Age-Related Differences in Takeover Request Modality Preferences and Attention Allocation During Semi-autonomous Driving

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Abstract. Adults aged 65 years and older are the fastest growing age group worldwide. Future autonomous vehicles may help to support the mobility of older individuals; however, these cars will not be widely available for several decades and current semi-autonomous vehicles often require manual takeover in unusual driving conditions. In these situations, the vehicle issues a takeover request in any uni-, bi- or trimodal combination of visual, auditory, or tactile alerts to signify the need for manual intervention. However, to date, it is not clear whether age-related differences exist in the perceived ease of detecting these alerts. Also, the extent to which engagement in non-driving-related tasks affects this perception in younger and older drivers is not known. Therefore, the goal of this study was to examine the effects of age on the ease of perceiving takeover requests in different sensory channels and on attention allocation during conditional driving automation. Twenty-four younger and 24 older adults drove a simulated SAE Level 3 vehicle under three conditions: baseline, while performing a non-driving-related task, and while engaged in a driving-related task, and were asked to rate the ease of detecting uni-, bi- or trimodal combinations of visual, auditory, or tactile signals. Both age groups found the trimodal alert to be the easiest to detect. Also, older adults focused more on the road than the secondary task compared to younger drivers. Findings may inform the development of next-generation of autonomous vehicle systems to be safe for a wide range of age groups.

Keywords: Autonomous driving · Older adults · Takeover · Multimodal displays · Attention · Preferences

1 Introduction

Interest in autonomous transportation has grown steadily in recent years. In fact, several auto manufacturers are testing autonomous vehicles in many U.S. states, such as California, Texas, Nevada, and Florida [1]. These vehicles, which can control various driving functions without continuous input from human drivers' [2], are being designed to provide various benefits to society, such reducing drivers' workload and lowering the number of traffic accidents [3–7]. They are also expected to support the mobility

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of populations, particularly older adults, who might have experienced difficulties being mobile prior to this technology.

Aging is becoming a major concern for many countries. In the United States alone, by the year 2030, the baby boomer generation, i.e., individuals born between the years 1946 and 1964, will account for approximately 17–29% of the general population [8, 9]. The root of many concerns regarding older adult populations is that perceptual, cognitive, and physical declines are often associated with an increase in age [10, 11]. These changes are likely to create challenges in performing common daily tasks, such as personal care, home chores, and transportation (e.g., [10]). With respect to driving, a daily task that is considerably more complex than most, age-related biological changes can result in driving performance decrements, and Eby et al. [12] concluded that older drivers had higher fatal crashes rates compared to younger adults. Given that the majority of older adults assign a high level of importance to maintaining independence and autonomy throughout later stages of life [13, 14], limiting driving privileges does not represent a feasible solution for this age group.

Autonomous vehicles may help to mitigate some of the problems faced by older adults. Yet, in their current state, these vehicles have their own set of challenges. The Society of Automotive Engineers (SAE) International [15] defines 6 levels of vehicle automation (see Fig. 1). Levels 0–2 require manual input, as well as continuous monitoring of the driving environment. However, for Levels 3 & 4, drivers will be allowed to disengage (to some extent) from driving and perform non-driving related tasks (NDRTs), such as watching a video, reading a book, or resting [15]. For Level 5, drivers will not need to control the vehicle. It will take several decades before SAE Level 5 vehicles makeup the majority of vehicle fleet on roadways. In the interim, Levels 2–4 will likely remain the focus of many research efforts [2, 7]. Specifically, Levels 3 and 4 automated driving systems can reach their design limits, when faced with difficult or unusual conditions, such as encountering road construction, poorly visibility, or loss of GPS connection, and require drivers to resume driving. In these cases, the vehicle will issue a takeover request to signify the need for manual intervention [16–19]. However, age-related declines may limit elderly drivers' abilities to quickly notice and interpret takeover alerts, and successfully resume control of the vehicle [10]. For this reason, it will be critical to ensure that takeover warning alerts are designed considering age-related differences in perception and cognition.

Research studies have evaluated the effectiveness of different types of multimodal warning signals as takeover requests, particularly, different combinations of visual (V), auditory (A), and tactile (T) signals during Level 3 autonomous driving. Many have found bi- and trimodal alert requests to result in the fastest braking response time [21, 22], hands-on steering response time [23], and/or automation disengagement time (captured by button presses) [23]. However, most of these studies involved younger adults only and did not confirm their findings with respect to older groups. But in manual driving, Pitts and Sarter [24] showed that older adults have more difficulty in noticing a tactile signal when it is combined with visual and auditory cues. While this work highlights potential limits in older adults' abilities to recognize and respond to different types of multimodal stimuli, little is known about how drivers subjectively perceive these warning signals. This knowledge is important because it will determine how drivers interpret and

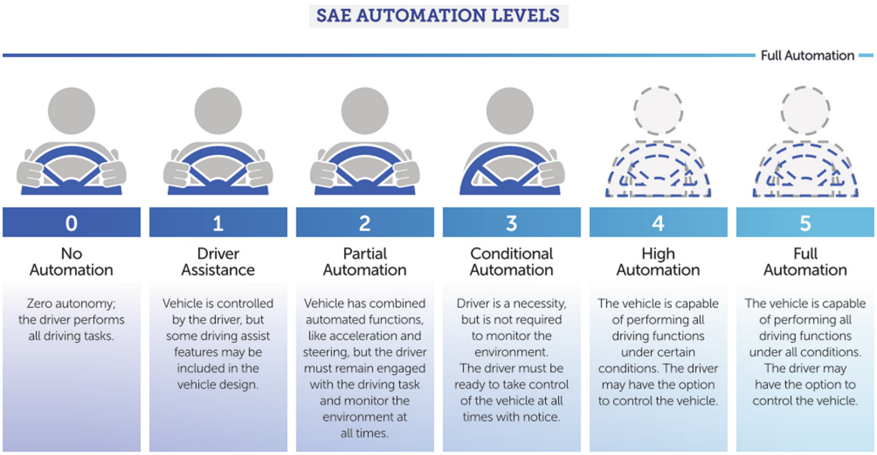

Fig. 1. SAE levels of automation [15] (taken from [20])

respond to notifications. For example, if alarms appear annoying, drivers may decide to ignore them overtime [25, 26]. Therefore, examining the ease of detecting multimodal warning takeover alerts warrants more investigation. Here, perceived ease is defined as the extent to which a system is used without effort [27]. One particular study asked younger drivers to rate all singles, pairs, and triplets of multimodal cues (i.e., V, A, T, VA, VT, AT, and VAT) while using conditional automation and found higher evaluation scores, in terms of usefulness and satisfaction, for bi- and trimodal warnings compared to unimodal warnings [23]. However, it is not clear whether older adults have the same or similar preferences.

In addition, the allocation of attention during semi-autonomous driving between younger and older drivers is also likely to affect the perception of warning signals. For example, Lee, Kim, and Ji [28] found older adults to pay more attention to the road during manual driving, even when instructed to engage in secondary tasks. This behavior may increase their overall readiness to perceive in-vehicle warnings. Currently, it is unclear if older drivers will employ this same strategy (compared to younger adults) during Level 3 autonomous driving operations, when engagement in NDRTs is more tolerated. At the same time, however, this engagement may alter their perception of ease in detecting takeover alerts.

Therefore, the goals of this study were to determine if age-related differences exist in a) the perceived ease of detecting multimodal takeover requests, and b) attention allocation in SAE Level 3 conditional automation. Based on previous studies [21–23, 28], we expected that both age groups would rate multimodal alerts as easier to perceive compared to single signals, and that older adults would focus more on the road (and less on NDRTs) compared to younger drivers.

2 Methods

2.1 Participants

Twenty-four younger and 24 older adults participated in this study. Younger adults were all students from Purdue University and older adults were residents of the Lafayette/West Lafayette, Indiana community. Table 1 provides demographic information about each group. Requirements for participation in the study included: a) possession of a valid U.S. driver's license, b) normal/corrected-to-normal vision; c) no impairments to the sense of hearing and touch, and d) no self-reported susceptibility to motion sickness. Also, the Montreal Cognitive Assessment (MoCA) [29] was used to ensure that older participants did not suffer from any cognitive impairments that would affect their ability to perform our tasks.

Table 1. Demographic information of participants for both age groups. (Data are mean ± standard error of the mean)

	Age	Driving hours per week	Years of driving
Younger adults	21.9 ± 1.4	5.2 ± 5.8	5.3 ± 2.3
Older adults	71.7 ± 4.9	9.8 ± 9.1	54.1 ± 4.8

2.2 Apparatus

Driving Simulation. The experiment used a medium-fidelity driving simulator (miniSim developed by the National Advanced Driving Simulator - NADS) (see Fig. 2), which consisted of three 48-inch LED monitors that displayed the driving environment and one 24-inch LCD screen that simulated the in-vehicle dashboard. Other system hardware included a steering wheel, foot pedals, and a standard-sized leather seat.

Stimulus. Visual (V) warning signals were red circles (200 × 200 pixels) displayed in the center of the main monitor. Auditory (A) signals were 400 Hz beeps. Tactile (T) warnings were presented using two C-2 tactors (i.e., vibration apparatuses) developed by Engineering Acoustics, Inc. They delivered vibrations signals at 250 Hz. As seen in Fig. 3, the tactors were attached to a waist belt and attached to participants' low-back center. The duration of all signals was 1 s.

2.3 Driving Scenario and Study Design

A 2 (age group: younger and older) × 7 (signal type: V, A, T, VA, VT, AT, and VAT) full factorial design was employed. Participants experienced three different driving conditions, i.e., baseline (B), performing a non-driving-related task (NDRT), and performing a driving-related task (DRT), on a simulated 4-lane highway (with two lanes in each direction). Specifically, in condition B, participants were asked to monitor Level 3 automation. They were told that at any time, any of the 7 warning signal types would be presented

Fig. 2. MiniSim driving simulator

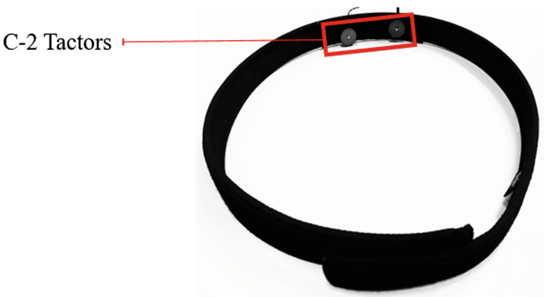

Fig. 3. C-2 tactors (Color figure online)

randomly and would represent 'takeover' requests. In the NDRT condition, participants were required to perform the same task as in condition B. However, now, a (technical talk) video played on the right-hand lower corner of the main display. This task was designed to simulate an in-vehicle (non-driving-related) interaction that drivers can expect to experience in the future. Participants were asked to pay attention to the content of the video. Finally, in the DRT condition, drivers monitored the automation as in condition B, while also performing a driving-related headway estimation task. The purpose of this task was to measure how accurately drivers could estimate the time-to-collision (TTC) with respect to a lead vehicle. This task presented participants with a scenario that could happen right after a takeover request. The researcher randomly probed participants about TTC judgements throughout the drive (12 times in total). At the end of the study, participants were simply asked to rate their perceived ease of detecting the signals.

After the experiment, participants completed a structured questionnaire where they were asked to rate, on a scale from 1 to 10, the ease of detecting each type of warning signal (with 1 being the easiest; 10 being the most difficult). They also answered open-ended questions related to their driving behavior in all three driving conditions, such as the allocation of their attention and headway gap preferences. Questions are listed below:

1) *Based on your ratings of the ease of detecting the signals, explain if any of the seven signals were more difficult to detect compared to others?*
2) *Please describe where your attention was mostly concentrated during the driving while watching a video condition*
3) *In real-life driving, what distance do you feel most comfortable keeping between you and a vehicle in front of you?*

2.4 Procedures

Participants first signed the experimental consent form. Then, a pre-experiment questionnaire was administered to gather information about participants and their driving experiences. After completing this questionnaire, participants completed a 10-min training session. This training introduced them to the experimental equipment, including the driving simulator and warning signal stimuli, reviewed experimental procedures, and provided a sample driving scenario for participants to become familiar with the driving environment and conditions.

For the experiment, the presentation of the three simulated conditions was counterbalanced for each participant, and each condition lasted about 15 min. Also, the 7 warning signals were randomly presented (4 times each) throughout the trials. No actually takeover action was required. A 5-min break was given between each driving condition. After the experiment, the post-experiment questionnaire was conducted.

2.5 Data Analysis

For perceived ease of detecting warning signals, a two-way mixed Analysis of Variance (ANOVA) was conducted to compare differences between age groups and signal types. In this case, independent variables were age (between-subject) and signal type (within-subject), and the dependent variable was the rating score selected by participants. Results were considered statistically significance where p $<$ 0.05. Partial eta squared (η_p^2) was used as a measure of effect size. In addition, analysis of the qualitative data from the open-ended questions included summary statistics, such as the number (or percentage) of people who shared common responses.

3 Results

3.1 Perceived Ease of Detecting Warning Signals

The scores for the ease of detecting warning signals were significantly affected by age ($F(1, 42) = 7.915, p = .007, \eta_p^2 = .159$) and signal type ($F(6, 252) = 18.686, p < .001, \eta_p^2 = .308$). With respect to age, older adults (2.007 $\pm$ .197) perceived all signals to be significantly easier to detect compared to younger adults (2.923 ± .180). For signal type, post-hoc comparisons revealed that the VAT trimodal signal (1.379 ± .126) was easiest to detect, followed by bimodal signals (VA (2.096 ± .163), VT (2.429 ± .170), and AT (2.004 ± .172)), followed by unimodal signals (V (3.488 ± .277), A (2.671 ± .213), and T (3.188 ± .293)). No significant differences were found between bimodal and unimodal signals (i.e., $p > .05$). See Fig. 4.

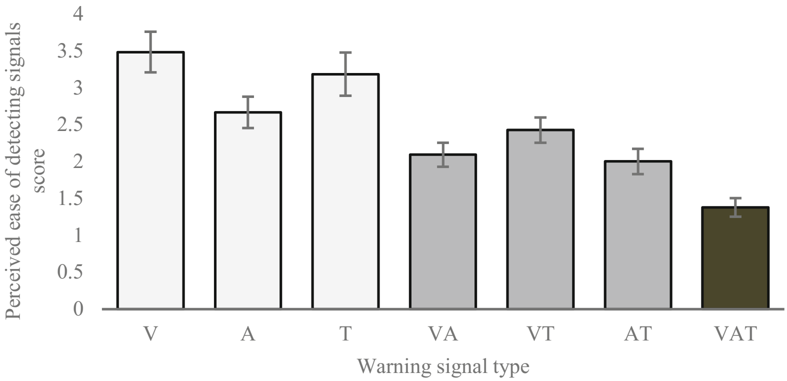

Fig. 4. Scores for the perceived ease of detecting each warning signal type

There was also a significant age × signal type interaction (F (6, 252) = 7.149, p < .001, $\eta_p^2 = .145$) on the scores for the perceived ease of detecting warning signals. According to post-hoc comparisons, younger adults had significantly higher scores for V, T, VA, and VT (i.e., V = 4.875 ± .448; T = 3.875 ± .483; VA = 2.542 ± .255; VT = 2.958 ± .244) compared to older adults for the same signals (i.e., V = 2.100 ± .280; T = 2.500 ± .276; VA = 1.650 ± .182; VT = 1.900 ± .228). Also, older adults rated the single tactile signal (T = 2.500 ± .276) as being more difficult to perceived compared to all other signals. Finally, for younger adults, V (4.875 ± .448) and T (3.875 ± .483) had the highest scores, followed by A (3.042 ± .304), VA (2.542 ± .255), VT (2.958 ± .244), and AT (1.958 ± .204), followed by VAT (1.208 ± .104) (Fig. 5).

3.2 Open-Ended Questions

For the question, *Based on your ratings of the ease of detecting the signals, explain if any of the seven signals were more difficult to detect compared to others?*, 9 out of 24 (37.5%) younger adults felt that the visual signal was the hardest to detect, compared to 4 out of 24 (16.7%) older adults. Here, participants commented that performing secondary tasks impacted the detection of visual signal and also felt that the size of the visual signal made it less salience. For the tactile signal, the same number of younger and older adults (that is, 5) stated that it was more difficult to detect compared to other signals. They explained that the vibration from the driving simulator influenced their perception of the tactile signal. Only 3 participants (i.e., 1 younger adults and 2 older adults) felt that the auditory signal was the hardest to perceive.

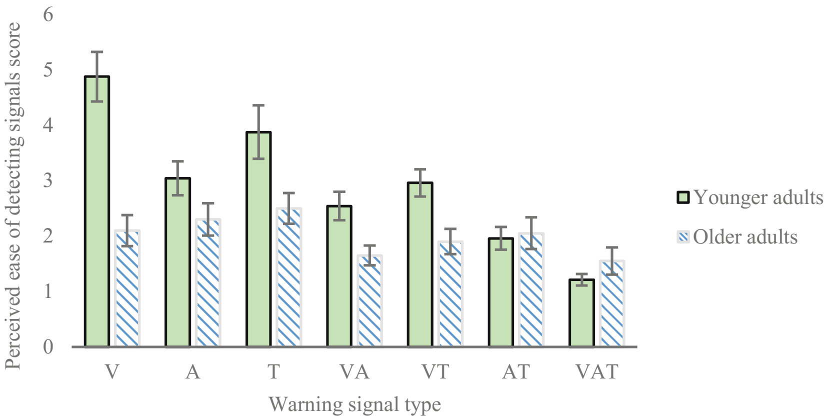

Fig. 5. Scores for the perceived ease of detecting each warning signal type between age groups

For the question, *Please describe where your attention was mostly concentrated during the driving while watching a video condition*, 84.2% of younger drivers reported that they focused mainly on the video in the NDRT (non-driving related task) video watching condition. In contrast, 78.6% of older adults explained that they focused on the road and only seldomly listened to the video.

For the question, *In real-life driving, what distance do you feel most comfortable keeping between you and a vehicle in front of you?*, four options were provided to participants: 1) 1–2 s, 2) 4–5 s, 3) 7–8 s, or 4) if other, please specify. Numerical responses were given by participants. An independent-sample t-test was conducted to compare the mean differences between younger and older adults. The results indicated that older adults preferred a larger headway, 6.43 $\pm$ .524 s, compared to younger drivers, 4.73 $\pm$ .456 s ($p = .018$).

4 Discussion

The goal of this study was to investigate the effects of age on a) the ease of perceiving takeover requests in different sensory modalities and b) attention allocation during SAE Level 3 conditional autonomous driving. Overall, both age groups perceived the trimodal (VAT) signal to be the easiest to detect, followed by bimodal signals. Also, when engaging in non-driving related tasks (NDRT), most of older adults focused on the road, while younger drivers paid more attention to the NDRT.

4.1 Signal Perception

For overall score comparisons between the seven types of signal, trimodal warnings were perceived to be the easiest, followed bimodal signals. This finding is very much consistent with the results of other studies on multimodal warning signal deign, even though the dependent measure is different. In particular, studies that found the same trend with respect to trimodal and bimodal signals often measured response times to cues (e.g., [23, 24, 30, 31]). This consistency may be explained by the notion that multimodal warning signals are often perceived to convey a higher level of urgency [32, 33]. In addition, as many participants mentioned, when visual attention was consumed by watching the video, or when tactile attention was consumed by perceiving the vibration produced by the simulator, it was difficult to detect single signals presented in single modalities. In this case, multimodal signals that used more than one sensory channel (i.e., redundant cues) made it easier to perceive the warnings.

For the observed age-related differences in sensory perception, older adults had the most difficulty in perceiving tactile signals, while younger adults struggled more with visual signals. This phenomenon may be the result of older adults having less exposure to technologies with tactile feedback. Younger adults, on the other hand, thought that visual signals were hardest to detect. This rating is consistent with their subjective responses in the first open-ended question. One possible explanation for this finding may have been captured by the second open-ended quesiton. Here, younger drivers explained that they focused more of their attention on the video watching task. This likely reduced their ability to detect the visual signals, which were located in the peripheral field-of-view, when they were engaged in the video.

4.2 Attention Allocation

The responses from the open-ended questions about the attention allocation in the non-driving related task condition were in accordance with our expectations, as well as previous studies [28] that found that older adults emphasize safety over entertainment compared to younger drivers. This was even further supported by the third open-ended question about the preference of time-to-collision. Here, older adults preferred to have longer headway distances. One possible explanation for this preference could be that older drivers moderate their driving behaviors/patterns (i.e., employ self-regulatory strategies) to compensate for age-related declines in abilities that are critical for driving [34–36]. Alternatively, less exposure to, and thus a general lack of knowledge regarding the capabilities of next-generation autonomous vehicles [37], may create hesitation in senior populations [38].

5 Conclusion

This study examined the effects of age on the ease of perceiving takeover requests in different sensory modalities, as well on the allocation of attention during SAE Level 3 conditional autonomous driving. Overall, trimodal warning signals were perceived easiest to be detected. Also, compared to younger participants, older adults rated the tactile signal as the most difficult unimodal signal to detect. They also focused more on the road even when asked to engage in a non-driving related task. Future work should investigate the perceived ease of detecting multimodal stimuli of different intensities. The findings of this usability study may help to inform the development of next-generation of autonomous vehicle systems that seek to achieve inclusive design.

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