Older				
	7.96 (4.44)	9.23 (4.72)				
Task Type	Audio Entertainment	Calling and Dialing	Text Messaging	Navigation Entry		
	9.27 (4.68)	7.53 (4.37)	7.96 (4.12)	9.22 (4.49)		
	Single-task	N-Back	SuRT			
	4.4 (3.0)	11.8 (3.9)	10.3 (4.4)			
Mode of Interaction	Auditory Vocal	Center Console	Center Stack			
	7.33 (4.17)	9.70 (4.27)	9.75 (4.60)			
Vehicle	Audi A6	Cadillac CT6	Lincoln Navigator	Mazda CX-5	Nissan Pathfinder	Volvo XC90
	8.97 (4.47)	8.75 (4.79)	8.45 (4.92)	8.91 (4.41)	8.56 (4.47)	7.86 (4.60)

Age Cohort by Task Type

Analysis of the two-way interaction between Age Cohort and Task Type on subjective workload indicated that the interaction was statistically significant, $\chi^2(1, 6) = 28.4$, $p < .001$. Age Cohort contrasts suggested that the effect of age was not significant in any of the baseline tasks but that it reached significance in all IVIS task types, except the calling and dialing task (see Table 16). Task Type contrasts suggested that drivers found the N-back task to be the most demanding, followed by the SuRT task, then the navigation entry and audio entertainment tasks, then the calling and dialing and text messaging tasks, followed by the single task (see Figure 11). Task Type by Age Cohort contrasts suggested that the effect of age was more pronounced in the audio entertainment task compared with the SuRT task, but that the age effect was largely consistent across other tasks.

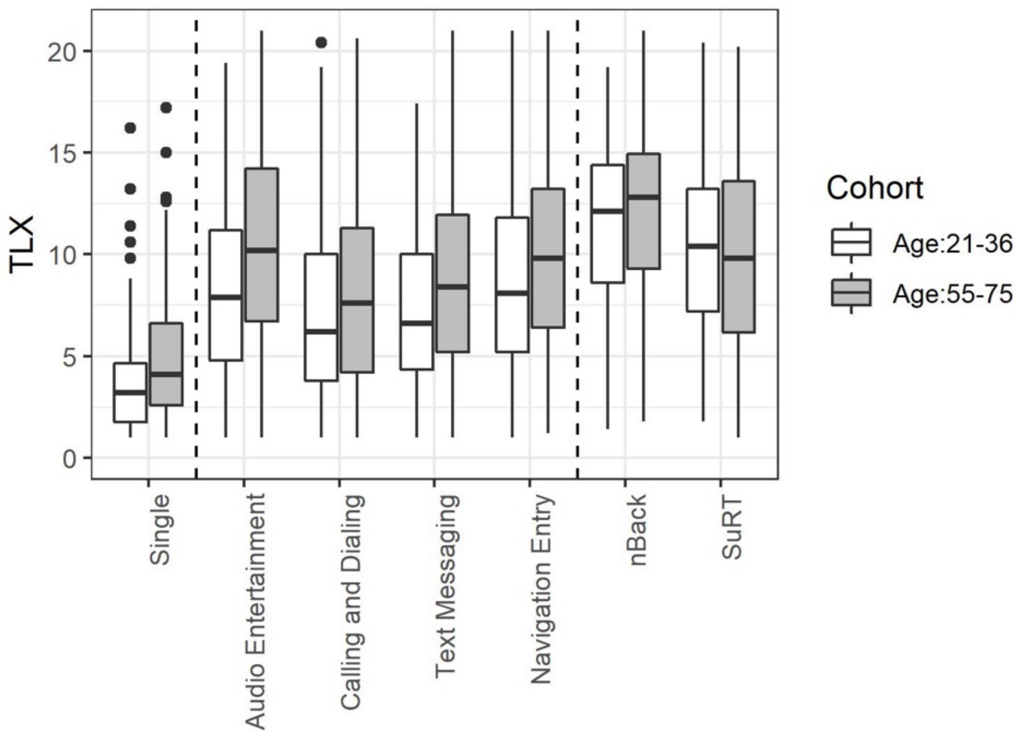

Figure 11. Subjective workload as a function of Age Cohort and Task Type. The vertical dashed lines visually separate the baseline and reference tasks.

Table 16. Pairwise comparisons for NASA-TLX subjective responses as a function of Task Type and Age Cohort.

	Task Type	Single	Audio Entertainment	Calling and Dialing	Text Messaging	Navigation Entry	N-back	SuRT
Means (SD)	Younger (21-36 yrs)	3.75 (2.65)	8.23 (4.33)	7.04 (4.15)	7.26 (3.88)	8.45 (4.32)	11.4 (3.73)	10.4 (4.25)
	Older (55-75 yrs)	5.08 (3.27)	10.3 (4.79)	8.03 (4.53)	8.68 (4.23)	10.0 (4.54)	12.1 (4.09)	10.1 (4.53)
Age Cohort Contrasts (t-value)		2.51	4.29**	2.15	2.85*	3.16*	1.50	-0.11
Task Type Contrasts (t-value)	Single							
	Audio Entertainment	20.17**						
	Calling and Dialing	12.93**	-8.86**					
	Text Messaging	14.24**	-6.80**	1.85				
	Navigation Entry	19.88**	-0.37	8.50**	6.45**			
	N-back	26.28**	10.19**	17.42**	15.61**	10.50**		
	SuRT	20.95**	4.01**	11.25**	9.54**	4.31**	-5.37**	
Task Type by Age Cohort Contrasts (t-value)	Single							
	Audio Entertainment	1.65						
	Calling and Dialing	-0.75	-2.93					
	Text Messaging	0.08	-1.87	0.98				
	Navigation Entry	0.38	-1.56	1.37	0.36			
	N-back	-1.10	-2.91	-0.53	-1.32	-1.64		
	SuRT	-2.86*	-4.95**	-2.56	-3.32	-3.68	-1.75	

Age Cohort by Mode of Interaction

The interaction between Age Cohort and Mode of Interaction was significant, $\chi^2(1, 5) = 20.7$, $p > .001$ (see Figure 12). Age contrasts found no significant effect of age in any of the tasks (Table 17). Mode of Interaction contrasts found that the subjective evaluation of workload differed between the different modes. Specifically, drivers felt that auditory vocal tasks were less demanding to complete compared with tasks using the center console or center stack displays (see also Table 15). All tasks were reported to be easier than the N-back task. Mode of Interaction by Age Cohort contrasts suggest that the age effect differed (and was even reversed) in the SuRT condition compared with all other tasks, except for the N-back task (see Figure 12).

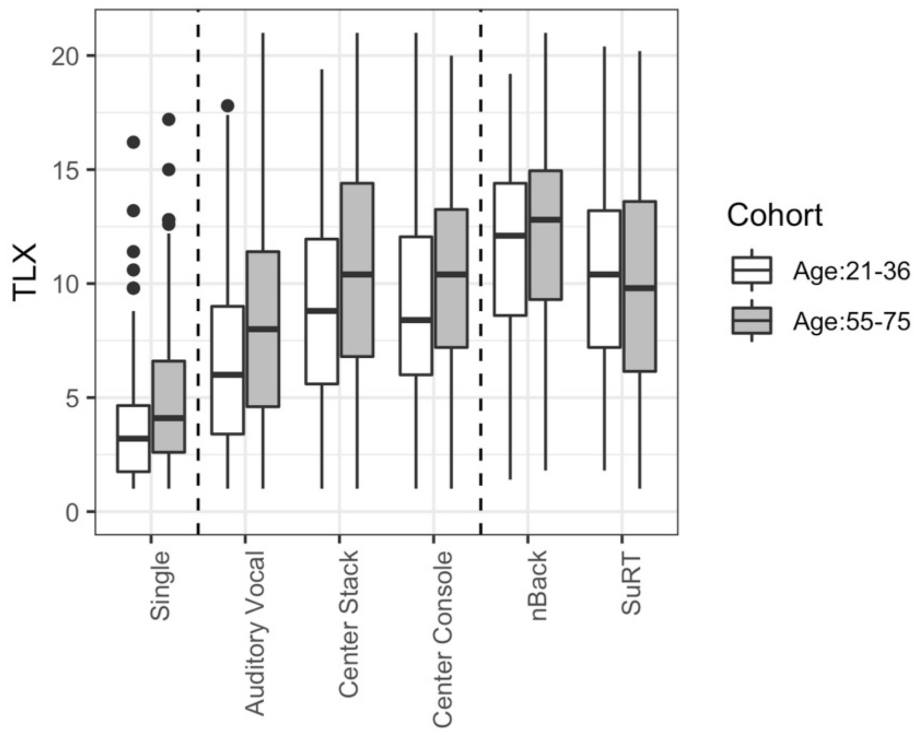

Figure 12. Subjective workload as a function of Age Cohort and Mode of Interaction. The vertical dashed lines visually separate the baseline and reference tasks.

Table 17. Pairwise comparisons for NASA-TLX subjective responses as a function of Mode of Interaction and Age Cohort.

	Mode of Interaction	Single	Auditory Vocal	Center Console	Center Stack	N-back	SuRT
Means (SD)	Younger (21-36 yrs)	3.75 (2.65)	6.57 (3.79)	9.02 (4.24)	8.98 (4.33)	11.4 (3.73)	10.4 (4.25)
	Older (55-75 yrs)	5.08 (3.27)	8.12 (4.39)	10.4 (4.2)	10.6 (4.74)	12.1 (4.09)	10.1 (4.53)
Age Cohort Contrasts (t-value)		2.55	3.42	2.93	3.21	1.53	-0.10
Mode of Interaction Contrasts (t-value)	Single						
	Auditory Vocal	13.60**					
	Center Console	20.29**	11.70**				
	Center Stack	23.46**	15.56**	0.69			
	N-back	27.00**	20.54**	8.29**	8.66**		
	SuRT	21.52**	13.61**	2.46	2.12	-5.52**	
Mode of Interaction by Age Cohort Contrasts (t-value)	Single						
	Auditory Vocal	0.43					
	Center Console	0.29	-0.09				
	Center Stack	0.34	-0.10	0.01			
	N-back	-1.13	-1.86	-1.49	-1.68		
	SuRT	-2.93*	-4.14**	-3.40**	-3.82**	-1.80	

Age Cohort by Vehicle

The interaction between Age Cohort and Vehicle was significant, $\chi^2(1, 5) = 14.2$, $p = .014$ (Figure 13). As shown in Table 18, age contrasts suggest that the effect of age was significant in the Audi A6, the Nissan Pathfinder and the Volvo XC90. Vehicle contrasts suggest several slight differences in the perception of workload when completing IVIS tasks in each of the vehicles. Vehicle by Age Cohort contrasts likewise revealed differences in the age effect across different vehicles (see Table 18).

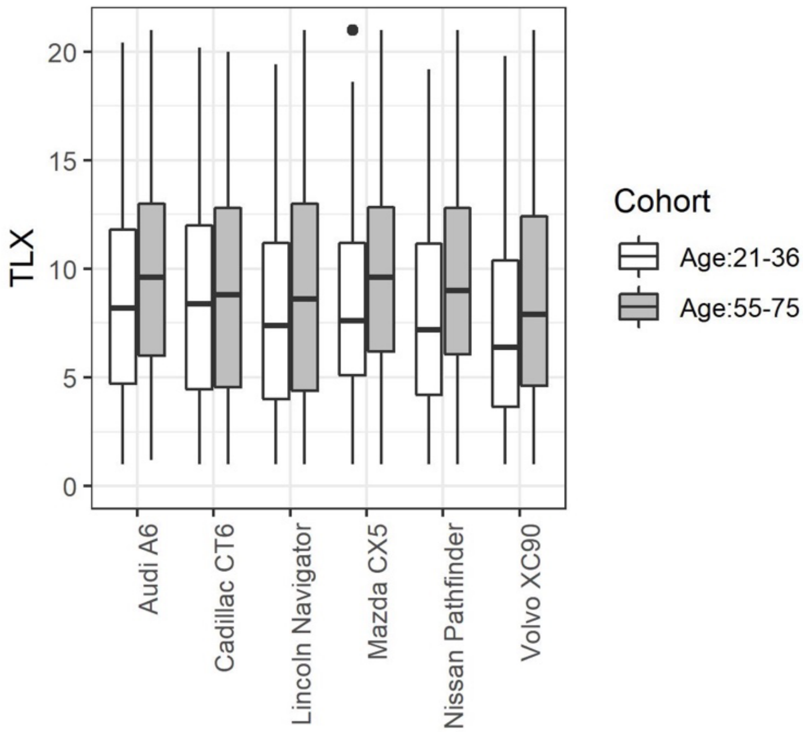

Figure 13. Subjective workload as a function of Age Cohort and Vehicle. The vertical dashed lines visually separate the baseline and reference tasks.

Table 18. Pairwise comparisons for NASA-TLX subjective responses as a function of Vehicle and Age Cohort.

	Vehicle	Audi A6	Cadillac CT6	Lincoln Navigator	Mazda CX5	Nissan Pathfinder	Volvo XC90
Means (SD)	Younger (21-36 yrs)	8.36 (4.45)	8.59 (4.68)	7.83 (4.61)	8.23 (4.30)	7.70 (4.32)	7.12 (4.19)
	Older (55-75 yrs)	9.55 (4.42)	8.92 (4.91)	9.07 (5.16)	9.62 (4.43)	9.49 (4.45)	8.66 (4.89)
Age Cohort Contrasts (t-value)		3.08*	0.38	1.59	2.55	2.85*	3.25*
Vehicle Contrasts (t-value)	Audi A6						
	Cadillac CT6	-1.82					
	Lincoln Navigator	-3.51**	-1.56				
	Mazda CX5	3.51**	4.99**	6.68**			
	Nissan Pathfinder	3.00*	4.48**	6.23**	-0.66		
	Volvo XC90	-0.46	1.29	2.90*	-4.04**	-3.55**	
Vehicle Contrasts by Age Cohort (t-value)	Audi A6						
	Cadillac CT6	-3.09**					
	Lincoln Navigator	-1.79	1.40				
	Mazda CX5	-0.51	2.30	1.09			
	Nissan Pathfinder	-0.22	2.63*	1.43	0.32		
	Volvo XC90	0.24	3.16**	1.94	0.75	0.46	

Open-Ended Responses

All participant responses or comments regarding the open-ended question (i.e., "Do you have any comments about the task or vehicle after this last run?") were aggregated and processed in order to better understand the subjective perspective of participants' experience and to account for potential age-related differences. A team of five researchers read through comments as a group several times to identify and reach consensus on common themes and tones. This resulted in seven themes, each with a definition and example (See Table 19) and three tones: positive, neutral and negative. Thematic categories were chosen based on the frequency of keywords, while tones were chosen based on the connotation of the value of preferences, features or design. All seven themes could potentially be identified in a single comment. Therefore, comments were separated for each individual theme and weighted equally. In actuality, the highest number of themes observed in a single comment was five, which resulted in five separate statements given equal weights of 0.2. Similarly, if neutral comments contained nested positive and negative statements, the statements were split into two separate units and weighted appropriately. Reviewers were first trained on identifying each of the themes and tones. Then, they practiced coding comments together until comments could be reliably classified. Reviewers were then assigned an equal number of comments to classify.

Table 19. Thematic key used for coding participant responses.

Term	**Definition**	**Example**
General Usability	- Ergonomics/Affordances - Ease of mapping to action	"I don't know why you had to go back to the main menu."
Safety/Risk	- Comment related to danger, distractibility, fatigue, discomfort - Safety: eyes/on off the road	"I would have pulled over" "How is this legal?"
Comparative Statements and Preferences	- Comparing any feature with another task, activity, vehicle	"This is better than _____."
Physical Design	- Comments regarding physical accessibility of the system itself	"The button is hard to reach." "There is too much glare on the [touch screen]."
Familiarity/Learning	- General musings on training - Length of time to use/navigate - Intuition/flexibility/difficulty	"This would be easier to learn if I had more time."
Real World Application	- Likelihood of mapping tasks onto a practical application	"I would *never* use this feature if this were my car."
Miscellaneous	- Ambiguous, irrelevant, unidentifiable or out-of-context statements - Other comments	"I did bad on this one."

In general, older drivers were more likely than younger drivers to provide a comment following each condition. Overall, 247 comments were provided by younger drivers and 554 by older drivers (see Table 20). As comments were not required, many participants chose not to comment. Due to the disparity in the rate of comments made by older (86% response rate) and younger drivers (67% response rate), coded comments are presented as ratios. Descriptive statistics were then applied to each of the themes in order to gain insight into the relative distribution of comments between age cohorts.

Table 20. Themes ranked by percentage of tone in participant responses.

Younger Drivers (247 Comments)				
Theme	**Negative**	**Neutral**	**Positive**	**Row Total**
General Usability	31.0%	3.0%	16.4%	50.4%
Safety/Risk	10.3%	0.4%	1.0%	11.7%
Comparative Statements and Preferences	5.3%	1.2%	4.3%	10.8%
Physical Design	5.7%		3.4%	9.1%
Familiarity/Learning	2.5%	1.4%	1.0%	5.0%
Real World	3.2%	0.8%		4.0%
Miscellaneous	7.0%	2.0%		9.0%
Column Total	65.0%	8.9%	26.1%	100.0%
Older Drivers (554 Comments)				
Theme	**Negative**	**Neutral**	**Positive**	**Row Total**
General Usability	25.1%	3.1%	18.2%	46.4%
Safety/Risk	15.6%	0.6%	1.6%	17.7%
Comparative Statements and Preferences	5.7%	1.7%	5.2%	12.6%
Physical Design	7.8%	0.4%	1.8%	10.0%
Familiarity/Learning	1.6%	3.3%	0.6%	5.4%
Real World	2.3%	0.2%	0.5%	3.0%
Miscellaneous	3.1%	1.0%	0.7%	4.9%
Column Total	61.2%	10.2%	28.5%	100.0%

General Usability

We observed that 50% of younger drivers' comments were related to general usability, while 46% of comments made by older drivers related to this theme (see Table 20). We also found that 25% of older drivers' comments were characterized by a negative tone, compared with 31% of younger drivers. This illustrated that more of the younger drivers' comments pertained negatively to general usability than older drivers' comments. Two-thirds of younger drivers' comments were found to be negative and related to general usability, nearly double the number of their positive comments on this theme.

Examples of positive, neutral and negatively toned comments made by younger and older drivers related to general usability included:

- "Easy to use! System was very receptive to voice commands." *(Older drivers) (Positive)*
- "Fairly intuitive, but multiple steps make it more difficult to accomplish." *(Older drivers) (Neutral)*
- "Confused and disappointed that it wouldn't play the band called Nirvana after asking several different ways." *(Older drivers) (Negative)*

- “Good voice recognition and easy to use commands.” *(Younger drivers) (Positive)*
- “Relatively easy to use but wish there was an easier way to return to home.” *(Younger drivers) (Neutral)*
- “...Too many categories, lots of touching needed to get to your chosen destination.” *(Younger drivers) (Negative)*

Safety/Risk

We observed that approximately 12% of comments made by younger drivers were related to safety and risk. Older drivers made more comments related to this theme (17%). Both younger and older drivers made 10 times as many negatively toned comments as positively toned comments related to safety and risk.

Examples of positive, neutral and negatively toned comments made by younger and older drivers related to safety and risk included:

- “...felt very safe operating it and driving at same time.” *(Older drivers) (Positive)*
- “Was successful but still felt distracted. Can hear the computer voice quite well.” *(Older drivers) (Neutral)*
- “...dangerously distracting due to all the screen time needed.” *(Older drivers) (Negative)*
- “...didn’t take away from my driving focus.” *(Young drivers) (Positive)*
- “Not bad, but still distracting.” *(Young drivers) (Neutral)*
- “...felt like I wasn’t doing a great job of watching the road while entering coordinates, the nav system seems unsafe to use while driving.” *(Younger drivers) (Negative)*

Comparative Statements and Preferences

We found that 12.6% of all comments made by older drivers were comparative statements and preferences, compared with 10.8% of comments by younger drivers. The tone of comments made by younger and older drivers was similar.

Examples of positive, neutral and negatively toned comparative statements and preferences included:

- “Best so far.” *(Older drivers) (Positive)*
- “While I still do not like the rotary wheel, it was simpler than voice recognition.” *(Older drivers) (Neutral)*
- “Voice is better. Using wheel took eyes off the road far too long.” *(Older drivers) (Negative)*
- “Had an easier time using the system when I was driving than during practice beforehand.” *(Younger drivers) (Positive)*
- “It’s fine.” *(Young drivers) (Neutral)*

- “Harder to use than the voice system.” *(Younger drivers) (Negative)*

Physical Design

Of comments made by younger drivers, 9.1% related to physical design compared with 10% for older drivers. We found that 38% of younger drivers’ comments made on physical design were positive, while only 18% of the comments made by older drivers were positive. Thus, while younger and older drivers commented with a similar frequency, there was a large discrepancy in tone related to this theme. Young drivers made no neutral comments on physical design.

Examples of positive, neutral and negatively toned comments made by younger and older drivers related to physical design included:

- “Large icons are helpful...” *(Older drivers) (Positive)*
- “Put a bump on the voice activation button.” *(Older drivers) (Neutral)*
- “Control knob inconsistent in direction.” *(Older drivers) (Negative)*
- “I like how large the buttons are on the touch screen, it makes them easy to push.” *(Younger drivers) (Positive)*
- “...I wish the dialing buttons were a little bigger....” *(Younger drivers) (Negative)*

Familiarity and Learning

We observed that 5% of younger drivers’ total comments were coded to the familiarity and learning theme, compared with 5.4% for older drivers. We saw that 60% of older drivers’ comments were coded as neutral.

Examples of positive, neutral and negatively toned comments made by younger and older drivers related to familiarity and learning included:

- “...Maybe as I became more familiar with the system and the list, this dial system would become easier...” *(Older drivers) (Positive)*
- “Just need practice.” *(Older drivers) (Neutral)*
- “Lots of information needed to familiarize oneself with this system.” *(Older drivers) (Negative)*
- “...eventually got it right with better pronunciation.” *(Younger drivers) (Positive)*
- “I think if I spent more time with this system, I would be able to finish the tasks more quickly and efficiently.” *(Younger drivers) (Neutral)*
- “I struggle to remember to wait for the beep before speaking and then mess up.” *(Younger drivers) (Negative)*

Real World (Real-World Application)

We observed that 4% of younger drivers’ total comments were coded as real-world application, compared with 3% of older drivers’ comments. Both age cohorts tended to make comments that were negatively toned. None of the younger drivers commented in a positively toned manner related to this theme.

Examples of positive, neutral and negatively toned comments made by younger and older drivers related to real world application included:

- "I would like to use this system for my car." *(Older drivers) (Positive)*
- "...The actual menu is too similar to a smartphone. Those menus don't work well when you're driving and need to find a thing fast..." *(Older drivers) (Neutral)*
- "I would only use a system like this if it was completely voice activated..." *(Older drivers) (Negative)*
- "...but I am more likely to use the voice navigation for other music things since it was easier to focus on driving with it." *(Younger drivers) (Neutral)*
- "I probably would not use this feature…" *(Younger drivers) (Negative)*
- "I don't think I would use the SMS voice command. Too many questions to send a text." *(Younger drivers) (Negative)*

Miscellaneous

We observed that 9% of younger drivers' total comments were coded as miscellaneous, compared with 4.9% of older drivers' comments. Both cohorts tended to make negatively toned comments. As seen in Table 20, younger drivers refrained from making any positively toned comments.

Examples of positive, neutral and negatively toned comments made by younger and older drivers included:

- "This is a win!" *(Older drivers) (Positive)*
- "Wondering if 'beep' sound level is adjustable." *(Older drivers) (Neutral)*
- "It was sorta crazy!" *(Older drivers) (Negative)*
- "Did the same way every time." *(Younger drivers) (Neutral)*
- "More text response answers." *(Younger drivers) (Negative)*

Discussion

This research investigated the challenges that older drivers face when completing several common tasks using the In-Vehicle Information System (IVIS) of six 2018 vehicles. Prior research has shown that, compared with younger drivers, older drivers exhibit greater difficulty dividing attention between tasks. This has been shown both in general laboratory tasks and in driving. How these generally reported differences are manifest in interactions with real-world vehicle technologies has not been well studied. This research provides additional insight into the unique challenges faced by older drivers as they interact with modern in-vehicle technologies, by addressing two sets of previously unanswered questions related to IVIS use.

Q1: Do IVIS interaction demands differ for older and younger drivers? If so, how?

Results suggest that, compared with younger drivers, older drivers experienced increased workload when interacting with IVIS. Older adults were slower to respond to the DRT stimuli (higher cognitive demand), were more likely to fail to respond to the forward LED (higher visual demand) and required more time to complete all tasks (increased exposure). Measures of cognitive, visual and temporal demand for older and younger drivers indicated nearly identical patterns between all conditions (e.g., conditions that resulted in high workload for younger drivers also resulted in high workload for older drivers). However, measured workload for older drivers was consistently higher than for younger drivers.

Q2: Are some interfaces more difficult for older drivers to use? If so, why?

Older drivers had an especially difficult time maintaining visual attention to the forward roadway during secondary task interactions (as quantified by hit rate to the forward LED DRT stimulus; see Strayer et al., 2017), especially when completing IVIS tasks. IVIS task interactions are demanding in general but especially so for older drivers. Older drivers may benefit from interface designs that promote their continued visual attention on or near the forward roadway (e.g., careful placement of physical controls and dials, screen placement in line with forward vision, use of voice controls, etc.).

Summary of Results

Task Completion Time

When compared with younger drivers, older drivers required more time to complete tasks in all experimental conditions. Some noteworthy differences occurred between task type, mode of interaction and vehicle.

- Task type: On average, both younger and older drivers completed the audio entertainment and calling and dialing task types in less than the 24-second time reference. Navigation entry and text messaging task types each required significantly more than 24 seconds for both younger and older drivers (Table 4).
- Mode of interaction: Tasks were completed more quickly using the center stack display by both age groups. Older drivers, on average, required more than 24 seconds to complete the auditory vocal, Center Console, Center Stack tasks (Table 5).

- Vehicle: On average, both age groups completed tasks in the Cadillac CT6 and the Lincoln Navigator in under 24 seconds. Task completion time for older and younger drivers straddled the time threshold in the Audi A6, Nissan Pathfinder and Volvo XC90, where younger drivers were below and older drivers above 24 seconds. In the Mazda CX-5, both younger and older drivers required more than 24 seconds, on average, to complete tasks (see Table 6).

Task completion time is an important facet of driver workload as it represents exposure. All other demands being equal, tasks that require twice as long to complete will result in twice the distraction potential. Thus, task completion time can be treated as multiplier of distraction potential (see Strayer et al., 2015).

DRT Reaction Time

Younger drivers' reaction times were consistently faster than older drivers across task type, mode of interaction and vehicle. Specifically:

- Task type: Older drivers exhibited slower reaction time, compared with younger drivers, across all task types. These differences were amplified in the IVIS task conditions, compared to the single-task baseline (Table 8).
- Mode of interaction: Older drivers were slower than younger drivers in their responses. The age-related differences were similar across all modes of interaction (Table 9).
- Vehicle: Reaction time was slightly elevated in the Mazda CX-5 and in the Nissan Pathfinder for both younger and older drivers (Table 10).

Reaction time to the DRT stimulus is a reliable and valid indicator of cognitive demand (cf. ISO 17488; ISO, 2015). Interestingly, reaction time to each of the tasks appeared to be relatively less sensitive to differences in task type, differences in the mode of interaction, and largely, differences in the vehicle. Reaction time did, however, greatly differ between the single task baseline and any of the other tasks. Reaction time also differentiated between the effects of age (i.e., main effect of Age Cohort as well as significant interactions and contrasts). The stability of reaction time during IVIS interactions, regardless of task type, mode of interaction and vehicle, suggests that at least with some tasks, cognitive demand remains constant throughout task engagement.

Several studies using the DRT have found differences in reaction time between tasks. For example, Strayer et al., (2014) reported reaction time differences among various auditory-vocal tasks. Yet, as noted above, in the current study, reaction time was less sensitive to the different IVIS task types, modes of interaction or vehicle. The observed parity in the current study indicates that the cognitive performance requirements of each task were likely similar across conditions. Miller and colleagues (1960) suggested that less demanding tasks require fewer steps to complete and processing demands for them can be chunked into working memory. Consistent with this, the IVIS tasks evaluated in the current research were discrete and well-structured with clear task steps. This structure may have encouraged drivers to fully engage with each IVIS task until the task was completed. Conversely, tasks such as listening to the radio or conversing on a cell phone may impose less demand because they are easier to chunk in working memory, resulting in intermittent performance requirements (e.g., characterized by epochs of talking, listening, and silence; see Strayer et al., 2013).

DRT Hit Rate

Older drivers evaluated in this research had a more difficult time dividing visual attention between driving and secondary tasks (i.e., responding to the LED stimuli in the DRT). Like reaction time, the effect of Age Cohort on hit rate was consistent for each of the four task types, and across each of the three modes of interaction.

- Task type: Older drivers exhibited greatly reduced hit rates across all task types compared with younger drivers (Table 12).
- Mode of interaction: Older drivers were less likely to respond to the forward LED across each of the three modes of interaction. When completing tasks with the center console controller, older drivers responded to just 21% of the LED stimuli, on average (Table 13).

  Vehicle: Older drivers were also less likely to respond to the forward LED in each of the vehicles. The magnitude of the age cohort effect on hit rate was greater for the Mazda CX-5 than it was for several of the other vehicles. This finding suggests that older drivers had an especially difficult time dividing their visual attention in the Mazda. This may have been due to the menu structure or the unconventional center console controls. However, further research needs to be completed to better understand why older adults more greatly struggled with the Mazda IVIS system (Table 14).

Subjective Workload

As with the other measures, subjective workload reflected age-related differences.

- Task type: All drivers found the calling and dialing and text messaging task types to be less demanding to perform than the navigation entry and audio entertainment task types. Overall, older drivers reported IVIS task interactions to be more demanding than younger drivers (Table 16).
- Mode of interaction: Both older and younger drivers reported that voice commands were less demanding to use than the center console or center stack controls. Older drivers reported that all modes of interaction were nominally more demanding than reported by younger drivers (Table 17).
- Vehicle: The effect of age cohort on subjective workload was dependent on the vehicle being driven. That is, for some vehicles, older drivers' ratings of demands were similar to those of younger drivers, whereas differences were observed for other vehicles (Table 18).

Participant Comments

The greatest challenge of processing drivers' comments was to categorize the central meaning of each comment and assign it to a theme. Each comment contained descriptive information with potential implications for the design of IVIS. Overwhelmingly, older drivers were more likely to comment than younger drivers, and responses from both groups were primarily negative in tone. Few differences between themes and age cohorts were observed, though older drivers expressed a greater desire to learn each system.

The similarity in comments made by drivers emphasizes a need for improvement of these in-vehicle systems for all drivers, regardless of age. Comments about each IVIS could clarify design requirements to maximize driver attention and safety. A well-designed in-vehicle system could support older drivers' attention and reduce the impact on their driving performance. Universal Design tenets could be employed as a future metric of how to improve iterations of IVIS to serve older drivers. Participant comments collected in this study help to expand the understanding of older drivers' experiences.

Implications

In-vehicle interfaces are becoming increasingly complicated. Controls are transitioning from traditional knobs and dials to those presented via voice or touch-screen displays. For older drivers, the transition to increased electronics and automation will present several unique opportunities and challenges. Once fully implemented, vehicle automation will have the potential to increase mobility of older drivers well beyond the years of when they would have otherwise given up driving. Even now, vehicles offer a variety of automated features that have the potential to aid older and younger drivers in highway environments as well as during low-speed parking maneuvers. A variety of active and passive safety systems may also help older drivers avoid collisions and even perform evasive maneuvers should they fail to act during collision events. Older drivers may benefit greatly from these advances in vehicle technology to the extent that they support driving related functions; yet ironically, older drivers may have a more difficult time making use of them.

A logical and potentially incorrect generalization of these findings would be to assume that poorly-performing tasks, modes of interaction or vehicles would result in increased on-road distraction. While this may be true, it may also be the case that drivers naturally refrain from activities that are complex, error-prone or slow to complete. Frustration arising from these tasks may cause drivers to seek out simpler IVIS interactions. For example, voice recognition systems in vehicles show promise; however, driver usage of these systems continues to be low (Viita, 2014), the reason being that they often require the use of precise keywords spoken in a very specific, and rigid order. The result may be an interaction that is more complex, frustrating and distracting than the same action completed using the touch screen on the center stack. Results from this evaluation should, therefore, be interpreted as a measure of the user experience, or distraction potential (Ranney et al., 2009; Lee & Strayer, 2004), and not necessarily a reflection of the level of on-road distraction that would be expected from these in-vehicle systems. Paradoxically, it may be the case that the most difficult and demanding systems evaluated in this research are also the least likely to result in driver distraction because they are not used while driving. Furthermore, there is the possibility that the in-vehicle information systems that are the most cumbersome to use may ultimately result in users abandoning the IVIS and using their personal smartphone to achieve the same tasks. This captures what has been described as the usability paradox (Lee & Strayer 2004) wherein distraction may increase with usability. Complex user requirements may pose unnecessary system-based barriers, which could result in circumstances where older drivers are faced with no good options.

The time required to complete tasks is a simple and effective way to evaluate general task demands. This has been noted by other researchers when applied to visual-manual interactions with IVIS systems (e.g., Green 1999). We found that all tasks, regardless of whether they used voice commands, the center stack display or the center console controller, imposed cognitive and visual demands. Not surprisingly, however, hit rates to the forward LED were even lower for tasks that removed vision from the road. Reaction time differed between older and younger drivers, and as drivers interacted with the in-vehicle information systems but did not often differ within task type, mode of interaction or vehicle. Thus, a simple two-measure approach of distraction potential, which includes the assessment of task completion time with a measure of visual attention, may be sufficient to understand driver workload when completing discrete tasks with IVIS.

Findings from this research suggest that generalizing driver workload from younger to older drivers may underestimate the workload experienced by older drivers. Systems that meet specific testing criteria when evaluated using younger testers may perform very differently when evaluated using older drivers. In the Visual Manual Distraction Guidelines published by NHTSA, a participant sampling strategy that includes drivers from four age groups is indicated (NHTSA 2013). These broad age inclusion criteria have caused some researchers to note that older drivers may disproportionally sway the outcome of testing (e.g., Domeyer et al., 2014). Given the consistent performance differences between younger and older drivers when interacting with vehicle technologies, we recommend that future testing give higher priority to evaluating older users. Systems that are usable by older adults will also be usable by younger adults, but the converse may not always be the case.

Design Recommendations

Compared with younger drivers, older drivers in this research exhibited slower reaction time, decreased hit rate, longer task completion time and reported higher task demand when interacting with IVIS. These general findings suggest that, at a minimum, older drivers should be included in a Universal Design validation as their interactions with vehicle technologies may significantly differ from that of younger drivers. Universal Design tenets revolve around the accessibility and ease of use of objects, systems and environments for all people regardless of their age, physical ability or gender identity (Czaja et al., 2009). Relevant principles of Universal Design for vehicle manufacturers include *Equity, Flexibility, Simplicity, Perceptibility, Error Recovery,* and *Accessibility* (Farage et al., 2012). These principles may provide a framework for improvement of IVIS design. An emphasis on simplicity would benefit drivers of all ages (Farage et al., 2012).

Both older and younger drivers exhibited difficulty dividing attention between tasks presented on the touch screen and the forward roadway. Minimizing the visual scanning distance between IVIS and the road is critical. Data from this study suggests that a center console controller is especially cumbersome for older drivers and that care should be taken to help drivers maintain their visual attention on the forward roadway without introducing unnatural interfaces that may cause interference with safe driving (e.g., rotary wheels, multi-function buttons, character drawing pads, etc.). While voice commands may help to reduce many of the potential problems of other interface types, they will only be used by drivers if the systems accurately process requests in a timely fashion. Furthermore, even auditory vocal interactions imposed a relatively high level of demand on drivers. Thus, no interface is demand free and all interactions with vehicle technologies should be carefully considered and restricted where possible and when reasonable.

Conclusion

This research investigated the unique challenges faced by older drivers as they completed several common tasks using the In-Vehicle Information System (IVIS) of six 2018 vehicles. Compared with younger drivers, older drivers exhibited significant increases in cognitive and visual workload when completing IVIS tasks. Older drivers struggled to divide their visual attention between IVIS tasks and the forward roadway. In some cases, older drivers responded to as few as 21% of LED illuminations presented on the forward windscreen (see Table 13).

Older drivers also required significantly more time than younger drivers to complete all task interactions. An analysis of subjective workload found that drivers were generally aware of task demands but may have underestimated their actual workload, as quantified in the other measures. Comments provided by drivers after each task interaction suggested that both older and younger drivers shared similar concerns about the experience of modern IVIS. In addition, the classification of comments into positive, negative and neutral tones indicated that comments were predominantly negative. Results from this research suggest that current versions of IVIS are demanding and difficult to use, especially for older drivers. For older drivers to fully realize the potential benefits of current and future vehicle technologies, a renewed focus on accessible design is required.

Acknowledgement

Equipment comprising the Detection Response Time (DRT) task was provided by Red Scientific, which was founded by the lead investigator, JMC.

References

Albert, G., Lotan, T., Weiss, P., & Shiftan, Y. (2018). The challenge of safe driving among elderly drivers. *Healthcare Technology Letters, 5*(1), 45-48. doi:10.1049/htl.2017.0002

Barhorst-Cates, E. M., Rand, K. M., & Creem-Regehr, S. H. (2016). The effects of restricted peripheral field-of-view on spatial learning while navigating. *PLOS ONE, 11*(10). doi:10.1371/journal.pone.0163785

Barhorst-Cates, E. M., Rand, K. M., & Creem-Regehr, S. H. (2017). Let me be your guide: Physical guidance improves spatial learning for older adults with simulated low vision. *Experimental Brain Research*, *235*(11), 3307-3317. doi:10.1007/s00221-017-5063-8

Bates D., Maechler M., Bolker B., & Walker S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software, 67*(1), 1-48. doi:10.18637/jss.v067.i01

Bédard, M., Leonard, E., Mcauliffe, J., Weaver, B., Gibbons, C., & Dubois, S. (2006). Visual attention and older drivers: The contribution of inhibition of return to safe driving. *Experimental Aging Research, 32*(2), 119-135. doi:10.1080/03610730500511918

Bellet, T., Paris, J., & Marin-Lamellet, C. (2018). Difficulties experienced by older drivers during their regular driving and their expectations towards Advanced Driving Aid Systems and vehicle automation. *Transportation Research Part F: Traffic Psychology and Behaviour, 52*, 138-163. doi:10.1016/j.trf.2017.11.014

Braun, V. & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, *3*(2), 77-101.

Breen, D. A., Breen, D. P., Moore, J. W., Breen, P. A., & O'Neill, D. (2007). Driving and dementia. *BMJ*, *334*(7608), 1365-1369.

Brouwer, W. H., Waterink, W., Wolffelaar, P. C., & Rothengatter, T. (1991). Divided attention in experienced young and older drivers: Lane tracking and visual analysis in a dynamic driving simulator. *Human Factors, 33*(5), 573-582. doi:10.1177/001872089103300508

Castro, S., Cooper, J., & Strayer, D. (2016). Validating two assessment strategies for visual and cognitive load in a simulated driving task. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 60,* 1899-1903.

Chandraratna, S. & Stamatiadis, N. (2003). Problem driving maneuvers of elderly drivers. *Transportation Research Record*, 1843(1), 89-95.

Clapp, W. C., Rubens, M. T., Sabharwal, J., & Gazzaley, A. (2011). Deficit in switching between functional brain networks underlies the impact of multitasking on working memory in older adults. *Proceedings of the National Academy of Sciences*, *108*(17), 7212-7217.

Cooper, J. M., Castro, S. C., & Strayer, D. L. (2016). Extending the Detection Response Task to simultaneously measure cognitive and visual task demands. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 60*, 1962-1966.

Cooper, J. M., Ingebretsen, H., & Strayer, D. L. (2014). *Measuring Cognitive Distraction in the Automobile IIa: Mental Demands of Voice-Based Vehicle Interactions with OEM Systems*. Washington, D.C.: AAA Foundation for Traffic Safety.

Craik, F. I. M. (1977). Age differences in human memory. In J. Birren & K. W. Schaie (Eds.), *Handbook of the Psychology of Aging* (pp. 384–420). New York: Van Nostrand Reinhold.

Crowe, M., Inder, M., & Porter, R. (2015). Conducting qualitative research in mental health: Thematic and content analyses. *Australian & New Zealand Journal of Psychiatry,* 49(7), 616-623.

Cummings, M. L., Kilgore, R. M., Wang, E., Tijerina, L., & Kochhar, D. S. (2007). Effects of single versus multiple warnings on driver performance. *Human Factors*, *49*(6), 1097–1106. doi: 10.1518/001872007X249956

Czaja, S. J., Rogers, W. A., Fisk, A. D., Charness, N., & Sharit, J. (2009). *Designing for older adults: Principles and creative human factors approaches*. Baton Rouge, FL: CRC press. http://dx.doi.org/10.1201/9781420080681.

Dingus, T.A., Guo, F., Lee, S., Antin, J.F., Perez, M., Buchanan-King, M., Hankey, J. (2016). Driver crash risk factors and prevalence evaluation using naturalistic driving data. *Proceedings of the National Academy of Sciences,* 113(10), 2636-2641. doi: 10.1073/pnas.1513271113

Domeyer, J.E., Diptiman, T., & Hamada, H. (2014). Using occlusion to measure the effects of the NHTSA participant criteria on driver distraction testing. *Proceedings of the Human Factors and Ergonomics Society 58th Annual Meeting, 58,* 2205-2209.

Farage, M. A., Miller, K. W., Ajayi, F., & Hutchins, D. (2012). Design principles to accommodate older adults. *Global Journal of Health Science*, *4*(2), 2.

Fellbaum, C. (1998). *WordNet: An Electronic Lexical Database and Some of its Applications*. Cambridge, MA: MIT Press.

Graham, J. W., Taylor, B. J., Olchowski, A. E., & Cumsille, P. E. (2006). Planned missing data designs in psychological research. *Psychological Methods*, *11*(4), 323.

Green, P. (1999). The 15-second rule for driver information systems. *Proceedings of the ITS America Ninth Annual Meeting.* Washington, D.C.: Intelligent Transportation Society of America.

Hart, S. G., & Staveland, L. E. (1988). Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. *Advances in Psychology, 52*, 139-183.

Hartley, A. (1992). Attention. In F. Craik & T. Salthouse (Eds.), *Handbook of Aging and Cognition* (pp. 3–49). Hillsdale, NJ: Erlbaum.

Hartley, A. A. & Little, D. M. (1999). Age-related differences and similarities in dual-task interference. *Journal of Experimental Psychology: General*, *128*(4), 416.

Huisingh, C., Owsley, C., Levitan, E. B., Irvin, M. R., MacLennan, P., & McGwin, G. (2018). Distracted driving and risk of crash or near-crash involvement among older drivers using naturalistic driving data with a case-crossover study design. *The Journals of Gerontology: Series A*, *74*(4), 550-555.

International Organization for Standardization (2015). *Road Vehicles – Transport Information and Control Systems – Detection Response Task (DRT) for Assessing Attentional Effects of Cognitive Load in Driving* (Rep. ISO 17488). Geneva, Switzerland: International Organization for Standardization.

International Organization for Standardization (2012). *Road vehicles – Ergonomic aspects of transport information and control systems – Calibration tasks for methods which assess driver demand due to the use of in-vehicle systems.* (Rep. ISO 14198) Geneva, Switzerland: International Organization for Standardization. ISO/TC 22/SC 39.

Kelley-Baker, T., Kim, W. & Villavicencio, L. (2017). *The Longitudinal Research on Aging Drivers (LongROAD) Study: Understanding the Design and Methods*. Washington, D.C.: AAA Foundation for Traffic Safety.

Kramer, A. F. & Larish, J. L. (1996). Aging and dual-task performance. *Aging and Skilled Performance*, 83-112.

Lee, J. D. & Strayer, D. L. (2004). Preface to the special section on driver distraction. *Human Factors*, *46*(4), 583-586.

Little, T. D., & Rhemtulla, M. (2013). Planned missing data designs for developmental researchers. *Child Development Perspectives*, *7*(4), 199-204.

McDowd, J. M. & Shaw, R. J. (2000). Attention and aging: A functional perspective. In F. I. M. Craik & T. A. Salthouse (Eds.), *The Handbook of Aging and Cognition* (pp. 221-292). Mahwah, NJ: Lawrence Erlbaum Associates.

Mehler, B., Reimer, B., & Dusek, J. A. (2011). *MIT AgeLab Delayed Digit Recall Task (n-back).* Cambridge, MA: Massachusetts Institute of Technology.

Miller, G. A., Galanter, E., & Pribram, K. H. (1960). Plans and the structure of behavior. *New York: Henry Holt and Co.*

National Safety Council (2017). *Injury Facts: 2017 Edition*. From http://viewer.zmags.com/publication/20020222#/20020222/1.

National highway Transportation Safety Administration (2013). Visual-Manual NHTSA Driver Distraction Guidelines for In-Vehicle Electronic Devices: Notice of Federal Guidelines (pp. 24817 – 24890): Federal Register 78:81 (26 April 2013).

Ott, B. R., Heindel, W. C., Papandonatos, G. D., Festa, E. K., Davis, J. D., Daiello, L. A., & Morris, J. C. (2008). A longitudinal study of drivers with Alzheimer disease. *Neurology, 70*(14), 1171-1178. doi:10.1212/01.wnl.0000294469.27156.30

Ott, B. R., & Daiello, L. A. (2010). How does dementia affect driving in older patients? *Aging Health, 6*(1), 77-85. doi:10.2217/ahe.09.83

Owsley C. (2010). Aging and vision. *Vision Research*, *51*(13), 1610-1622.

R Core Team (2019). *R: A Language and Environment for Statistical Computing*. Vienna: R Foundation for Statistical Computing. URL: https://www.R-project.org/.

Ranney, T. A., Baldwin, G. H., Vasko, S. M., & Mazzae, E. N. (2009). *Measuring Distraction Potential of Operating In-Vehicle Devices* (No. HS-811 231). Washington, D.C.: National Highway Traffic Safety Administration.

Regan, M. A., Hallett, C., & Gordon, C. P. (2011). Driver distraction and driver inattention: Definition, relationship and taxonomy. *Accident Analysis & Prevention*, *43*(5), 1771-1781.

Strayer, D. L., Cooper, J. M., Goethe, R., McCarty.M, Getty, Biondi, F. (2017) *Visual and Cognitive Demands of Using In-Vehicle Infotainment Systems*. Washington, D.C.: AAA Foundation for Traffic Safety.

Strayer, D., Cooper, J., McCarty, M., Getty, D., Wheatley, C., Motzkus, C., Mackenzie, K., Loveless, S., Esplin, J., Goethe, R., & Biondi, F. (2018). *Visual and Cognitive Demands of Using Apple's CarPlay, Google's Android Auto and Five Different OEM Infotainment Systems*. Washington, D.C.: AAA Foundation for Traffic Safety.

Strayer, D. L., Cooper, J. M., Turrill, J. M., Coleman, J. R., & Hopman, R. J. (2015). *Measuring Cognitive Distraction in the Automobile III: A Comparison of 10 2015 In-Vehicle Information Systems*. Washington, D.C.: AAA Foundation for Traffic Safety.

Strayer, D. L., Cooper, J. M., Turrill, J., Coleman, J., Medeiros-Ward, N., & Biondi, F. (2013). *Measuring Cognitive Distraction in the Automobile.* Washington, D.C.: AAA Foundation for Traffic Safety.

Strayer, D. L., Drews, F. A., & Johnston, W. A. (2003). Cell phone-induced failures of visual attention during simulated driving. *Journal of Experimental Psychology: Applied*, *9(*1), 23.

Strayer, D. L., Turrill, J., Coleman, J., Ortiz, E., & Cooper, J. M. (2014). *Measuring Cognitive Distraction in the Automobile: II. Assessing In-vehicle Voice-based Interactive Technologies*. Washington, D.C.: AAA Foundation for Traffic Safety.

Swinkels, R. A., & Swinkels-Meewisse, I. E. (2014). Normal values for cervical range of motion. *Spine*, *39*(5), 362-367.

Thompson, K. R., Johnson, A. M., Emerson, J. L., Dawson, J. D., Boer, E. R., & Rizzo, M. (2012). Distracted driving in elderly and middle-aged drivers. *Accident Analysis & Prevention, 45*, 711-717. doi:10.1016/j.aap.2011.09.040

Vaportzis, E., Clausen, M. G., & Gow, A. J. (2017). Older adults perceptions of technology and barriers to interacting with tablet computers: A focus group study. *Frontiers in Psychology*, *8*, 1687.

Viita, D. (2014). Usage and Satisfaction of Voice Recognition and Touchscreen HMI. Retrieved December 12, 2018, from https://www.strategyanalytics.com/access-services/automotive/in-vehicle-ux/reports/report-detail/usage-and-satisfaction-of-voice-recognition-and-touchscreen-hmi?Related

Watson, J. M., Miller, A. E., Lambert, A., Strayer, D. L. (2011). The magical letters P,F,C, and sometimes U: The rise and fall of executive attention with the development of prefrontal cortex. In K. Fingerman, C. Berg, T. Antonucci, & J. Smith (Eds.), *Handbook of Lifespan Psychology* (pp. 407-436). New York: Springer.

Winter, B. (2013). A very basic tutorial for performing linear mixed effects analyses. arXiv: 1308.5499.

Wood, J. M., Anstey, K. J., Lacherez, P. F., Kerr, G. K., Mallon, K., & Lord, S. R. (2009). The on-road difficulties of older drivers and their relationship with self-reported motor vehicle crashes. *Journal of the American Geriatrics Society, 57*(11), 2062-2069. doi:10.1111/j.1532-5415.2009.02498.x

Appendix 1

A. Audio Entertainment Tasks - *Standardized Task List*

- Radio frequency tuning (AM, FM)
- iPod content (songs, artists, albums, genres)
- This task is complete when the audio entertainment has successfully been changed

1. Choose a **jazz song** from the **iPad**
2. Play **1020 AM**
3. Tune the **radio** to **98.5 FM**
4. Listen to the **song "99 Red Balloons"**
5. You want to hear a song by the **band Nirvana**
6. Change the **radio** to your favorite **FM station**
7. Play a **song** in the **metal genre**
8. Let's hear the **song "I'm Gonna Be (500 Miles)"**
9. You want to hear one of **your favorite AM stations**
10. Tune **AM 1540**
11. **89.1**
12. Tune to **1240**
13. **iPod** play **album "Storyline"**
14. **AM 1160**
15. Play a song by the **artist Eminem**
16. Play the **album "Homesick"**
17. **90.1**
18. You want to **play Johnny Cash** songs
19. **Radio 1630**
20. You want to play the **song "Riptide"** from the **iPod**
21. Switch to **the artist Louis Armstrong**
22. Play the **alternative genre**
23. Change the **genre to reggae**
24. **Radio** tune to **97.1 FM**
25. You want to hear the **artist Hunter Hayes**
26. Change the music to the **song "Three Little Birds"**
27. Listen to **FM 99.5**

Vehicle	Audi A6		Cadillac CT6		Lincoln Navigator		Mazda CX-5		Nissan Pathfinder		Volvo XC90	
Mode of Interaction	CS	VC	CC	VC	CS	VC	CC	VC	CS	VC	CS	VC
Audio Entertainment	A	A	A	A	A	A	A	A	A	A	A	A
Calling and Dialing	B	B	B	B	B	B	B	B	C	B	B	B
Navigation	D	D	D	D	E	D	F	F	G	D	D	D
Text Messaging	H	H	I	-	J	J, K	H	H	H	H	-	H

B. Calling and Dialing Tasks - *Standardized Task List*

- Participant calls contacts (cellphone, work).
- Dials numbers (participant's own phone number, 801-555-1234).
- Task is complete once call has been successfully ended.

1. **Jack Olsen** would like you to call him on his **cellphone** **2.** You need to call **8"OH"1-555-1234** **3.** Place a call to the contact **Willow Brooks** **4.** Try to reach **Brad Peterson** **5.** Enter **8"ZERO"1-555-1234** **6.** You can't find **your phone**. Call it to find it. **7.** Ring **Felicity Gomez's office** **8.** Enter your **own number** **9.** You missed a call from **Oliver Reed** **10.** Telephone **8"OH"1-555-1234** **11.** **Violet Wheeler** is waiting to hear back from you on her **mobile**	**12.** Dial your **own number** **13.** Give **Phil Potter** a call back **at work** **14.** Give **8"ZERO"1-555-1234** a call **15.** Try **Helen Harold** on her **business number** **16.** Call your **own phone** **17.** **8"OH"1-555-1234** **18.** **Bethany Swan, cellphone** **19.** Telephone **Jennifer Long** **20.** You need to talk to **Yolanda Chavez** **21.** Dial **Tanya Henry** **22.** Call **Andrew Fink's mobile** back

Vehicle	Audi A6		Cadillac CT6		Lincoln Navigator		Mazda CX-5		Nissan Pathfinder		Volvo XC90	
Mode of Interaction	CS	VC	CC	VC	CS	VC	CC	VC	CS	VC	CS	VC
Audio Entertainment	A	A	A	A	A	A	A	A	A	A	A	A
Calling and Dialing	**B**	**B**	**B**	**B**	**B**	**B**	**B**	**B**	C	**B**	**B**	**B**
Navigation	D	D	D	D	E	D	F	F	G	D	D	D
Text Messaging	H	H	I	-	J	J, K	H	H	H	H	-	H

C. Calling and Dialing Tasks - *Standardized Task List*

- Participant calls contacts (cellphone, work).
- Dials numbers (participant's own phone number, 801-555-1234).
- The task is complete once the call has been successfully ended.

1. **Jack Olsen** would like you to call him on his **cellphone** **2.** Place a call to the contact: **Willow Brooks** **3.** Try to reach **Brad Peterson** **4.** Ring **Felicity Gomez's cell** **5.** You missed a call from **Oliver Reed** **6.** **Violet Wheeler** is waiting to hear back from you on her **mobile** **7.** Give **Phil Potter** a call back **8.** Try **Helen Harold** on her **mobile number** **9.** **Bethany Swan, cellphone** **10.** Telephone **Jennifer Long**	**11.** You need to talk to **Willow Brooks** **12.** Dial **Brad Peterson** **13.** Call **Jack Olsen mobile** back **14.** You need to call **Jennifer Long** **15.** Place a call to **Helen Harold** **16.** You can't reach **Bethany Swan**. Call her again. **17.** You need to reach **Oliver Reed** **18.** Telephone **Phil Potter** **19.** Dial **Felicity Gomez mobile** **20.** Give **Violet Wheeler** a call

Vehicle	Audi A6		Cadillac CT6		Lincoln Navigator		Mazda CX-5		Nissan Pathfinder		Volvo XC90	
Mode of Interaction	CS	VC	CC	VC	CS	VC	CC	VC	CS	VC	CS	VC
Audio Entertainment	A	A	A	A	A	A	A	A	A	A	A	A
Calling and Dialing	B	B	B	B	B	B	B	B	**C**	B	B	B
Navigation	D	D	D	D	E	D	F	F	G	D	D	D
Text Messaging	H	H	I	-	J	J, K	H	H	H	H	-	H

D. Navigation Tasks - *Adjustments for Vehicle Capabilities*

- Participant sets the destination to a point of interest that best fits the task goal.
- The task is complete once the participant successfully cancels route guidance.

1. **(Gas)** Fill up at the closest gas station.
2. **(Library)** Your library book is overdue. Let's return it at the closest library.
3. **(Italian Restaurant)** You're headed out for some Italian food at nearby restaurant.
4. **(Coffee shop)** Grab yourself a cup of coffee from the closest Starbucks.
5. **(Grocery store)** You need some items from Whole Foods.
6. **(ATM\bank)** You need to get cash from a Wells Fargo bank.
7. **(Mexican Restaurant)** Find a Mexican restaurant nearest you.
8. **(Hospital)** Go visit your friend at the LDS Hospital.
9. **(Chinese Restaurant)** You're craving food from Panda Express.
10. **(Movie theater)** You're on your way to see a movie at the nearby theater.
11. **(Hotel/Motel)** Drive to the nearest lodging to stay the night.
12. **(Post office)** You have a package to drop off at the closest post office.
13. **(Museum)** Go check out the new exhibit at the Utah Museum of Natural History.
14. **(Shopping Center)** Go pick out some new clothes at a nearby shopping mall.

Vehicle	Audi A6		Cadillac CT6		Lincoln Navigator		Mazda CX-5		Nissan Pathfinder		Volvo XC90	
Mode of Interaction	CS	VC	CC	VC	CS	VC	CC	VC	CS	VC	CS	VC
Audio Entertainment	A	A	A	A	A	A	A	A	A	A	A	A
Calling and Dialing	B	B	B	B	B	B	B	B	C	B	B	B
Navigation	**D**	**D**	**D**	**D**	E	**D**	F	F	G	**D**	**D**	**D**
Text Messaging	H	H	I	-	J	J, K	H	H	H	H	-	H

E. Navigation Tasks - *Standardized Task List*

- Participant sets the destination to a point of interest that best fits the task goal.
- The task is complete once the participant successfully cancels route guidance.

1. **(Gas)** Fill up at the closest gas station.
2. **(Library)** Your library book is overdue. Let's return it at the closest library.
3. **(Restaurant)** You're headed out for some food at a nearby restaurant.
4. **(Coffee shop)** Grab yourself a cup of coffee from the closest coffee shop.
5. **(Grocery store)** You need some items from a nearby grocery store.
6. **(ATM\bank)** You need to get cash from a nearby bank or ATM.
7. **(Restaurant)** Find another restaurant nearby.
8. **(Hospital)** Go visit your friend at a nearby hospital.
9. **(Cafe)** You're craving food from a nearby cafe.
10. **(Movie theater)** You're on your way to see a movie at the nearby theater.
11. **(Hotel/Motel)** Drive to the nearest lodging to stay the night.
12. **(Post Office)** You have a package to drop off at the closest post office.
13. **(Museum)** Go check out the new exhibit at a nearby museum.
14. **(Shopping Center)** Go pick out some new clothes at a nearby shopping mall.

Vehicle	Audi A6		Cadillac CT6		Lincoln Navigator		Mazda CX-5		Nissan Pathfinder		Volvo XC90	
Mode of Interaction	CS	VC	CC	VC	CS	VC	CC	VC	CS	VC	CS	VC
Audio Entertainment	A	A	A	A	A	A	A	A	A	A	A	A
Calling and Dialing	B	B	B	B	B	B	B	B	C	B	B	B
Navigation	D	D	D	D	**E**	D	F	F	G	D	D	D
Text Messaging	H	H	I	-	J	J, K	H	H	H	H	-	H

F. Navigation Tasks - *Adjustments for Vehicle Capabilities*

- Participant sets the destination to a point of interest that best fits the task goal.
- The task is complete once the participant successfully cancels route guidance.

1. **(Gas)** Fill up at the closest gas station.
2. **(Library)** Your library book is overdue. Let's return it at the closest library.
3. **(Italian Restaurant)** You're headed out for some Italian food at nearby restaurant.
4. **(Cafe)** Grab yourself a cup of coffee from the closest Starbucks.
5. **(Grocery store)** You need some items from Fresh Market.
6. **(ATM\Bank)** You need to get cash from a Wells Fargo bank.
7. **(Mexican Restaurant)** Find a Mexican restaurant nearest you.
8. **(Hospital)** Go visit your friend at the LDS Hospital.
9. **(Chinese Restaurant)** You're craving food from Panda Express.
10. **(Movie theater)** You're on your way to see a movie at the nearby theater.
11. **(Hotel/Motel)** Drive to the nearest lodging to stay the night.
12. **(Post office)** You have a package to drop off at the closest post office.
13. **(Museum)** Go check out the new exhibit at the Utah Museum of Natural History.
14. **(Shopping Center)** Go pick out some new clothes at a nearby shopping mall.

Vehicle	Audi A6		Cadillac CT6		Lincoln Navigator		Mazda CX-5		Nissan Pathfinder		Volvo XC90	
Mode of Interaction	CS	VC	CC	VC	CS	VC	CC	VC	CS	VC	CS	VC
Audio Entertainment	A	A	A	A	A	A	A	A	A	A	A	A
Calling and Dialing	B	B	B	B	B	B	B	B	C	B	B	B
Navigation	D	D	D	D	E	D	**F**	**F**	G	D	D	D
Text Messaging	H	H	I	-	J	J, K	H	H	H	H	-	H

G. Navigation Tasks - *Standardized Task List*

- Participant sets the destination to a point of interest that best fits the task goal.
- The task is complete once the participant successfully cancels route guidance.

1. **(Gas)** Fill up at the closest gas station.
2. **(Rest Stop)** You left your wallet at the Jordanelle rest stop. Go retrieve it.
3. **(Restaurant)** You're headed out for some dinner at nearby restaurant.
4. **(Gas Station/Restaurant)** Grab a beverage from somewhere nearby to hydrate yourself.
5. **(Hotel/Motel)** Go check in at the closest motel for the night.
6. **(ATM\bank)** You need to get cash from a Wells Fargo bank.
7. **(Restaurant)** You are hungry for a sandwich, go to a place to satisfy your craving.
8. **(Hospital)** Go visit your friend at a Hospital.
9. **(Gas)** Go check your tire pressure at a nearby gas station.
10. **(Hotel/Motel)** Drive to the nearest lodging to stay the night.
11. **(Fire Station)** Attend the free CPR training at the nearby fire station.
12. **(ATM)** Deposit a check at a nearby ATM.
13. **(Rest Stop)** Make sure to see the sights at Coalville rest stop.

Vehicle	Audi A6		Cadillac CT6		Lincoln Navigator		Mazda CX-5		Nissan Pathfinder		Volvo XC90	
Mode of Interaction	CS	VC	CC	VC	CS	VC	CC	VC	CS	VC	CS	VC
Audio Entertainment	A	A	A	A	A	A	A	A	A	A	A	A
Calling and Dialing	B	B	B	B	B	B	B	B	C	B	B	B
Navigation	D	D	D	D	E	D	F	F	G	D	D	D
Text Messaging	H	H	I	-	J	J, K	H	H	H	H	-	H

H. SMS - *Standardized Task List (Read and Send)*

- Participant reads or listens to text messages and responds with system-specific predetermined messages.*
- The task is complete once the participant successfully sends a message.

1. Read out the message from **Cam Whitman**. Please respond. **2.** Read and reply to the text from **Scarlet Miles** **3.** What did **Duncan Redford** send you? Send your answer. **4.** **Maggie Carter** just messaged you. What should you send back? **5.** What did **Connie Motts** say? Reply to her. **6.** Find a message from **Andy Cameron**. Reply. **7.** **Jane Evans** sent you a new text. Send something back. **8.** Read the text from **Duncan Redford** and respond to it. **9.** What did **Maggie Carter** send you? Send a text back.	**10.** Read and respond to the text from **Scarlet Miles.** **11.** New message from **Cam Whitman**. How do you reply? **12.** What did **Andy Cameron** send you? Answer him. **13.** You need to read and reply to **Jane Evan's** message. **14.** Read out the message from **Maggie Carter.** Send your reply. **15.** What did **Connie Motts** send you? Text her back. **16.** How do you respond to the text from **Duncan Redford**? **17.** What does the message from **Jane Evans** say? Respond. **18.** Read and then reply to the new message from **Connie Motts.**

Vehicle	Audi A6		Cadillac CT6		Lincoln Navigator		Mazda CX-5		Nissan Pathfinder		Volvo XC90	
Mode of Interaction	CS	VC	CC	VC	CS	VC	CC	VC	CS	VC	CS	VC
Audio Entertainment	A	A	A	A	A	A	A	A	A	A	A	A
Calling and Dialing	B	B	B	B	B	B	B	B	C	B	B	B
Navigation	D	D	D	D	E	D	F	F	G	D	D	D
Text Messaging	**H**	**H**	I	-	J	J, K	**H**	**H**	**H**	**H**	-	**H**

I. SMS - *Adjustments for Vehicle Capabilities (Read Only)*

- Participant reads or listens to text messages and responds with system-specific predetermined messages.
- Task is complete once the participant successfully sends a message.

1. Read out the message from **Cam Whitman**. Please respond.
2. Read and reply to the text from **Connie Motts**
3. What did **Duncan Redford** send you? Send your answer.
4. **Maggie Carter** just messaged you. What should you send back?
5. What did **Connie Motts** say? Reply to her.
6. Find a message from **Cam Whitman**. Reply.
7. **Maggie Carter** sent you a new text. Send something back.
8. Read the text from **Duncan Redford** and respond to it.
9. What did **Connie Motts** send you? Send a text back.
10. Read and respond to the text from **Maggie Carter.**
11. New message from **Cam Whitman**. How do you reply?
12. What did **Duncan Redford** send you? Answer him.
13. You need to read and reply to **Connie Motts'** message.
14. Read out the message from **Maggie Carter.** Send your reply.
15. What did **Connie Motts** send you? Text her back.
16. How do you respond to the text from **Duncan Redford**?
17. What does the message from **Cam Whitman** say? Respond.
18. Read and then reply to the new message from **Connie Motts.**

Vehicle	Audi A6		Cadillac CT6		Lincoln Navigator		Mazda CX-5		Nissan Pathfinder		Volvo XC90	
Mode of Interaction	CS	VC	CC	VC	CS	VC	CC	VC	CS	VC	CS	VC
Audio Entertainment	A	A	A	A	A	A	A	A	A	A	A	A
Calling and Dialing	B	B	B	B	B	B	B	B	C	B	B	B
Navigation	D	D	D	D	E	D	F	F	G	D	D	D
Text Messaging	H	H	I	-	J	J, K	H	H	H	H	-	H

J. SMS - *Adjustments for Vehicle Capabilities (Read Only)*

- Participant listens to text messages and responds with system-specific predetermined messages.
- The task is complete once the participant successfully reads the desired message aloud.

1. Read out the message from **Cam Whitman**.
2. Read the text from **Scarlet Miles.**
3. What did **Duncan Redford** send you?
4. **Maggie Carter** just messaged you.
5. What did **Connie Motts** say?
6. Find a message from **Andy Cameron**.
7. **Jane Evans** sent you a new text.
8. Read the text from **Duncan Redford**.
9. What did **Maggie Carter** send you?
10. Read the text from **Scarlet Miles.**
11. New message from **Cam Whitman**.
12. What did **Andy Cameron** send you?
13. You need to read **Jane Evan's** message.
14. Read out the message from **Maggie Carter.**
15. What did **Connie Motts** send you?
16. How do you respond to the text from **Duncan Redford**?
17. What does the message from **Jane Evans** say?
18. Read the new message from **Connie Motts.**

Vehicle	Audi A6		Cadillac CT6		Lincoln Navigator		Mazda CX-5		Nissan Pathfinder		Volvo XC90	
Mode of Interaction	CS	VC	CC	VC	CS	VC	CC	VC	CS	VC	CS	VC
Audio Entertainment	A	A	A	A	A	A	A	A	A	A	A	A
Calling and Dialing	B	B	B	B	B	B	B	B	C	B	B	B
Navigation	D	D	D	D	E	D	F	F	G	D	D	D
Text Messaging	H	H	I	-	**J**	**J**, K	H	H	H	H	-	H

K. SMS - ***Adjustments for Vehicle Capabilities (Send Only)***

- Participant replies to the most recent text message with system-specific predetermined messages.
- The task is complete once the participant successfully sends the desired message.

1. Let **Duncan Redford** know you're going to be late.
2. **Duncan Redford** is asking if you want to go to the movies tonight.
3. **Duncan Redford** wants to go dancing tonight.
4. **Duncan Redford** texted you a funny joke.
5. Ask **Duncan Redford** to call you
6. **Duncan Redford asked where you are**.
7. Tell **Duncan Redford** you can call him soon.
8. Tell **Duncan Redford** you are on your way.
9. **Duncan Redford** texted you a silly dad joke.
10. **Duncan Redford** has big news and is wondering if you can talk right now.
11. **Duncan Redford** dropped off your favorite cookies at your house.
12. **Duncan Redford** is wondering where you are.
13. **Duncan Redford** can pick you up from the airport next week.
14. Tell **Duncan Redford** to call you after **work.**
15. Tell **Duncan Redford** you want to talk later
16. **Duncan Redford** wants to know if they can copy your homework.
17. **Duncan Redford** wants to know why you're not at the restaurant yet.
18. **Duncan Redford** says they will clean your car for you tonight.

Vehicle	Audi A6		Cadillac CT6		Lincoln Navigator		Mazda CX-5		Nissan Pathfinder		Volvo XC90	
Mode of Interaction	CS	VC	CC	VC	CS	VC	CC	VC	CS	VC	CS	VC
Audio Entertainment	A	A	A	A	A	A	A	A	A	A	A	A
Calling and Dialing	B	B	B	B	B	B	B	B	C	B	B	B
Navigation	D	D	D	D	E	D	F	F	G	D	D	D
Text Messaging	H	H	I	-	J	J, **K**	H	H	H	H	-	H

Appendix 2

Task Completion Time

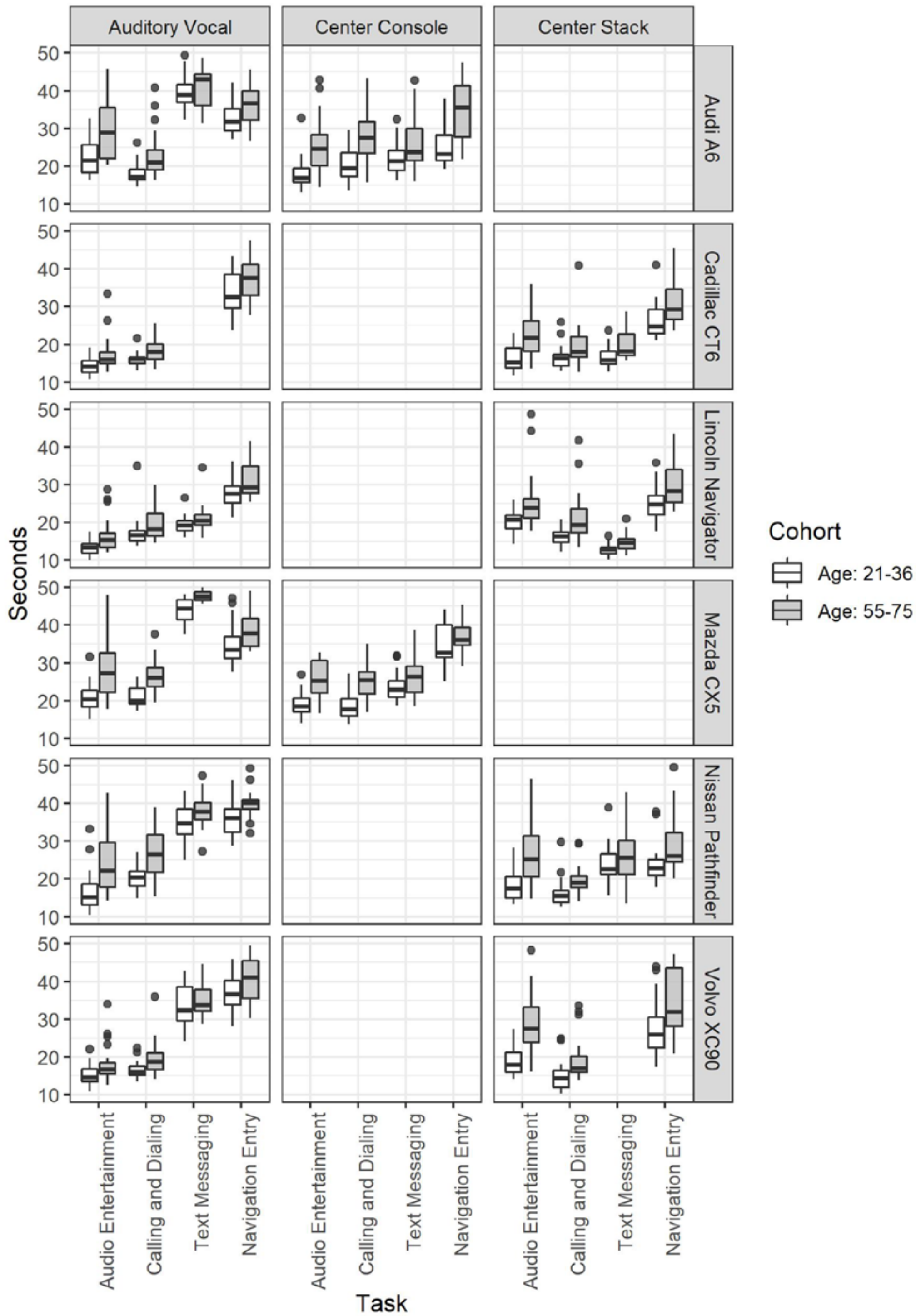

Figure A1. Task completion time (s) as a function of Age Cohort, Mode of Interaction, Task Type, and Vehicle

DRT reaction time

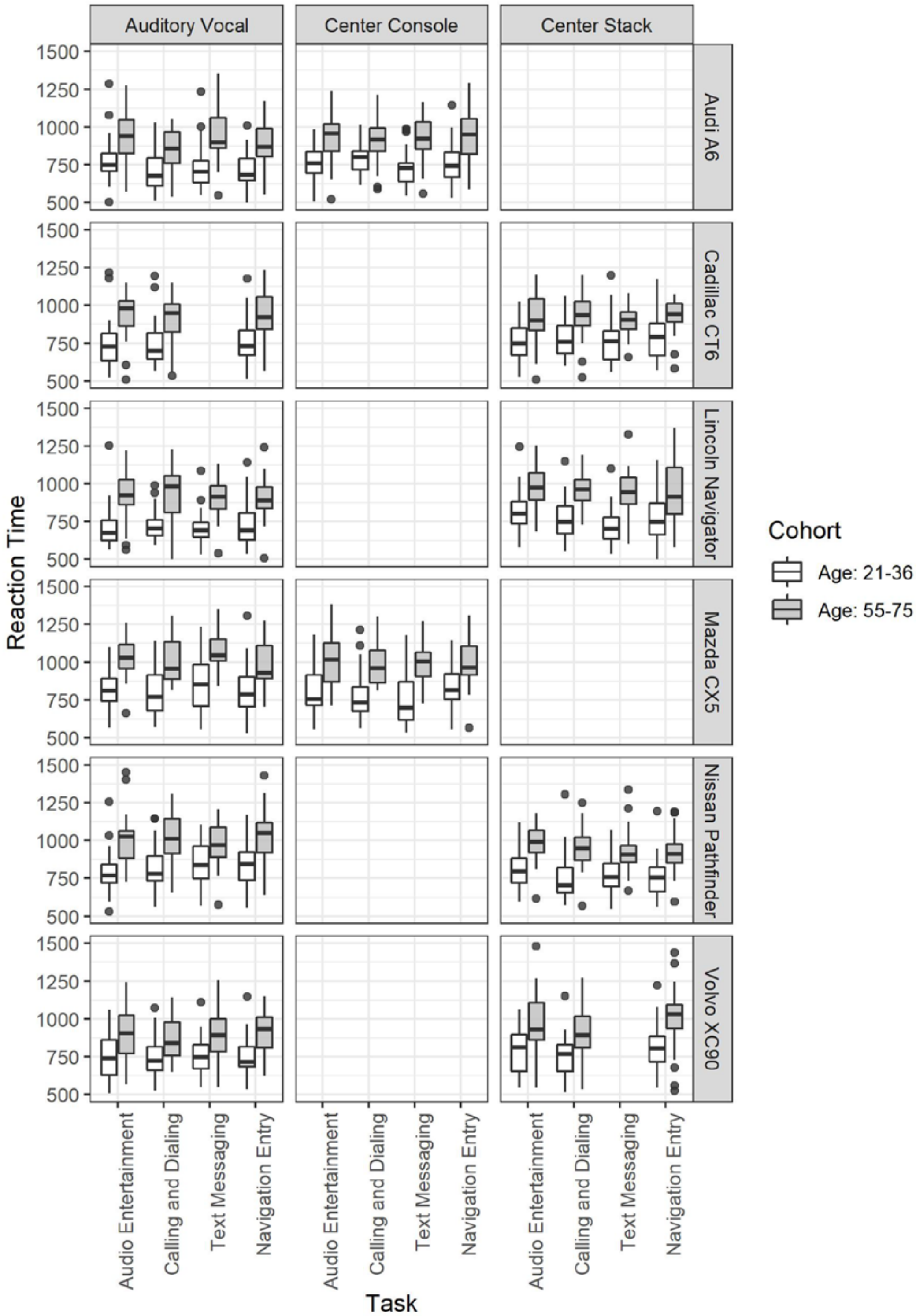

Figure A2. DRT reaction time (ms) as a function of Age Cohort, Mode of Interaction, Task Type, and Vehicle

DRT Hit Rate

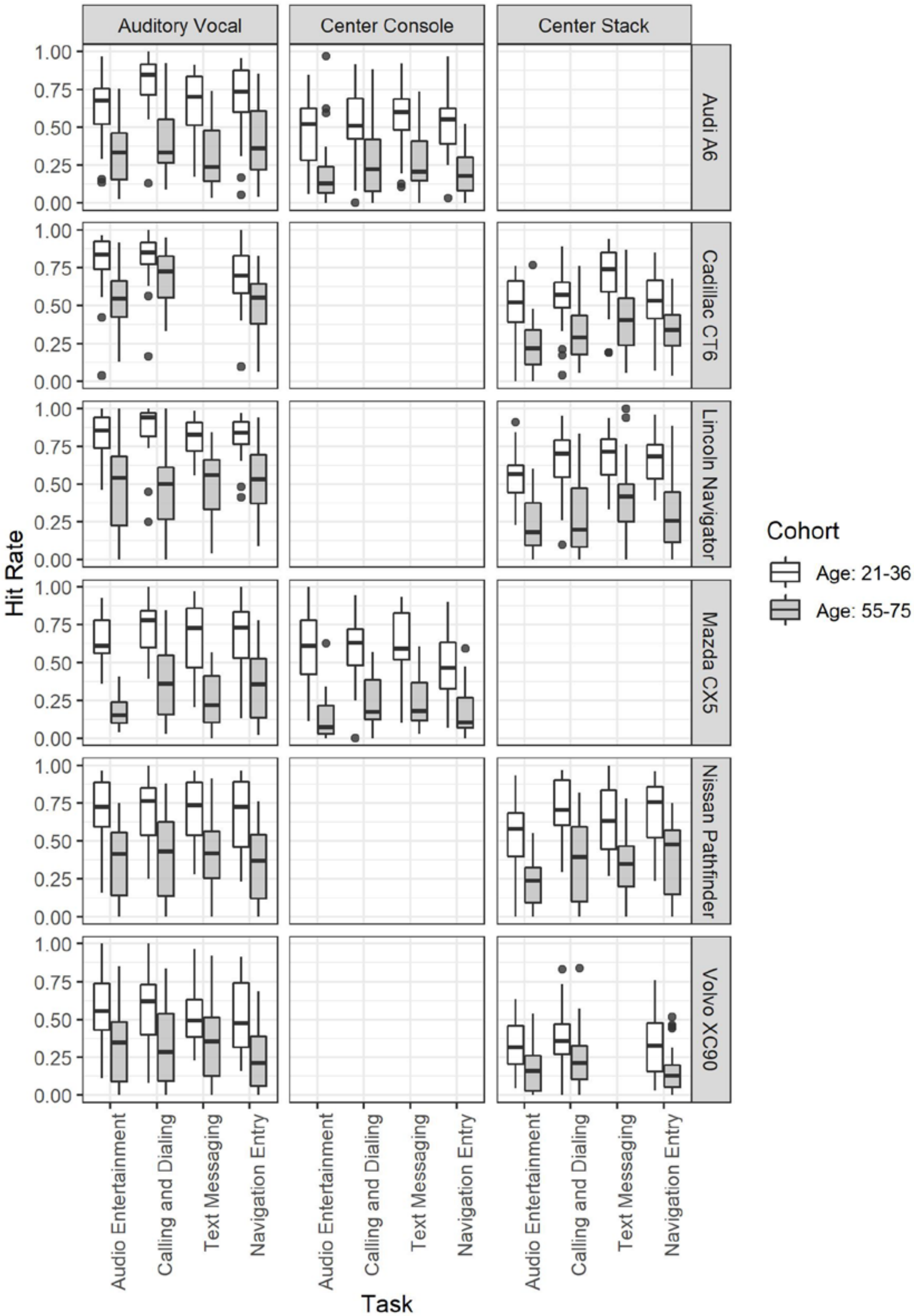

Figure A3. DRT hit rate as a function of Age Cohort, Mode of Interaction, Task Type, and Vehicle

Subjective Workload

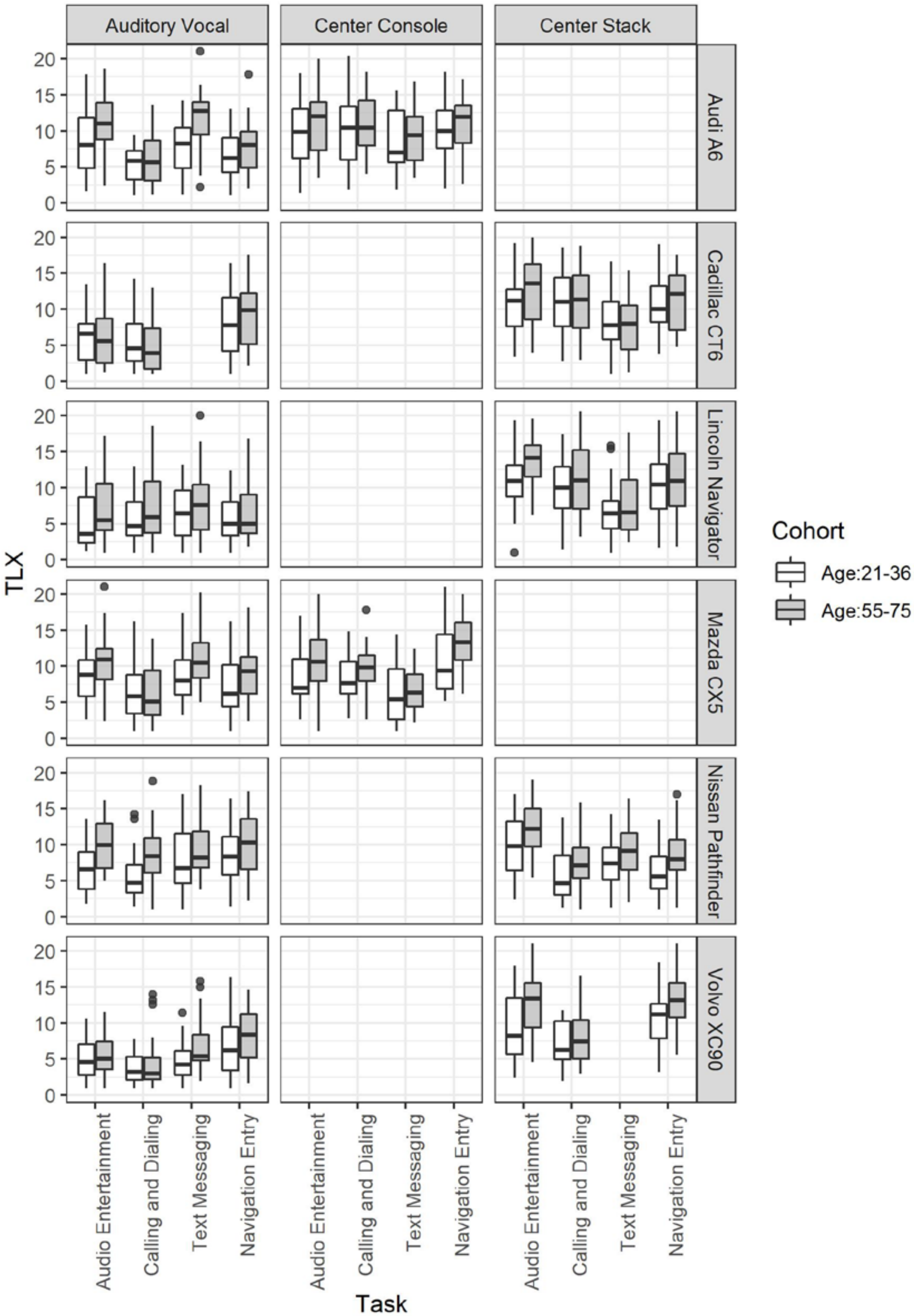

Figure A4. Subjective workload as a function of Age Cohort, Mode of Interaction, Task Type, and Vehicle