Age-Related Differences in Driver Behavior Associated with Automated Vehicles and the Transfer of Control between Automated and Manual Control: A Simulator Evaluation

Lisa J. Molnar[1], Anuj K. Pradhan[1], David W. Eby[1], Lindsay H. Ryan[2], Renée M. St. Louis[1], Jennifer Zakrajsek[1], Brittany Ross[1], Brian T. Lin[1], Chen Liang[1], Bethany Zalewski[1], and Liang Zhang[1]

[1]University of Michigan
Transportation Research Institute

[2]Institute for Social Research

May 2017

UMTRI 2017-4

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Age-Related Differences in Driver Behavior Associated with Automated Vehicles and the Transfer of Control between Automated and Manual Control: A Simulator Evaluation		5. Report Date May, 2017 6. Performing Organization Code
7. Author(s) Lisa J. Molnar, Anuj K. Pradhan, David W. Eby, Lindsay H. Ryan, Renée M. St. Louis, Jennifer Zakrajsek, Brittany Ross, Brian T. Lin, Chen Liang, Bethany Zalewski, and Liang Zhang		8. Performing Organization Report No.
9. Performing Organization Name and Address University of Michigan Transportation Research Institute 2901 Baxter Rd. Ann Arbor, MI 48109-2150 U.S.A		10. Work Unit No. (TRAIS) 11. Contract or Grant No. MTC Project Number: 2015-08
12. Sponsoring Agency Name and Address Mobility Transformation Center 2901 Baxter Rd. Ann Arbor, MI 48109-2150 U.S.A		13. Type of Report and Period Covered Final 14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

The overall objective of this exploratory research was to examine specific human factors issues associated with transfer of control between automated and manual driving to characterize age-related differences in behaviors and reactions to this transition. Seventy-two participants were recruited from three age groups (young novice drivers age 16-19, older drivers age 65-75, and comparison drivers age 25-45). Participants were presented with simulated driving environments containing manual and automated driving modes with multiple transition scenarios. Objective driving data were collected on take-over related measures and visual gaze behaviors. Following the drive, participants completed the NASA TLX questionnaire, a structured interview to explore perceptions related to the drive, and a questionnaire to gather background information and to explore the use of various technologies. When analyzing performance in the driving simulator in terms of take-over related measures and visual gaze behaviors, it appeared that the young driver group markedly different, whereas the older driver group was closer in behaviors to the comparison group. There were also age differences found in the structured interview, questionnaire, and NASA TLX. This project extended research on automated vehicle technologies to encompass the social and behavioral aspects of the transfer of control between automated and manual control, and helps provide a foundation knowledge for age-specific issues related to automated vehicles.

17. Key Word Automated vehicles, simulator, older adults, novice drivers, transfer of control	18. Distribution Statement Unlimited		
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 55	22. Price

BACKGROUND AND INTRODUCTION

Motor vehicle crashes represent a significant public health problem in the United States. Per mile traveled, fatal crash rates are elevated for both older and young drivers (Insurance Institute for Highway Safety, 2016). The increased crash and injury risk of older drivers has been attributed to age-related declines in abilities important for driving, as well increased fragility and frailty (Boot, Stothart & Charness, 2014; Dickerson et al., 2007; Meuleners, Harding, Lee & Legge, 2006). The elevated crash risk among younger drivers is generally considered to result from inexperience and immaturity (Romer, Lee, McDonald & Winston, 2014). Efforts to reduce crashes have been multifaceted, focusing on vehicle and road improvements, as well as changes in driver behavior.

Of particular note in the vehicle arena are advances being made in automated vehicle technology leading to vehicle designs in which at least some aspects of a safety-critical control function (e.g., steering, throttle, or braking) occur without direct input from the driver (National Highway Traffic Safety Administration, NHTSA, 2016). These advances hold promise for increasing vehicle safety and reducing fatal and non-fatal injuries, particularly among the more vulnerable or high-risk segments of the driving population. However, at least during the early stages of automation adoption, vehicle automation can lead to new and yet unstudied types of risks and errors in drivers or operators. Given the differences in driving abilities, skills, and behaviors of the older and younger novice driving population from other segments of the driving population (Hakamies-Blomqvist et al., 1999; Ponds et al, 1988), these potential errors and risks can have a different impact on safety and thus warrant closer investigation.

Important safety issues related to the role of the operator remain and there exists an acknowledged research gap in the understanding of human behavior and interaction with automation (Merat & Lee, 2012), especially in the context of age and experience. An important example of this gap is the fundamental human factors question on the issue of transitioning, or transfer of control, between automated control and manual control in an automated vehicle, especially in Level 2 and Level 3 automated vehicles characterized by some self-driving automation but not the full self-driving automation anticipated for Level 4 (see NHTSA, 2016 for more detail on levels).

PROJECT OBJECTIVE AND AIMS

The overall objective of this exploratory research was to examine specific human factors issues associated with transfer of control to characterize age-related differences in behaviors and reactions to this transition. Behavioral issues and challenges related to automated vehicles are only beginning to be recognized and investigated. The research results from this project provide new insights into age-related differences in the transfer of control between the driver and the automated vehicle with regard to expectations, trust, acceptance, and performance, and how such differences might affect safety. Thus, the knowledge gained from the project will contribute to improving highway safety, an integral component of MTC's mission.

Specific Project Aims

The project had several specific aims including to: 1) characterize driving behavior and responses to transfer of control in an automated vehicle (from automated control to manual control and vice-versa) for older drivers, novice teen drivers, and a comparison group; 2) examine visual scanning behaviors in the three groups during automated driving versus manual driving; 3) assess and compare perceived workload for the three groups when operating an automated vehicle; and 4) explore participants' perceptions about driver expectations, trust, acceptability, and performance as they relate to automated vehicle transfer of control.

APPROACH

Experimental Design

The study employed an independent measures design with three groups based on driver age (novice teen drivers age 16-19, older drivers age 65-75, and a comparison group of drivers age 25-45). Participants in each group were presented with simulated driving environments that contained multiple mode transition scenarios (automated mode to manual mode and vice versa). Each participant completed a structured interview immediately following the simulated drive to explore self-perceptions related to the drive. Finally, they completed a self-administered questionnaire to obtain background information.

Participants

Three groups of drivers were recruited using various techniques (see Appendix A for recruitment materials). The goal was to have enrolled 24 participants in each group at study completion (with attrition estimated at 10% due to simulator sickness and other reasons for withdrawal). The first group was comprised of novice drivers age 16-19 who held a Michigan Level 2 provisional driver license (which allows independent driving with some restrictions) and had their licenses less than 6 months. The second group was comprised of older drivers age 65-75 who had had a regular license for at least 12 months. The third group was comprised of comparison drivers age 25-45 who had had a regular license for at least 12 months.

All participants had to drive at least twice a week on average to be eligible for enrollment (based on self-report). Each group was balanced for sex to the extent possible. Teen assent and parental consent were obtained for the participants under age 18 and consent was obtained from those over age 18. Participants were provided with an incentive of $50 for roughly 1.5 hours of study participation (1 hour of simulated driving and .5 hours for the structured interview and background questionnaire).

Data Collection and Analysis

Driving simulation

A high-fidelity advanced driving simulator from the University of Michigan Transportation Research Institute (UMTRI) was used to present the virtual driving environment to participants. UMTRI's fixed-base simulator consists of a Nissan Versa sedan located in a dedicated lab space, integrated with a simulation system running version 2.63 of Realtime Technology's (RTI) simulation engine, SimCreator (Figure 1) along with custom code for automated vehicle features. The simulator system incorporates a total of 10 central processing units (CPUs): a Host, which serves as the operator interface, six Image Generators, which render the various projected scenes, one CPU to render the virtual instrument cluster, one data-logging CPU, and one CPU to run the SmartEye eye-tracking system. Forward road scenes are projected on three screens about 16 feet in front of the driver (120-degree field of view) and a rear channel 12 feet away (40 degree field of view). Each forward channel has 1400x1050 resolution and updates at 60 Hz. Optional lateral-view screens on the left and right of the simulator vehicle provide an additional 80 degrees of visual view, for a total 200-degree field of view. The lateral screens and the rear channel has

1024x768 resolution. A servomotor provides steering feedback, and road vibration is delivered through a bass-shaker mounted under the cab. A virtual instrument cluster controlled by one of the simulation computers has replaced the original instrument cluster. Its interface can be custom designed to meet study demands using the industry standard development tool, Altia Design. There are three separate audio systems: 1) the fully functional production system in the Versa; 2) a cab interior system for issuing alerts, etc.; and, 3) a room system for simulating the external automotive audio environment.

The simulation system is highly programmable to create a variety of virtual driving worlds and scenarios, including automated vehicle functions and appropriate transitions between automated and non-automated driving conditions. Various parameters of transitions can be selectively programmed including time, alerts, and switching modalities. In addition, the simulator records various categories of driving data such as velocity, acceleration, and lane position at 30Hz, as well as in-cab audio and video. A SmartEye four-camera eye-tracking system is installed in the simulator (Figure 2), and provides head-pose, eye-blink, and gaze location and time data that are used to determine at which objects in the real and the virtual world the subject looks at and for how long. The system includes a dedicated data-logging computer, which records objective measures from the simulation, synchronized with the eye-tracking data, and up to six channels of video and two channels of audio. The system contains in-house developed analysis software that allows the overlay of the gaze vector onto the video of the forward scene.

FIGURE 1. UMTRI Driving Simulator

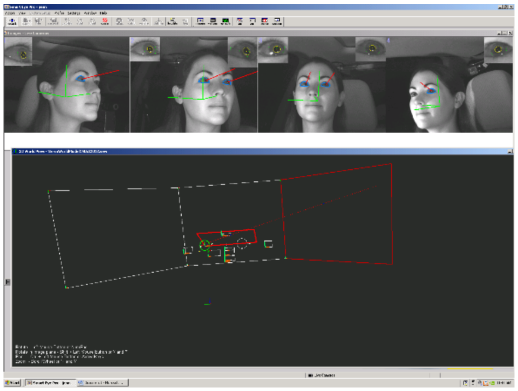


FIGURE 2. Eye tracker

The protocol for the driving simulation experiment exposed participants to automated driving situations and to the associated transitions between automated and manual driving. Each participant was presented with a simulated drive about 20 minutes in length that had two driving modes embedded within, manual mode and automated mode. In the manual mode the participant had full control of the vehicle, with the drive designed to elicit natural driving behavior. The automated mode simulated a Level 3 automated vehicle. By the Society of Automotive Engineers (SAE) definition of vehicle automation levels (SAE, 2014), in a Level 3 vehicle, an automated system can both perform some aspects of the driving task and monitor the driving environment in some instances, but the human driver must be ready to take back control when the automated system requests (SAE, 2014). In this mode, the participant relinquishes all control of the simulated vehicle to the automation including steering, brake, and throttle. In the automated mode, the simulated vehicle 'self-drives' in a virtual world containing rural, expressway, urban, and residential sections.

After completing informed consent, participants were calibrated for the eye-tracking system in the driving simulator. They were familiarized with the driving simulator via a representative practice drive for about 5-10 minutes, based on laboratory studies establishing this duration as normally sufficient for simulator adaptation (Sahami & Sayed, 2013). The practice drive presented both the manual driving as well as the automated driving modes to participants and they were familiarized with the various transition conditions and associated alerts.

Participants were then instructed to drive the experimental simulated drives. The drives began in a driveway in a residential area in the manual-driving mode. Participants always started in manual-driving mode but were instructed in advance that they should manually engage the automated-driving mode whenever they felt comfortable doing so (i.e., after attaining a steady state in speed and heading). At the beginning of each drive, participants were instructed to steer onto residential streets and, after attaining a steady state of speed and heading, to engage the automated driving mode. The automated mode could be engaged by pressing a button on the steering wheel. No other instruction was provided to participants with respect to expected behaviors during the automated modes but their behavior and eye movements during automation were continuously recorded.

While in the automated mode, the system was programmed to frequently but unpredictably transfer control back to the driver with appropriate visual (on the dash), verbal, and haptic (vibrating seat) alerts. Drivers were provided with the alerts approximately 5 seconds before the control was handed back to the driver by the system. Participants were instructed in advance that when the automated vehicle transferred control back to them, they were expected to manually drive the simulated vehicle for a few minutes until a steady state had been achieved in speed and heading, and then to reengage the automated mode. The driving simulation was programmed such that seven incidents (scenarios) of transfer of control from automation to manual were presented to each driver during the simulated drive. The seven scenarios were designed to provide realistic and credible rational for the system transferring control back to the driver. This was designed to increase the ecological validity of the simulation, the automation, and the transfer of control. The scenarios were: 1) missing lane lines; 2) crash on shoulder; 3) traffic jam on highway; 4) construction zone; 5) police car on shoulder; 6) non-operational traffic light; and 7) road closure.

These scenarios were distributed over an approximately 20-minute drive that included rural, highway, and urban roadway sections. Each participant drove the experimental drive once, after the practice drive. The take-over scenarios occurred when the participant was in automated driving mode. At a predetermined time/location before the scenario, a 'take-over request' was provided to the driver. This comprised an audible message that said "handing-back control", a change in the background of the instrument cluster from green (automated mode) to yellow (handover mode), and a buzzing of the seat with the haptic actuators. Approximately five seconds (5.6 seconds) after the take-over request the control of the vehicle was handed back to the driver accompanied by an audible message that said "handing back control" and a change of the background of the instrument cluster to black. The driver had the option of manually taking back control after the take-over request but before the 5-second hand-back point by either pressing a button on the steering wheel, depressing the gas pedal, or depressing the brake pedal. After the hand-over, the driver drove manually until he or she was comfortable giving control back to the automation, at which point the control was handed back to the automation by the driver.

The driving simulation was also programmed to contain realistic ambient traffic and other roadway elements such as pedestrians, bicyclists, traffic control devices, and intersections appropriate for the type of roadway being presented (highway, rural, residential, and urban). The simulation was programmed to avoid any potential conflicts or crashes in order to maintain control over experimental conditions and remove potential confounding factors in the design.

Three categories of outcome measures were recorded for each participant's experimental drive: driving simulator measures; eye movement measures; and subjective workload surveys. For the first category, the main variables of interest were recorded during the transition scenarios, as well as over the entire drive. The outcome measures of interest were: take-over reaction time, disengagement time, reengagement time, percent manual disengagement, and number of unscripted disengagements. These outcome measures allowed an examination of participants' intentions, acceptance, and reactions to automation and transitions. The eye movement variables were recorded over the entire drive for both the manual and automated portions. The outcome measures of interest included gaze dispersal measures and percent time eyes off road. These variables offered insight into elements of attention and situational awareness during automated operation as well as during transitions. Finally, as a measure of workload, the participants were administered at the end of the simulated drive the NASA-TLX (NASA, 1986), a subjective workload assessment tool (see Appendix B).

The driving simulator measures were used to examine take-over behaviors, with the outcome variables designed to explain driver behaviors before, during, and after the take-over requests at the scenarios. The focus was more on driver choices about engagement and disengagement given a fixed take-over warning period of ~5 seconds. The outcome measures derived for this category are described in more detail below:

Take-over Reaction time (or Hands on Wheel time) (HOW): This variable describes the time taken by the participant to place his or her hands back on the steering wheel after a Take-Over request was provided. This measure was an aggregation of the hands-on-wheel time for all valid takeover scenarios per participant. Of the 72 participants, there was one participant that constantly drove the simulation with their hands on the wheel regardless of whether the system was in automated or manual mode. This participant was excluded from this outcome measure.

Percent manual disengagement (DE_Type_percent_manual): The participants had the option of either manually disengaging from the automation once a takeover request was received, or waiting till the system disengaged on its own. This variable describes the proportion of manual disengagements for a participant over all scenarios. (Scenarios where participant disengaged manually/total number of valid disengagement scenarios)

Disengagement Time (DE): This variable measures the time between the take-over request, and the actual system disengagement. This measure was an aggregation of the disengagement time for all valid takeover scenarios per participant. For non-manual disengagements, the value equals the warning period (~5.6 seconds), and for manual disengagements, this value reflects the time between take-over request and manual disengagement.

Re-engagement time (RE): This is a measure of the duration between disengagement from a scenario until when the participant re-engages automated driving. All participants had been instructed to re-engage automated driving when they felt comfortable doing so after a scenario (i.e., after a disengagement). Nonetheless, there were a non-trivial percentage of participants who did not re-engage for extended periods of time. In fact, some participants did not re-engage for so long that they manually drove through some planned take-over scenarios without those scenarios being triggered. This variable thus ranged widely across participants. This measure was an aggregation of the re-engagement time for all valid takeover scenarios per participant.

Unscripted Disengagements: This is a count variable that describes the number of times a participant manually disengaged from automation during the entire drive, not including the scripted “scenarios”. Participants were not restricted from manually disengaging, and many participants indeed manually disengaged at various unscripted locations.

The outcome measures related to the *visual gaze behaviors* of the driver were measured and derived from the integrated eye tracking system in the simulator. These variables are gross measures of visual gaze behaviors over the extended drive describing drivers' visual gaze behaviors during automated and manual driving, and are indicative of drivers' attention and distraction during the drive.

Gaze Dispersal: Gaze dispersal is a measure of the spread of the horizontal and vertical visual scanning patterns of a driver. In general, a wider gaze dispersal is associated with situation awareness in the driving context and a narrower dispersal with potential cognitive load. However, these interpretations are not straightforward for gaze dispersal during automated driving. Gaze dispersal in this context is the gaze angle (in radians) from the driver's eye point. There are three measures of dispersal, horizontal dispersal, vertical dispersal, and overall gaze angle. The overall gaze angle is the Euclidean distance between the origin (or focus of expansion) and the horizontal & vertical gaze angle. Although the gaze angle is a combined metric, it is still instructive to look separately at horizontal and vertical dispersal separately. The outcome measures are derived as the standard deviation of the values for horizontal, vertical, or Euclidean distance from the center, over automated portion and manual portions of the drive.

Time Eyes Off Road: This variable measures the proportion of time that the participants' gaze is away from the forward roadway. Although traditionally used as a metric for distraction, it is of interest to examine this visual behavior between automated and manual driving. There are thus two variables for this measure, percent eyes off road during automated driving, and eyes off road during manual driving.

The NASA Task Load Index, or the NASA-TLX (NASA, 1986), is a multidimensional scale that was designed to measure workload associated with the undertaking of a certain task. Given the complexity of workload as a construct, and the various definitions in the scientific literature, the NASA-TLX was developed with six sub-scales to represent Mental, Physical, and Temporal demand, Frustration, Effort and Performance. In the original NASA-TLX, the subscales are rated from 0-100 by the participants based on the experience of the task. A weighted mean is then derived. The weights are based on participants' completing paired comparisons of all combinations of the six sub-scales (15 comparisons) to compare which sub-scale contributed more to workload. Given the relative burden of this multiple comparison, a modified version of the NASA-TLX (referred to as raw TLX) is used when the sub-scales are averaged without the paired comparisons (Hart, 2006). There is a high correlation between the weighted score and the raw scores (Moroney et al., 1995).

Structured interviews

Following the simulated drive, participants completed a structured interview to explore their perceptions and opinions about transfer of control, particularly around the issues of expectations, trust, comfort, acceptance, and performance. The purpose of the interviews was to provide a context for better understanding and interpreting the simulation data. This was considered especially important given that many of the behavioral issues related to vehicle automation are still not well defined. The interview data were expected to provide valuable insights into enhancing public perceptions and awareness of automated vehicles and facilitating their adoption, as well as identify unanticipated and/or novel issues related to vehicle automation transfer of control that would benefit from further study. Each interview was led by an experienced moderator using a formal interview guide (see Appendix B). Analysis of the structured interview data focused on carefully reviewing the interview notes and discussions among the project team to identify key themes, with particular emphasis on differences between the three age groups.

Self-administered questionnaire

Following the interview, participants completed a short self-administered paper-and-pencil questionnaire to gather background information about participants' demographic characteristics, health and functioning, driving frequency, and use of various types of technology, (see Appendix B). The questionnaire data were intended to provide an additional context for understanding the simulator and structured interview data. Questionnaire data were analyzed using the Statistical Analysis Software (SAS) 9.4 package. Responses were tabulated for each question by age group and sex. Analysis of variance (ANOVA) was used to test differences among group means. Due to the small number of participants in each group when broken down by age and sex, comparisons of proportions were tested using Fisher's exact test to determine differences between groups. A p-value of less than .05 indicates a statistically significant difference between groups.

FINDINGS

Characteristics of the sample are shown in Table 1 by age group and overall. There was a nearly equal distribution of men and women across the three age groups, and as expected when comparing teens to older age groups, there was wide variation in education and marital status. Two participants in the youngest age group had graduated high school while the rest were current students in high school. The middle and older age groups were highly educated, with nearly three-quarters of participants in each group having attained at least a Bachelor's degree. As age increased, the average number of people living in a household decreased.

Overall, participants tended to drive quite often. On average per week, participants in the sample drove between 5 and 6 days and almost 125 miles. Participants were asked to estimate the number of miles of most of their out-and-back trips; that is starting from home, driving to one or more places, and then returning home. Forty-four percent of participants reported most of their trips were 6-10 miles, with approximately 20 percent reporting less than 6 miles and 35 percent reporting more than 10 miles. All participants in the youngest age group reported having someone available to give them a ride compared to approximately 79 percent of those in the two older age groups. Specifically, males in the oldest age group were most likely to report living alone and not having someone available to give them a ride if needed. One-third of participants in each age group reported that someone depended on them to provide rides.

The health status of participants was also assessed by asking if a doctor had told them that they have any of the following: Parkinson's disease, amyotrophic lateral sclerosis (ALS, also known as Lou Gehrig's disease), muscular dystrophy, attention deficit disorder/attention deficit hyperactivity disorder (ADD/ADHD), dementia or Alzheimer's disease (results not shown). Two males in the youngest age group and one male in the oldest age group reported having ADD/ADHD, with no other participants reporting any other disease or disorder listed. Similarly, very few participants reported experiencing issues with vision, physical mobility, memory or attention. Those who did were four males in the oldest age group who reported issues with physical mobility.

Table 1: Sample Characteristics

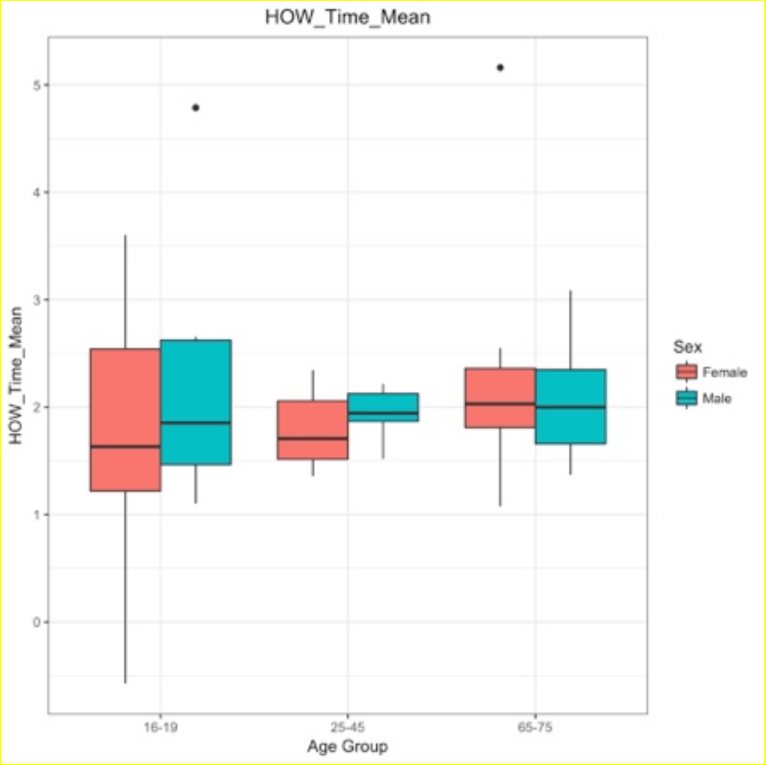
	Age			
	16-19	**25-45**	**65-75**	**All**
Number of participants	24	24	24	72
% Female	50.0	50.0	45.8	48.6
% Married	0.0	45.8	70.8	38.9
Highest level of education completed (%)				
1st-8th grade	91.7	0.0	0.0	30.6
High school	8.3	4.2	0.0	4.2
Vocational/technical/business/trade school	0.0	8.3	0.0	2.8
Some college	0.0	16.7	16.7	11.1
Associate's degree	0.0	0.0	4.2	1.4
Bachelor's degree	0.0	29.2	37.5	22.2
Master's, Professional or Doctoral degree	0.0	41.7	41.7	27.8
Avg. # of people in household	4.2	2.7	1.9	2.9
Avg. days driven per week	5.3	6.1	6.1	5.8
Avg. miles driven per week	79.5	158.7	133.4	123.9
Distance of out and back trips (%)				
Less than one mile	4.2	0.0	0.0	1.4
1-5 miles	12.5	8.3	37.5	19.4
6-11 miles	54.2	37.5	41.7	44.4
11-15 miles	20.8	29.2	12.5	20.8
More than 15 miles	8.3	25.0	8.3	13.9
Someone available to give you rides (%)	100.0	79.2	79.2	86.1
Someone depends on you to drive them (%)	33.3	33.3	33.3	33.3

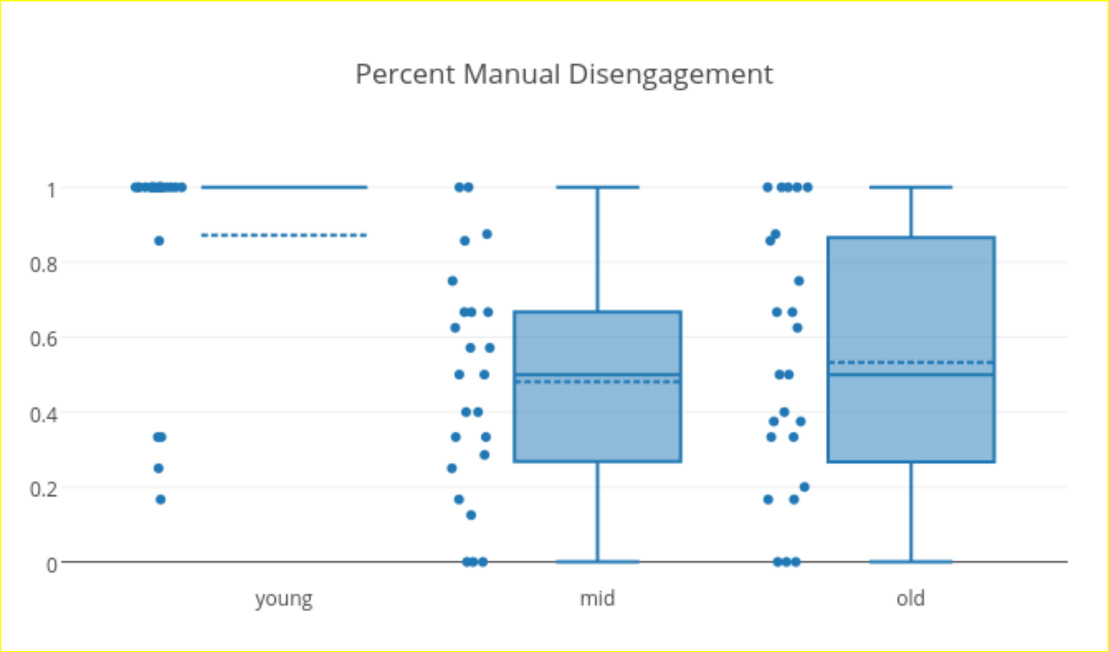
Driving Simulation

All scenarios were aggregated where appropriate for the variables in the engagement categories, and the gaze behavior variables were aggregated from the automated and the manual modes over the drive.

The following boxplots offer some summaries of the data for the outcome variables.

Take-over:


HOW_Time_Mean
HOW_Time_Mean
5
4
3
2
1
0
16-19
25-45
65-75
Age Group
Sex
Female
Male


Percent Manual Disengagement
1
0.8
0.6
0.4
0.2
0
young
mid
old

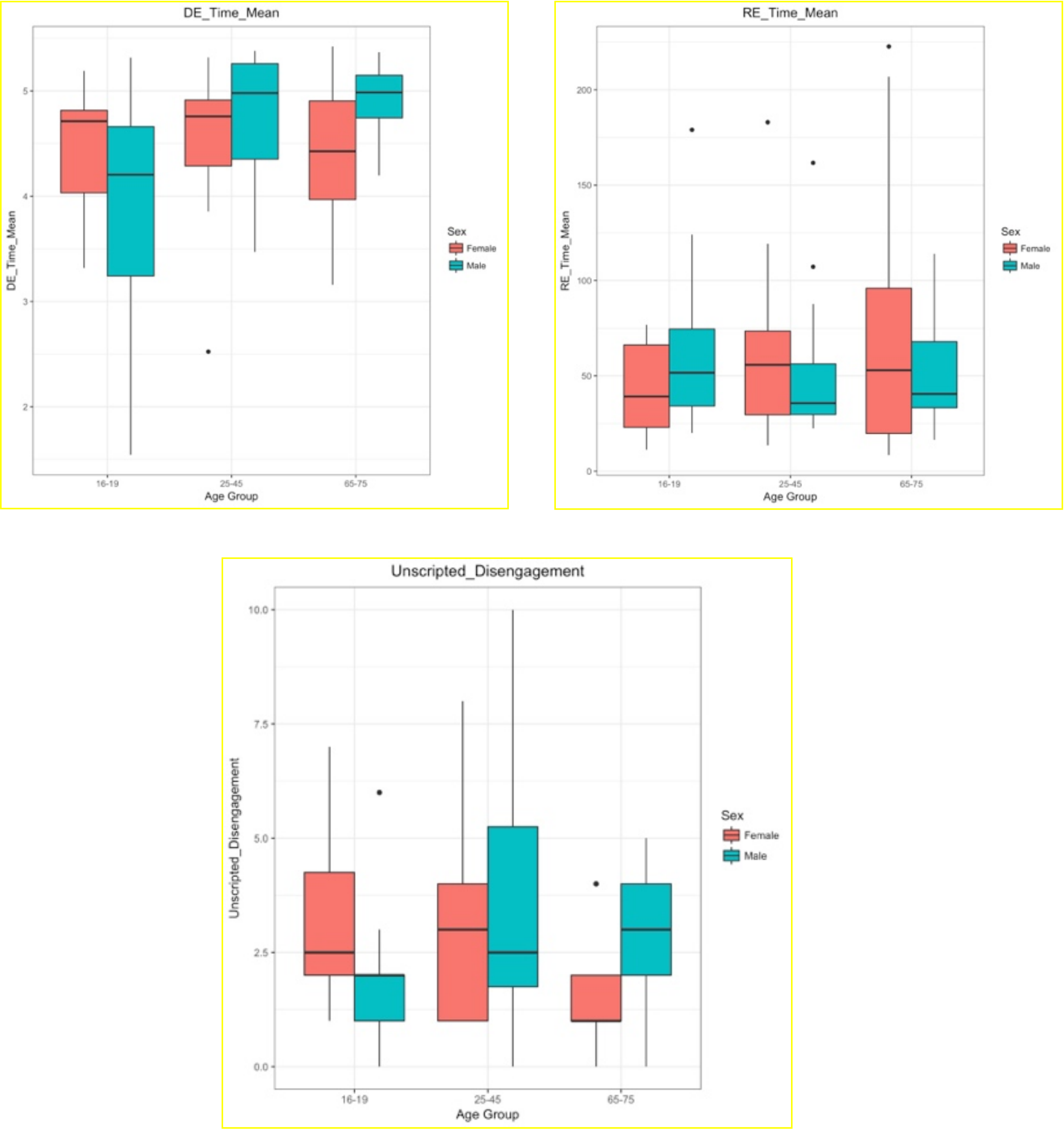
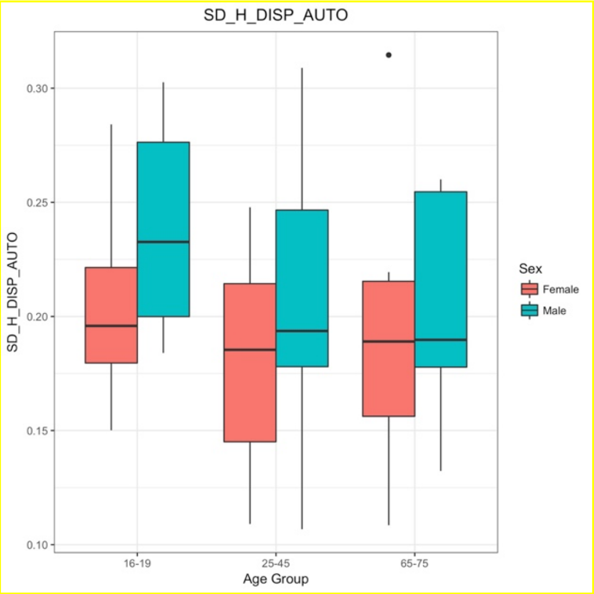
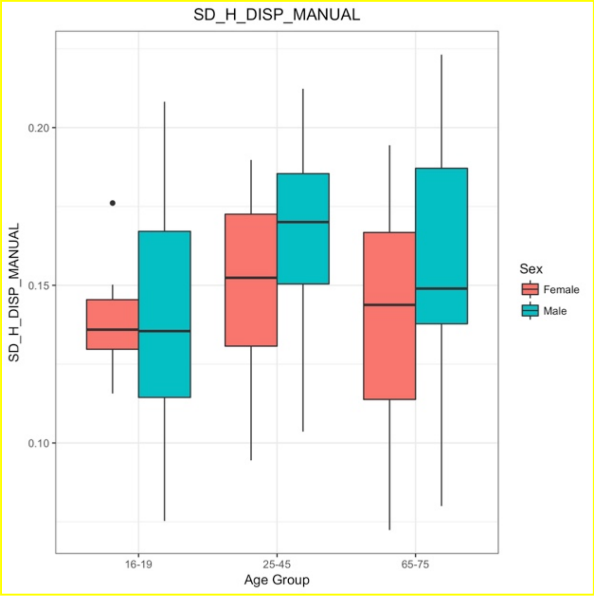
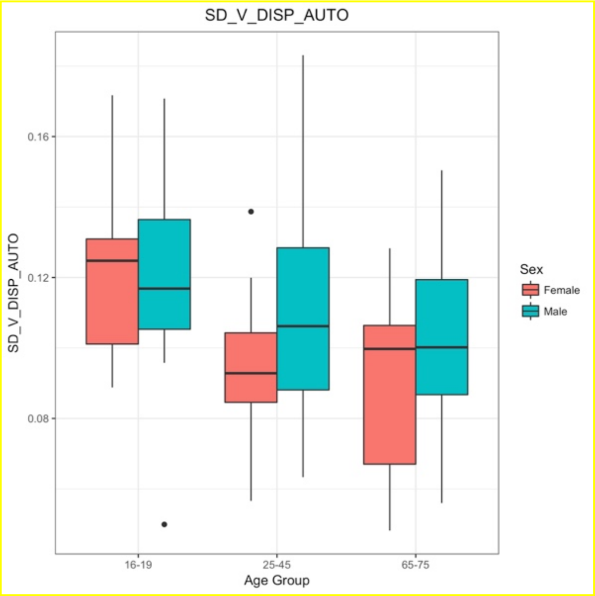


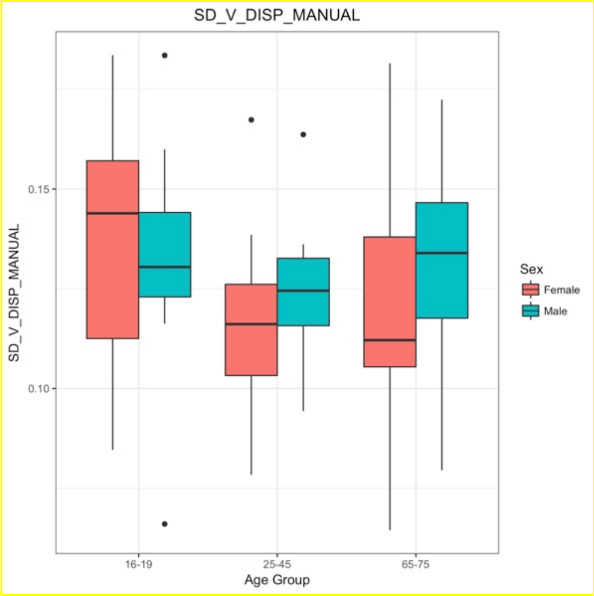
Figure 3 – Takeover measures - summaries

Visual gaze:


SD_H_DISP_AUTO
SD_H_DISP_AUTO
0.10
0.15
0.20
0.25
0.30
16-19
25-45
65-75
Age Group
Sex
Female
Male


SD_H_DISP_MANUAL
SD_H_DISP_MANUAL
0.10
0.15
0.20
16-19
25-45
65-75
Age Group
Sex
Female
Male


SD_V_DISP_AUTO
SD_V_DISP_AUTO
0.08
0.12
0.16
16-19
25-45
65-75
Age Group
Sex
Female
Male


SD_V_DISP_MANUAL
SD_V_DISP_MANUAL
0.10
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16-19
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Age Group
Sex
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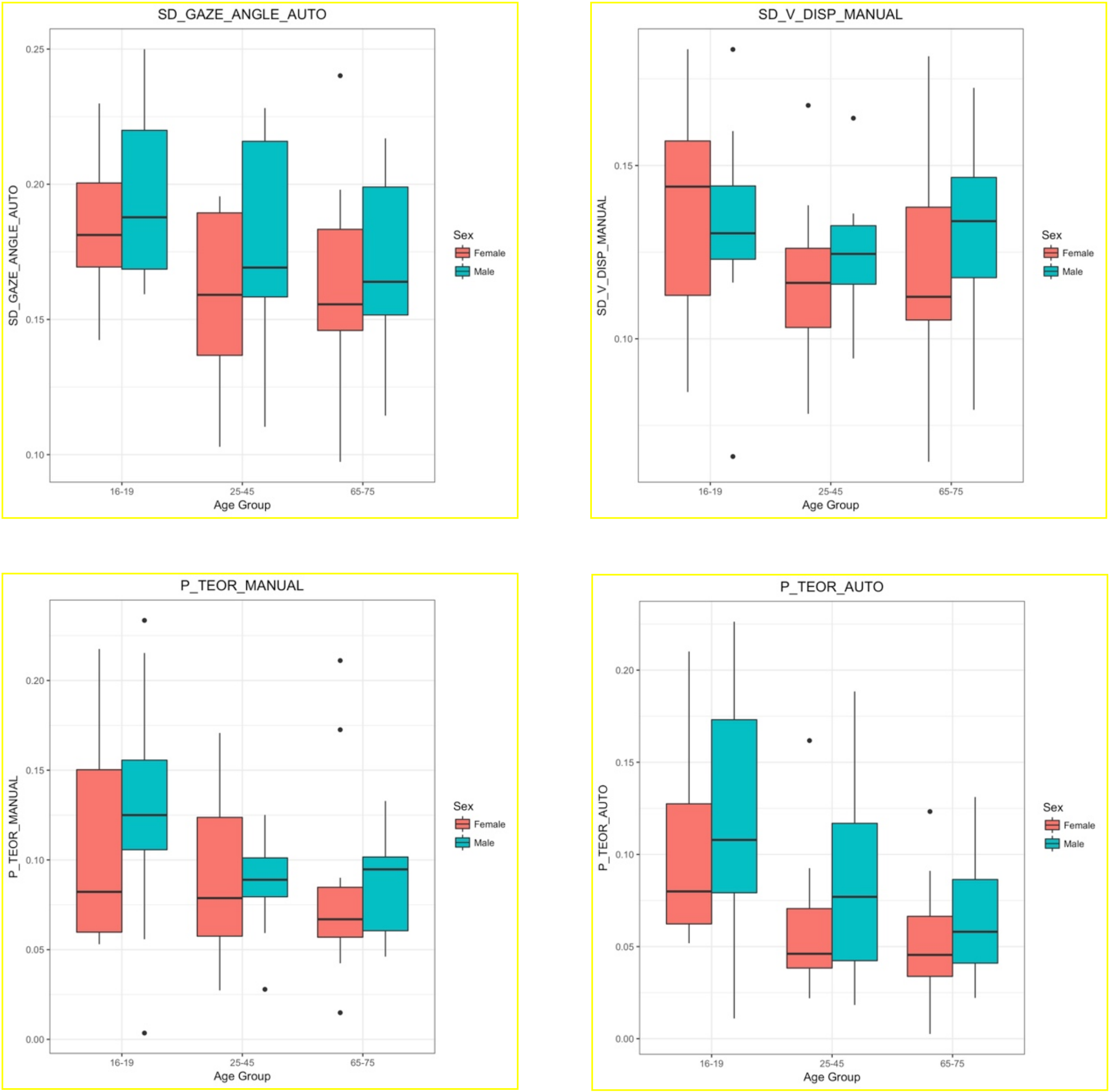

Figure 4 – Eye gaze measures – summaries

Two-way ANOVA were conducted that examined the effect of sex and age on take-over and gaze variables. Significant results are reported below:

Disengagement Type.

A two-way analysis of variance on the Disengagement Type yielded a main effect for the participant age, F(2, 72) = 11.337, p < .05. The main effect of sex was non-significant, F(1, 72) = 3.51, p > .05, and the interaction effect was non-significant, F(2, 72) = .95, p > .05.

Younger drivers had significantly higher proportions of manual disengagement than the middle age range or the older age range drivers.

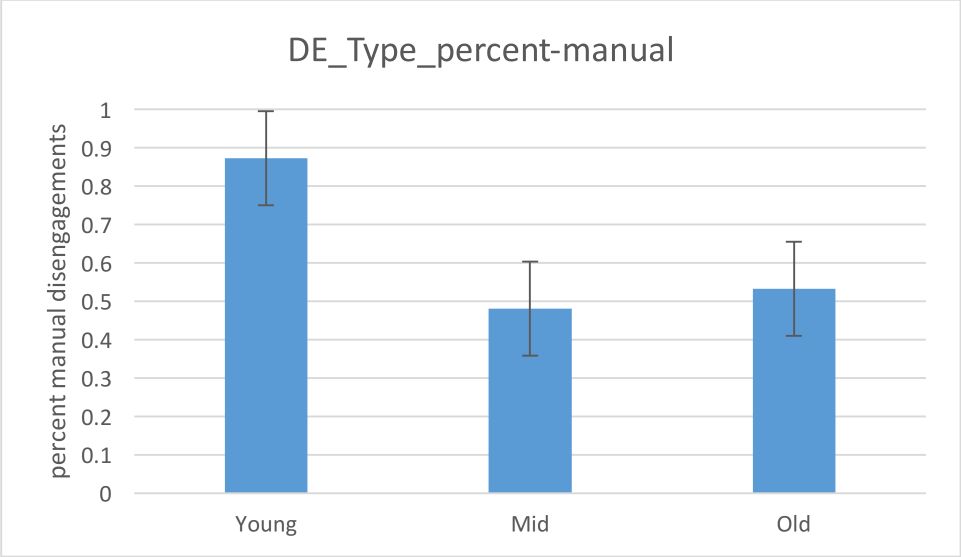

Figure 5 – Percent of manual disengagements

Disengagement Time.

A two-way analysis of variance on the Disengagement Time yielded a significant interaction between age & sex, F(2, 72) = 3.428, p < .05. Younger male drivers had significantly shorter disengagement times than the two older driver groups, and significantly shorter disengagement times than younger females.

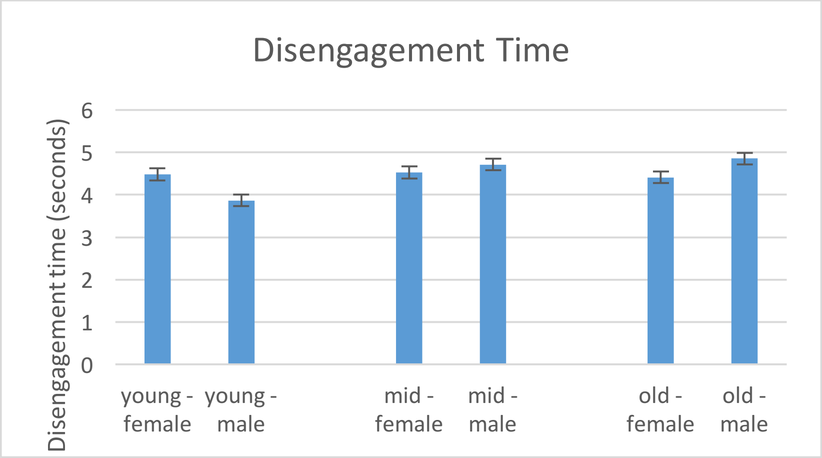

Figure 6 – Average disengagement time

Gaze Angle:

There were no differences between the age groups in terms of gaze dispersal during the manual drives. However, there were significant differences between the age groups in terms of the vertical and the overall gaze angle during the automated modes, with the younger drivers having larger vertical gaze dispersal than the older age groups (F(1,46)=4.978, p<0.05; F(1,46)=8.513, p<0.01). Mid-aged and older drivers had no difference. Similarly, for the overall gaze angle, younger drivers had significantly wider gaze angles than the older groups (F(1,46)=4.596, p<0.05; F(1,46)=6.839, p=0.01).

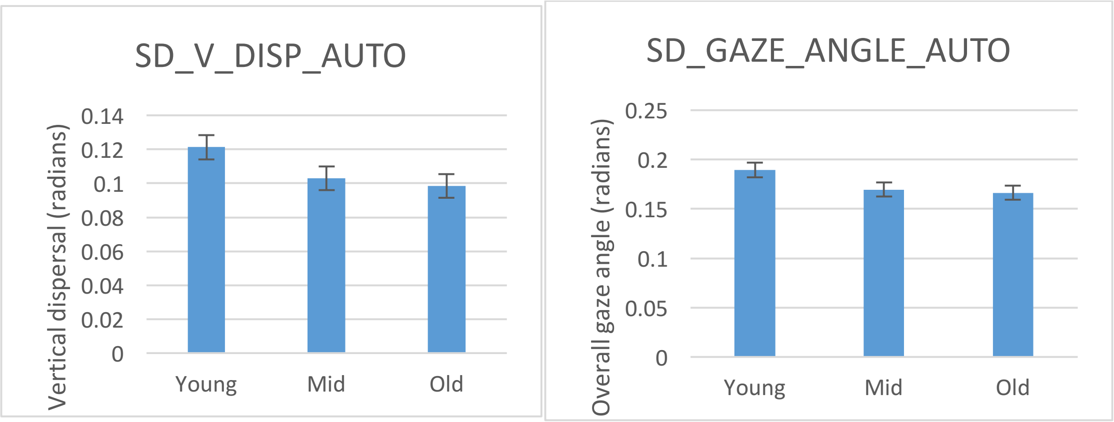

Figure 7 –Vertical and Overall gaze dispersal

Time Eyes off road:

For both manual and auto modes, there was a significant main effect of age on eyes-off-road, F(2, 72) = 3.554, $p < .05$ for manual, and F(2, 72) = 7.138, $p < .05$ for auto. For both modes, younger drivers tended to have statistically longer eyes-off-road durations than the other older driver groups.

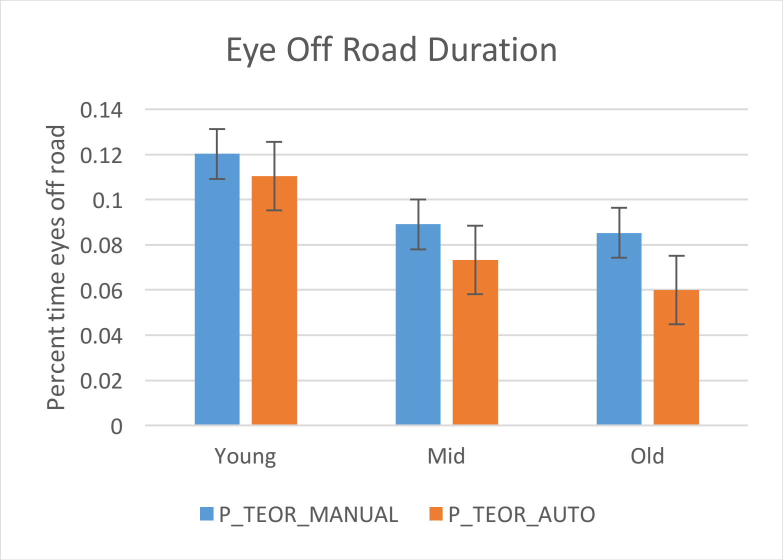

Figure 8 – Percent eyes off road

In addition to the between group comparisons of eye gaze variables, within subject analyses were conducted to examine differences in eye movements behaviors between manual driving and automated driving for the three age groups. Paired t-tests were conducted for all eye-gaze variables comparing manual and automated modes for each driver age cohort (See Figure 9).

For horizontal gaze dispersal, there were significant differences between manual modes and automated modes for all three age groups with significantly lower horizontal dispersal during manual driving than during automated driving (Young: Manual, M = 0.14, SD=.03, Auto, M = 0.22, SD=0.04, t(23) = -9.493, $p<0.05$; Mid: Manual, M = 0.15, SD=.03, Auto, M = 0.19, SD=0.05, t(23) = -3.978, $p<0.05$; Old: Manual, M = 0.14, SD=.04, Auto, M = 0.19, SD=0.04, t(23) = -4.709, $p<0.05$).

For vertical gaze dispersal also, there were significant differences between manual modes and automated modes for all three age groups, but with significantly higher vertical dispersal during manual driving than during automated driving (Young: Manual, M = 0.13, SD=.03, Auto, M = 0.12, SD=0.02, t(23) = 2.629, $p<0.05$; Mid: Manual, M = 0.12, SD=.02, Auto, M = 0.10, SD=0.02, t(23) = 2.696, $p<0.05$; Old: Manual, M = 0.12, SD=.02, Auto, M = 0.09, SD=0.02, t(23) = 6.607, $p<0.05$).

Despite the significant differences for vertical and horizontal gaze dispersal, when combined to derive gaze angle, there were significant differences between manual modes and automated modes for only the younger group, with significantly lower gaze angle dispersal during manual driving compared to automated driving (Manual, M = 0.15, SD=.02, Auto, M = 0.18, SD=0.02, t(23) = -4.408, $p<0.05$).

On the other hand, for the percent times eyes off road variable, there were significant differences between manual modes and automated modes for only the older group, with significantly lower percent eyes off road during automated driving compared to manual driving (Manual, M = 0.08, SD=.04, Auto, M = 0.05, SD=0.03, t(23) = 3.792, $p<0.05$).

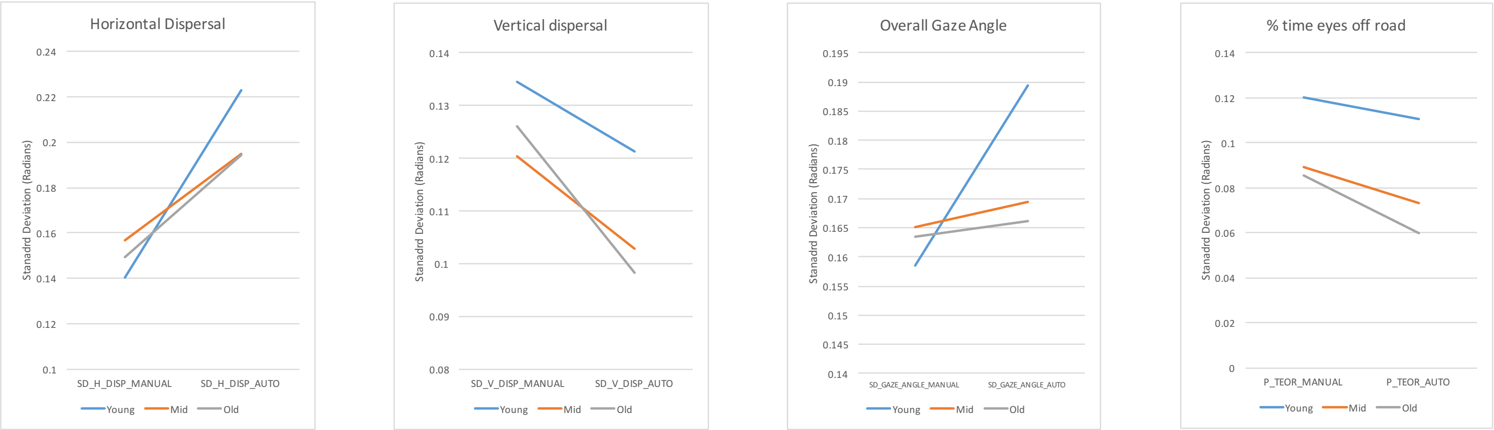

Figure 9 – Eye measures across driving modes by age-group

NASA-TLX

Using non-weighted scores, following the Raw TLX method, higher workload was shown on the performance subscale, with physical subscale scoring the lowest.

Table 2: Summary of Scores on NASA-TLX by Subscale

	Mental	Physical	Temporal	Performance	Effort	Frustration
Average score	41.9	21.7	29.3	67.8	37.0	29.3

Independent-samples median test was used to examine the effect of participant age and sex to NASA-TLX scores. Only the Mental Demand sub-scale was significant across age groups, with the older driver cohort reporting significantly higher workload (p=0.006) than the two younger cohorts. Younger and mid-aged subjects reported no significant difference on scores. There were no significant sex differences. (p=0.82).

Table 3: Average Mental Score by Age Group

	Younger 16-19	Mid-aged 25-45	Older 65-75
Average mental score	33.5	38.8	**53.3**

Structured Interviews

In this section, major themes that emerged from the structured interviews are discussed and differences by age group are noted. Findings are grouped by relevant topic.

Expectations about driving or operating an automated vehicle

Most participants did not have any specific expectations about driving or operating an automated vehicle prior to their study participation. This was true of all age groups, although members of the middle age and older age groups were more likely than members of the youngest age group to have held a neutral view of automation; that is, they had heard about vehicle automation but did not have either positive or negative expectations for what their driving in the study would be like. Given the lack of expectations expressed by participants, it is not surprising that most reported that their driving simulation experience did not differ from their expectations coming in.

Challenge associated with transitions between automated and manual driving

In each age group, the majority of participants reported that they did not find the transitions between automated to manual driving and vice versa to be a challenge. However, members of the youngest and middle age groups were more likely than members of the oldest age group to express this view, with close to three-quarters of these groups reporting no challenge versus just over half of the oldest participants. The oldest participants were more likely to find the transitions challenging in terms of refocusing their attention, judging the vehicle speed or speed limit, or just taking over in difficult situations (e.g., in traffic).

Feeling prepared for take over and extent to which transfer was obvious

At least three-quarters of each age group reported that they felt prepared when the automated driving disengaged and they were asked to take control of the vehicle. This view was strongest among the youngest age group, with only one person reporting that timing was a problem. By contrast, three participants in the middle age group and four in the oldest age group reported that either timing was a problem or that it was unclear to them which situations would trigger hand back of control. A similar pattern emerged when participants were asked if it was obvious to them when control of the vehicle was being transferred back to them. Most participants said it was obvious; among participants in the youngest group, this view was unanimous. Most participants preferred some combination of alerts to signal the transfer of control (i.e., visual, verbal, and haptic). While the specific combination varied across individuals, it appeared that the haptic and verbal alerts were the most popular across age groups.

How well transfer of control was handled

Most participants reported that in general, they did pretty well in handling the transfer of control of the vehicle from the automated mode to normal or regular driving. The oldest participants appeared slightly more likely to report that they handled the transfer poorly or to qualify their response (e.g., that it depended on the situation or improved over time), especially compared to the youngest participants.

What participants did during automated driving

Participants were asked what they did during the time that the automated technology was in control of the car. We were particularly interested in whether they still paid close attention to the road and driving situation or relaxed and even got sleepy or started day dreaming. Sizable numbers in every age group reported that they remained alert throughout the drive, paying close attention to the road and ready to take back control if necessary. Among the middle age group, this high level of vigilance was reported by a third of participants, compared to considerably fewer of the youngest and oldest participants. The middle age group was also the least likely to report being relaxed and looking around at scenery without any mention of still remaining vigilant. By comparison, the youngest age group was the most likely to have had this experience (over one-third of them). Distributions across the age groups were more similar with regard to the classifications of being alert at first and then relaxed over time, or being mainly relaxed but still ready to take back control.

Trust in the automation

When participants were asked if they trusted the automated driving, most participants leaned toward trusting it but the trust was often qualified. For example, 10 participants in each of the youngest and oldest age groups said they trusted it outright, but many others reported that their trust depended on the driving situation or only increased over time. The middle age group was the least likely to express trust outright and much more likely to report that they did not trust the automated driving at this point in time. Sizable numbers of participants expressed their trust within the context of the simulator rather than automated driving per se. For example, several participants across all age groups said that they trusted the automation because the manual driving in the simulator was difficult or because they knew that the simulator was not a “real world experience.”

Comfort with others behind the wheel and preference for control in general

When asked if they were usually comfortable with other people behind the wheel, the majority of the young and middle age groups reported that it depended on who was driving. Among the young age group, the remaining participants were more likely to report being comfortable than not being comfortable with someone else driving. This pattern was reversed for middle age participants, with more being uncomfortable than comfortable with someone else driving. The oldest participants appeared to be the most comfortable with someone else driving; 10 said they were comfortable and an additional 9 said it depended on who was driving.

However, when asked if generally speaking, participants liked to have control over things, a different pattern emerged. Close to half of both the middle and oldest age groups said they liked to have control; this view was not as strong among the youngest participants. On the other hand, the youngest and oldest age groups were more likely than the middle age group to respond in the negative when asked if they liked to have control. Responses that it depended on the situation were more similar across the groups.

Concerns about automated driving for self or others

The young and middle age groups were the most likely to express concerns about the use of automated vehicle technology for both themselves and others, with over one-third of each group expressing such a concern compared to about half as many of the oldest participants. On the other hand, about half of older participants reported they had no concerns for either themselves or others, considerably more than either the young or middle age groups. The remaining participants were divided in expressing concern for themselves but not others, or for others but not themselves. The only discernable pattern by age for these responses was that only one participant in the middle-age group was concerned for himself/herself but not others, compared to four participants in each of the other groups.

Interest in having an automated vehicle

Participants were asked if they would be interested in having an automated vehicle with features similar to those they experienced in the driving simulator. The middle age group was the most likely to give an unqualified no and the youngest age group was the most likely to give an unqualified yes. Most of the responses could be classified as a qualified yes, depending on: vehicle costs; further testing or acceptance of the technology; option for manual driving, particularly in certain driving situations only; and when driving was no longer possible. The oldest age group was more likely to call for further testing of and improvement to the technology and not surprisingly, was the only group to say they would be interested in an automated vehicle when driving was no longer possible. The issue of costs was most salient to the middle age group.

Self-Administered Questionnaire

Results from the self-administered questionnaire focus on participants' use of technology. Questionnaire data on participants' demographics, driving frequency, and health and functioning were presented earlier as part of sample characteristics.

Use of technology

To assess participants' familiarity and use of in-vehicle advanced technologies, participants were asked if they had ever driven a vehicle that had the following technologies: adaptive cruise control, automated lane keeping, automated emergency braking and automated parallel parking. Experience driving a vehicle equipped with adaptive cruise control was reported most often (n= 27), followed by automated emergency braking (n=8), automated lane keeping (n=5) and parallel parking (n=5). There were no significant differences found by age or sex. Although personal use of automated driving features was less common, participants reported to be familiar with the concept of automated or self-driving vehicles. In fact, nearly 92 percent of the sample had at least heard of automated or self-driving vehicles.

Participants were asked about how realistic they found the driving experience in the simulator. The majority of participants found the driving experience in the simulator to be somewhat realistic (60 percent), with 29 percent reporting very realistic and 11 percent reporting not very realistic. There were no statistically significant differences found by age or sex.

All participants in the sample had experience using various communication technologies in their daily life and reported being very or somewhat satisfied with the use of these technologies (see Table 4). Nearly all participants used email and a smart phone, as well as participated in social networking sites like Facebook or Twitter. Participants in the youngest age group were statistically significantly more likely to use online chatting and instant messaging in everyday life as compared to the middle and older age groups ($p<.004$). The oldest age group was significantly more likely to report that these technologies are now a necessity ($p<.03$) as compared to the middle and youngest age groups. Due to the ubiquitous use of communication technologies for this sample, there was an additional set of 10 questions within the questionnaire that all participants skipped (see Appendix B for full questionnaire).

Table 4: Use of Technology in Everyday Life	
	Percent n=72
Communication technologies used	
Email	97.2
Social networks	87.5
Online video or phones calls, Skype	63.9
Online chatting/instant messaging	75.0**
Smart phone	95.8
Satisfaction with communication technologies	
Very satisfied	80.6
Somewhat satisfied	18.1
Not very satisfied	1.4
Not at all satisfied	0.0
Saves you time	91.7
Gives you flexibility in how you communicate	98.6
Easy to learn how to use	95.8
Ease of use	
Not at all difficult	62.5
Not very difficult	33.3
Somewhat difficult	4.2
Very difficult	0.0
Technologies now a necessity for you	86.1*

**p<.01, *p<.03

Participants were asked about their use of other technologies, such as wearable devices to monitor health behaviors and devices used for entertainment purposes. Table 5 shows technology use by age and sex, and as shown in this table, there were several significant differences found. The middle and older age groups reported using online bill payment and online banking significantly more than the youngest age group. Females in the young and middle age groups reporting using exercise equipment more than males and those in the older age group. Both males and females in the middle and older age groups were significantly more likely to report using websites to find medical and health information than their younger counterparts as well as use devices to monitor health, such as blood sugar monitors or pedometers. Females in the young and middle age groups reported using MP3 players more than other groups. Video game use was reported most by males in the young and middle age groups, but females in the young age group also reported playing video games more often than the older age groups. Out of the 17 different technologies surveyed, women age 65 and older reported the most technologies used (Mean = 12.5 technologies, SD = 2.1) whereas 65+ age men reported the fewest on average (Mean = 9.7 technologies, SD = 2.9).

Table 5: Technology Use by Age and Sex

	16-19 Female n (%)	16-19 Male n (%)	25-45 Female n (%)	25-45 Male n (%)	65-75 Female n (%)	65-75 Male n (%)	Fisher's Exact Test
Online bill payment	0 (0.0)	3 (25.0)	12 (100.0)	11 (91.7)	11 (100.0)	11 (84.6)	p<.0001
Online banking	6 (50.0)	7 (58.3)	11 (91.7)	12 (100.0)	11 (100.0)	12 (92.3)	p=.0010
Exercise equipment, e.g. treadmill/weight machine	11 (91.7)	8 (66.7)	9 (75.0)	5 (41.7)	6 (54.5)	3 (23.1)	p=.0079
Exercise videos, DVDs, or TV shows	5 (41.7)	5 (41.7)	9 (75.0)	4 (33.3)	3 (27.3)	4 (30.8)	NS
Online wellness/health monitoring program	2 (16.7)	3 (25.0)	6 (50.0)	4 (33.3)	3 (27.3)	4 (30.8)	NS
Websites for finding medical/health info	6 (50.0)	5 (41.7)	11 (91.7)	9 (75.0)	11 (100.0)	13 (100.0)	p=.0002
Devices to monitor health, e.g. blood sugar meters/pedometers	1 (8.3)	2 (16.7)	4 (33.3)	3 (25.0)	7 (63.6)	7 (53.8)	p=.0342
Nintendo Wii Fit	3 (25.0)	1 (8.3)	2 (16.7)	1 (8.3)	0 (0.0)	1 (7.7)	NS
E-readers or tablets, e.g., iPad or Kindle	10 (83.3)	10 (83.3)	8 (66.7)	8 (66.7)	10 (90.9)	7 (53.8)	NS
MP3 players, e.g., an iPod	11 (91.7)	8 (66.7)	10 (83.3)	7 (58.3)	3 (27.3)	7 (53.8)	p=.0216
Live-streaming radio/TV/movies on the Internet	11 (91.7)	10 (83.3)	12 (100.0)	10 (83.3)	8 (72.7)	7 (53.8)	NS
Video games, e.g., X-box or Playstation	7 (58.3)	9 (75.0)	4 (33.3)	7 (58.3)	0 (0.0)	2 (15.4)	p=.0002

Relationship between technology and engagement in automated driving

As part of the simulated drive, participants were instructed to engage the automated driving mode as soon as they were comfortable, and that at different times throughout the drive control of the vehicle would be given back to them. After control of the vehicle was given back to the drivers, they were told to re-engage the automated driving mode as soon as they were ready. Given this instruction, the length of time in manual driving was up to the individual drivers, and as mentioned earlier, occasionally participants missed some of the planned transitions because they continued to drive manually and did not re-engage the automated driving. We kept track of the instances where drivers chose to manually drive and scored the number of automated-to-manual transitions that were missed due to manual driving. Overall, participants missed an average of 22% of the planned transitions due to manual driving. Thirty-one participants (43%) re-engaged the automated driving mode as expected and experienced all planned transitions, whereas seven individuals missed 71% of the transitions due to manual driving. We hypothesize that there are important reasons for which some individuals chose to keep control of the vehicle rather than engage the automated technology, such as feelings of trust and comfort with technology, which future research should investigate.

We undertook preliminary investigations on the association between the number of technologies used and missed transitions, using data from our self-administered questionnaire, but did not identify any significant associations. Specifically, t-tests examined mean differences in the number of technologies used (count score ranging from 0 – 17) by those who missed 50% of the driving transitions versus those who did not. These were done for the entire sample and by age-sex groupings. As some age-sex group sizes were small (n = 11), it is possible that this pilot did not provide sufficient statistical power to identify significant differences in technology use. In addition, it may be that a count of technologies used does not necessarily indicate tech savvy nor trust of technology – two key factors which may play an important role in the adoption of automated driving technology. We also examined associations of a single item assessing satisfaction with communication technologies (e.g. email, social networks) with missed transitions, but also failed to identify a significant relationship. Our interpretation of these null findings is that new measures of trust relevant to automated driving technology are needed.

CONCLUSIONS AND FUTURE DIRECTIONS

While this project was primarily intended to provide seed data for a larger-scale research project, the pilot data provide important new information and yield opportunities for dissemination of new understandings of age-related differences related to automated vehicles. Of special interest in this project were differences with regard to expectations, performance, trust, and acceptance.

Most participants in the study reported having no expectations about driving or operating an automated vehicle before they came for the study session. In terms of their performance in the simulated automated vehicle, results suggest that for some of the measured outcomes, there were significant differences by age group. Although not evident from all outcome variables, there seems to be a clear difference in behaviors between the youngest drive group and the two older groups of drivers in terms of both takeover behaviors and visual gaze behaviors, when considered over all scenarios. Younger drivers were more likely to manually disengage once a takeover request had been given thus likely to ‘take control’ from the automation, as compared to the older cohorts who tended to wait for the system to disengage and thus ‘receive control’ from the automation. Although correlated with the previous measure, it was also seen that younger drivers disengaged significantly quicker than the older cohorts. The young drivers also tended to scan wider, especially in the vertical direction than the older groups. This was also evident with the young drivers tending to look away from the forward roadway for longer duration as compared to the older groups.

These results show some age differences in driver behavior in the automated driving context when taking age into consideration. There seems to be no sex differences, although an important caveat is the even more limited sample sizes when looking at sex as a factor. For future work, secondary analyses of these data could be undertaken to study differences at specific types of scenarios. In the current work, there were seven scenarios chosen mainly for ecological validity and to increase the realism and believability of the simulated drives. The number of scenario exposures improves data quality given the aggregation of the variables across multiple exposures, and examining scenarios on an individual basis lowers this advantage. However, doing so may provide insight into behaviors during takeover scenarios based on the context of the scenarios themselves.

Despite not all outcome measures showing differences between age groups, the above results are novel and important as they are the first to show differences between age groups in terms of disengagement and visual behaviors. If the middle age group could be considered an ideal comparison group then it appears that young drivers are markedly different, whereas the older driver cohorts are closer in behaviors to a comparison cohort.

Results from the structured interviews following the simulated drive suggest that the majority of participants, regardless of age, thought they performed pretty well during the transitions between automated and manual driving, specifically in terms of feeling prepared for and handling the take overs well rather than finding them challenging. There were some age differences with the oldest participants more likely to report that the transfer of control was challenging and that they handled it poorly overall or at least in some situations. Interestingly, when we looked at participants' actual engagement in the various transitions, we found that many participants did not complete all of the transitions, with 11 participants missing 71% of the transitions due to manual driving. Further studies should be undertaken with greater statistical power to identify why some individuals may choose to maintain manual control rather than engage the automated technology, such as feelings of trust and comfort with technology.

Participants' interview responses with regard to trust in automated driving suggest that trust is a complex and multilayered concept, at least in this context. Views on trust were often qualified; that is, dependent on the driving situation or other conditions. Views were also frequently tied more to the experience of driving in the simulator than in an automated vehicle. Middle age drivers were the least likely to express outright trust in automated driving and the most likely to report a lack of trust. We also asked participants about their preference for control, both in the context of driving and more generally, because of its possible influence on trust. Results indicated that the older age group was more likely to be comfortable with someone else driving the vehicle. At the same time, half of older and middle age participants reported a preference for being in control in general in their lives, a much greater proportion than among young drivers.

Continuing research is needed to understand issues around trust and to tease out the potential effects of control preference on trust. In addition, more robust measures of trust and preference for control are needed that are specifically relevant to automated driving technology.

This project offered several key innovations. First, it extended research on automated vehicle technologies to encompass the social and behavioral aspects of the transfer of control between automated and manual control. Identification and understanding of these issues will have important implications for better formulating policy and practice, and helping to facilitate the widespread adoption of automated vehicle technology.

Second, it specifically focused on age differences in driving behavior related to transfer of control. This is clearly warranted, given age differences in many aspects of driver safety. Teen drivers and older drivers are at a higher risk of motor vehicle crashes, and the advent of automated vehicle technologies will play an important role in reducing crashes and injuries in these sub-groups. Little, however, is known about the age-specific issues related to automated vehicles. This research helps provide a foundation knowledge that, through effective dissemination, can expand knowledge in this area.

Third, the project leveraged an advanced high fidelity driving simulator to measure participant reactions during automated driving using a state of the art simulated driving environment to examine transfer of control, something that has only recently been developed. Finally, it paired driving simulation data with structured interview/questionnaire data to more fully explore issues around driver expectations, trust, acceptance, and performance. These two complementary approaches provide an innovative way to better understand driver behavior by allowing us to examine not only driving outcomes, but the more nuanced decision making process that drivers engage in during the transitions between automated and manual control. In particular, issues of driver expectations, trust, acceptance and self-perceived performance may be important predictors for actual performance during the transition process and the use of the two approaches is needed to yield meaningful conclusions about participant behavior. For example, we know from the older driver literature that awareness of and insight into functional and performance deficits can significantly influence driver behavior (Eby et al., 2009).

The project also had some limitations. An important limitation was that participants were asked about their perceptions and attitudes relative to driving automated vehicles without actually having the opportunity to drive a real automated vehicle. The issues of trust and acceptance are complex and embedded in the context or setting within which they are examined. In this study, the setting was the driving simulator rather than an actual automated vehicle. Many of participants' responses revealed more about their experience with the driving simulator than with an automated vehicle and therefore provided only modest insights into the issues of interest (thus, these results were largely not reported here for that reason). Future research should try to include data from using an automated vehicle on a test track to complement driving simulator data.

A second limitation was that most participants reported high levels of technology use, familiarity, and satisfaction. We had hypothesized that people's use of, familiarity, and comfort with technology might moderate their attitudes and perceptions about automated vehicles. However, the lack of variability across participants made it difficult to examine these relationships. Future research projects should focus on recruiting participants with varying levels of technology use and comfort. In addition, a larger sample should be recruited to provide sufficient statistical power to be able to detect differences in the variables of interest in this study.

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APPENDICES

Appendix A: Screening, Eligibility and Recruitment Materials

Screening and Eligibility Questions

1. What is your age? _________ years
   - ☐ 16-19 years old
   - ☐ 25-45 years old
   - ☐ 65-75 years old

2. Are you male or female? ☐ Male ☐ Female

[FOR THOSE IN 16-19 AGE GROUP]

3. What type of driver license do you currently have?
   - ☐ Learners Permit
   - ☐ Level 2 Intermediate
   - ☐ Full License

   [Learners Permit allows you to drive only under supervision; Level 2 Intermediate allows you to drive without supervision but with restrictions; Full license allows you to drive independently and without restrictions]
   [If Learners Permit or full license, candidate not eligible]

4. What day did you get, or do you expect to get, your Michigan Level 2 Intermediate driver license?

   ________ /________ (2015/2016) (Month/Day)

   [If Learners Permit, candidate can become eligible once Level 2 license is received]
   [If had Level 2 license more than three months, candidate not eligible]

[IF 18 OR 19 YEARS]

5. Can you tell me why you have not received your full licens

   ____
   ____
   ____
   ____
   ____

[FOR THOSE IN 25-45 AND 65-75 AGE GROUPS]

6. Do you have a regular license? ☐ Yes ☐ No

7. Have you had a regular license for at least 12 months? ☐ Yes ☐ No

[ALL]

8. On average, how many days per week do you drive?

   ________days/week

[If s/he does not drive at least 2 days per week, candidate not eligible]

9. On a scale from 0 to 3, with 0 being NEVER and 3 being NEARLY ALWAYS, how often do you experience nausea, headache, and/or dizziness (i.e., motion sickness) when (a) in a car; (b) on an amusement ride; (c) on an airplane; (d) on a boat; and, € in a simulator (if applicable)?

Car	☐ 0	☐ 1	☐ 2	☐ 3
Ride	☐ 0	☐ 1	☐ 2	☐ 3
Plane	☐ 0	☐ 1	☐ 2	☐ 3
Boat	☐ 0	☐ 1	☐ 2	☐ 3
Sim	☐ 0	☐ 1	☐ 2	☐ 3

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[If any response greater than 1, interviewer collects as much info as possible in terms of current vs. past incidences, frequency, severity, symptoms, etc. Based on this history, interviewer will make a decision. For certain, if respondent reports a 3 to any of the items, then s/he is not eligible. If interviewer is uncertain, tell them you need to contact your supervisor to verify that they are eligible.]

10. Do you frequently experience vertigo or dizziness? ☐ Yes ☐ No
[If yes, candidate not eligible]

11. Do you wear corrective eyewear? ☐ Yes ☐ No

A) If yes, do you wear glasses, contacts, or both? ☐ Glasses ☐ Contacts ☐ Both

[If participant has both, request that he wears conta to study appointment. If only glasses, find out thickn of lens and discuss with team.]

____
____
____

B) Do you have any visual impairment (other than corrective eyewear)?
[If visual impairment, take as much info as possible about impairment. Then tell them that you need to contact your supervisor to verify that they are eligible.]

____
____
____

[IF FEMALE IN 16-19 OR 25-45 AGE GROUPS]

12. Are you pregnant? ☐ Yes ☐ No
    [If yes, not candidate not eligible]

[IF FEMALE IN 16-19 OR 25-45 AGE GROUPS]

13. What was the first day of your most recent menstrual period (the first day of bleeding)?
    [If eligible, schedule appointment within 20 days of this date]

_______________ mm/dd/yy

IF ELIGIBLE TODAY:

Describe the study and ask if s/he is interested in participating: "You are eligible for our study. In this study, you will be asked to attend one appointment in the driving simulator at the UM Transportation Research Institute. The appointment will last no more than 90 minutes and you will be asked to drive a virtual car in a driving simulator and complete an interview following the drive. You will be given $50 at the end of your appointment. Would you like to participate in this study?"

Identify potential appointment dates based on diver and simulator lab availability. At that point, mark down participant's name, phone number, and/or email. Ask participant if they would prefer to be called, emailed, or texted when you're contacting them to schedule the study appointment.

IF ELIGIBLE IN FUTURE: For teens not yet eligible based on licensure status, tell person that you will re-contact them once they become eligible for the study. Repeat the earliest date on which they may become eligible. Mark down participant's name, phone number, and email. Ask participant if they would prefer to be called or emailed at that time.

IF INELIGIBLE: Tell person that we conduct many types of studies, but they do not qualify for the current one. However, they can leave us their contact information if they are willing to be re-contacted in the future when other studies become available.

☐ Agrees to be contacted for future studies

Online Recruitment Ads

Driving Simulator Study (Earn $50)
We need your help!

The University of Michigan seeks 16-19 year olds who have a Michigan Level 2 Provisional Driver License, and have had their licenses less than 3 months, to participate in a study to learn about how people will interact with an automated vehicle.

If you are eligible, you will be asked to attend a 90 minute appointment at a Simulator Lab where you will drive in a driving simulator. You will also complete a short interview about your simulated driving experience and a brief questionnaire. For participating, you will receive $50.

Please contact us to sign up or to learn more about this study. Call toll-free at 1-877-615-6124 or email drivingstudy@umich.edu.

Driving Simulator Study (Earn $50)
We need your help!

The University of Michigan seeks 25-45 year olds who have had a regular license for at least 12 months to participate in a study to learn about how people will interact with an automated vehicle.

If you are eligible, you will be asked to attend a 90 minute appointment at a Simulator Lab where you will drive in a driving simulator. You will also complete a short interview about your simulated driving experience and a brief questionnaire. For participating, you will receive $50.

Please contact us to sign up or to learn more about this study. Call toll-free at 1-877-615-6124 or email drivingstudy@umich.edu.

Driving Simulator Study (Earn $50)
We need your help!

The University of Michigan seeks 65-75 year olds who have had a regular license for at least 12 months to participate in a study to learn about how people will interact with an automated vehicle.

If you are eligible, you will be asked to attend a 90 minute appointment at a Simulator Lab where you will drive in a driving simulator. You will also complete a short interview about your simulated driving experience and a brief questionnaire. For participating, you will receive $50.

Please contact us to sign up or to learn more about this study. Call toll-free at 1-877-615-6124 or email drivingstudy@umich.edu.

Letter Mailed to Newly Licensed Teens

Dear Teen and Parent(s),

The University of Michigan (U-M) is conducting a study on self-driving cars using a driving simulator in order to learn about how people will interact with an automated vehicle, and we need your help!

If you are a 16-, 17-, 18- or 19-year-old who has received a Michigan driver license (Level 2 Intermediate) in the past 3 months, or will soon receive one, you may be eligible to earn up to $50 by participating in our study about automated vehicles.

We ask that you contact us to learn about the eligibility requirements. If you are eligible, you will be asked to attend one appointment lasting approximately 90 minutes. You will experience driving in a simulator and complete an interview and short questionnaire.

If you would like to learn more about our study, please contact us by calling toll-free 1-877-615-6124 or e-mailing drivingstudy@umich.edu.

Best Regards,

Lisa J. Molnar, PhD
Co-Principal Investigator
University of Michigan
Transportation Research Institute
734-764-5307

Anuj K. Pradhan, PhD
Co-Principal Investigator
University of Michigan
Transportation Research Institute
734-647-9191

Driver Education Recruitment Email

Subject: UM Simulator Study for Teens

Parents of Segment 2 students, your teens are invited to take part in a driving simulation study!

What is this about?

The University of Michigan (U-M) Transportation Research Institute is conducting a study on self-driving cars using a driving simulator in order to learn about how people will interact with an automated vehicle.

We are looking for teens who have had their Level 2 Intermediate license for less than 3 months.

What do I have to do?

If your teen is eligible, he/she will be asked to attend a 90 minute appointment at the U-M Simulator Lab where he/she will drive in a driving simulator. Your teen will also complete a short interview about their simulated driving experience and a brief questionnaire.

What do I get?

For participating, your teen will receive $50.

If you have a teen who might be interested in participating please call the UMTRI study staff directly at (734) 615-6124 or email drivingstudy@umich.edu to see if they qualify!

Your decision to participate or not in this study will not affect your teen's status at [Driving School]. [Driving School] will not be told who participates or does not participate.

Appendix B: Structured Interview Guide, Questionnaire, and NASA TLX

Study Follow-Up Interview
Estimated Length: 30 Minutes

1. Prior to driving in the simulator today, did you have any specific expectations about driving or operating an automated vehicle? If so, what did you expect?

2. Did your driving simulation experience today differ from these expectations? If so, in what way?

3. Were there any specific driving situations in which you were especially comfortable with the automated mode?

4. Were there any driving situations in which you were especially uncomfortable with the automated mode?

5. Did you find the transitions between automated to manual driving and vice versa a challenge? If so, in what way?

PROBES: What about when:

5a. The road lines were hard to see?

5b. There was a stopped police car on the side of the road?

5c. The transition happened during a traffic jam?

5d. The transition happened near construction?

5e. The transition occurred near a crash?

5f. The transition happened near an inoperational traffic light?

5g. The transition happened near the intersection detour?

6. Did you feel prepared when the automated driving disengaged and asked you to take control of the vehicle?

7. Was it obvious to you when control of the vehicle was being transferred back to you?

8. In general, how well do you feel you handled the transfer of control of the vehicle from the automated mode to normal or regular driving?

9. What did you do when the automated technology was in control of the car? For example, were you still paying close attention to the roads and driving situations? Did you day dream? Did you get sleepy? Did you keep your hands on the wheel?

10. Did you trust the automated driving? Why or why not?

    PROBES:

    10a. Are you usually comfortable with other people behind the wheel?

    10b. Generally speaking, do you like to have control over things?

11. Do you have any concerns about the use of automated driving technology for yourself? For other cars/drivers on the road?

12. Would you be interested in having an automated vehicle with features similar to those you experienced in the driving simulator?

Study Follow-Up Self-Administered Questionnaire
Estimated Length: 5 Minutes

1. How realistic did you find the driving experience in the simulator? Circle your response.

VERY REALISTIC

SOMEWHAT REALISTIC

NOT VERY REALISTIC

NOT AT ALL REALISTIC

2. In a normal week, how many days per week do you drive?

___________ DAYS

3. How many miles do you drive in a normal week?

__________ MILES

4. Thinking just of your out-and-back trips from home – that is, starting from home, driving to one or more places, and returning home – how many miles would you say most of these trips are? Circle your response.

LESS THAN 1 MILE

1-5 MILES

6-10 MILES

11-15 MILES

MORE THAN 15 MILES

FOR THE REMAINING QUESTIONS, PLEASE CIRCLE THE RESPONSE THAT BEST FITS YOUR SITUATION.

5. Had you ever heard of automated and/or self-driving vehicles before participating in this study?	Yes	No

The next set of questions are about your use of various kinds of technology in everyday life. We're mainly thinking about electronic technology and things like the Internet.

The first several questions are about communication. Following is a list of technologies some people use. For each item, just circle yes or no to indicate whether or not you use it.

6a. Email	Yes	No
6b. Social networks such as Facebook or Twitter	Yes	No
6c. Online video or phone calls, such as Skype	Yes	No
6d. Online chatting and instant messaging	Yes	No
6e. Smart phone, such as an iPhone, Android or Blackberry	Yes	No

If you circled "Yes" to ANY of the communication questions, please continue to Question 7. If not, please skip to Question 13.

7. Thinking about the technologies you use for communication, how satisfied are you?

VERY SATISFIED

SOMEWHAT SATISFIED

NOT VERY SATISFIED

NOT AT ALL SATISFIED

8. Do they save you time?	Yes	No
9. Do they give you more flexibility in how you communicate with other people?	Yes	No
10. Were they easy to learn how to use?	Yes	No

11. Once you learned how to use them, how difficult have they been to use?

VERY DIFFICULT

SOMEWHAT DIFFICULT

NOT VERY DIFFICULT

NOT AT ALL DIFFICULT

12. Are these technologies now a necessity for you?

	Yes **SKIP TO 16a]**	No **[SKIP TO 16a]**
13. Have you ever tried to use any of these technologies to communicate with other people?	Yes **[SKIP TO 15a]**	No **[GO TO 14]**
14. Would you be interested in trying any of the communication technologies we have mentioned?	Yes	No
15a. We’re interested in why you do not use these technologies to communicate with other people. Is it too expensive?	Yes	No
15b. Is the technology easily available?	Yes	No
15c. Is it too complicated?	Yes	No
15d. Is it too hard to learn how to use?	Yes	No
15e. Would it take too much time to learn how to use?	Yes	No
15f. Is it too difficult to keep up with all the changes in technology?	Yes	No
15g. Are you opposed to using new technologies?	Yes	No
15h. Do new technologies create unnecessary stuff?	Yes	No

Here is a list of other technologies. For each item, please circle yes or no to indicate whether or not you use it.

16a. Online bill payment	Yes	No
16b. Online banking	Yes	No
16c. Exercise equipment like a treadmill or weight machine	Yes	No
16d. Exercise videos, DVDs, or TV shows	Yes	No
16e. Online wellness or health monitoring program	Yes	No
16f. Websites for finding medical and health information	Yes	No
16g. Devices to monitor health, such as blood sugar meters or pedometers	Yes	No

16h. Nintendo Wii Fit	Yes	No
16i. E-readers or tablets, such as the iPad or Kindle	Yes	No
16j. Mp3 players, such as an iPod	Yes	No
16k. Live-streaming radio, television, or movies on the internet	Yes	No
16l. Video games, such as X-box or Playstation	Yes	No

The last several questions are just for background.

17. What is your marital status?

MARRIED

LIVING WITH A PARTNER

SEPARATED

DIVORCED

WIDOWED

NEVER MARRIED

18. What is the highest level of school you have completed?

NO SCHOOLING COMPLETED

1ST-8TH GRADE

9TH-12TH GRADE (NO DIPLOMA)

HIGH SCHOOL GRADUATE (HS DIPLOMA/EQUIVALENT)

VOCATIONAL, TECHNICAL, BUSINESS, OR TRADE SCHOOL CERTIFICATE/DIPLOMA

SOME COLLEGE BUT NO DEGREE

ASSOCIATE’S DEGREE

BACHELOR’S DEGREE

MASTER’S, PROFESSIONAL, OR DOCTORAL DEGREE

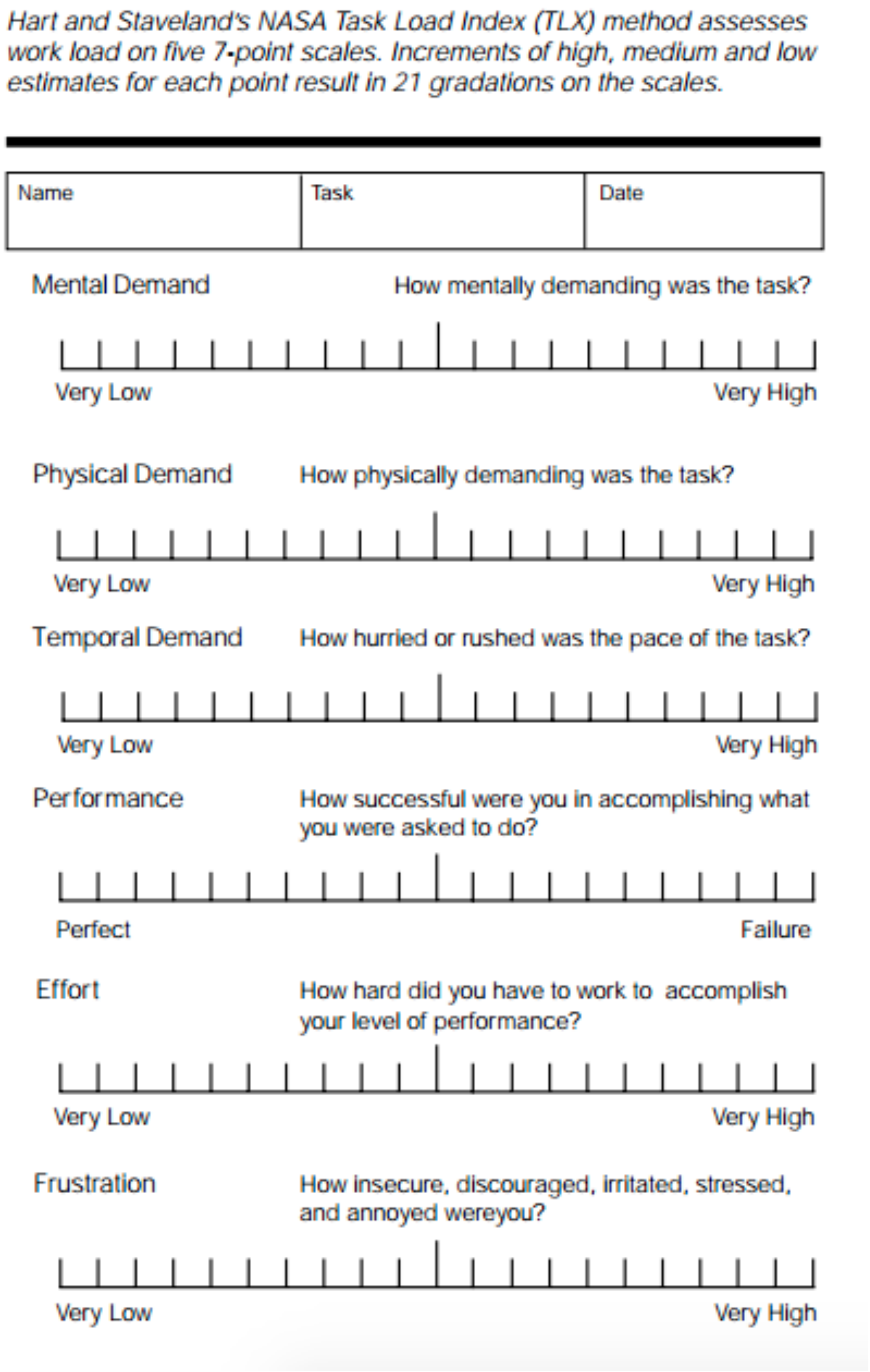
19. How many people are there living in your household?

___________ People

20. Is there someone available to give you rides if you need them?	Yes	No
21. Is there someone that depends on you to give them rides?	Yes	No
Has a doctor told you that you have any of the following:		
22a. Parkinson’s Disease?	Yes	No
22b. Lou Gehrig’s Disease (ALS)?	Yes	No
22c. Muscular Dystrophy?	Yes	No
22d. Attention Deficit Disorder/ Attention Deficit Hyperactivity Disorder (ADD/ADHD)?	Yes	No
22e. Dementia or Alzheimer’s Disease?	Yes	No
Are you currently experiencing problems with any of the following:		
23a. Your vision?	Yes	No
23b. Your physical mobility?	Yes	No
23c. Your memory or attention?	Yes	No

THANK YOU

NASA Task Load Index



Hart and Staveland's NASA Task Load Index (TLX) method assesses work load on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.

Name	Task	Date

Mental Demand — How mentally demanding was the task?

Very Low — Very High

Physical Demand — How physically demanding was the task?

Very Low — Very High

Temporal Demand — How hurried or rushed was the pace of the task?

Very Low — Very High

Performance — How successful were you in accomplishing what you were asked to do?

Perfect — Failure

Effort — How hard did you have to work to accomplish your level of performance?

Very Low — Very High

Frustration — How insecure, discouraged, irritated, stressed, and annoyed wereyou?

Very Low — Very High