Effects of a Voice Interface on Mirror Check Decrements in Older and Younger Multitasking Drivers

Ben D. Sawyer, Joonbum Lee, Jonathan Dobres, Bruce Mehler, Joseph F. Coughlin, & Bryan Reimer
Massachusetts Institute of Technology, AgeLab & New England University Transportation Center

Older drivers comprise an undue percentage of roadway crashes and fatalities, and existing data implicates decrements to situational awareness as one factor. Although forward attention in older drivers is well studied, rearward attention for this population is little explored. What evidence exists has suggested reduced mirror checks, especially under conditions of multitasking. Voice-enabled in-vehicle systems may represent a partial solution, requiring fewer resources and freeing drivers for behavior which maintains better rearward attention. The present study asked participants to drive on a highway in an instrumented vehicle under conditions of baseline driving, manual radio tuning, and radio tuning assisted by a voice-enabled interface. Results indicate that multitasking greatly reduced mirror checks for all groups. Older participants devoted a greater amount of time to mirror checks than younger participants when just driving, but dropped to levels similar to younger drivers while multitasking. Voice-enabled radio tuning was associated with reduced decrements in mirror checks for all age groups. Discussion centers around this new understanding of differing attentional patterns across lifespan, as well as the impact of voice-enabled interface.

INTRODUCTION

Older drivers are subject to the physical and cognitive impact of aging (Anstey et al., 2005, Owsley et al., 1998; for a review see Morgan & King, 1995) which result, epidemiologically, in higher crash involvement per mile driven, and collateral fatalities (Cicchino & McCartt, 2014). These rates are presently in decline, which can be partially attributed to a better understanding of older adult driver behavior, advances in vehicle safety and a range of interventions designed to meet the needs and challenges of this uniquely vulnerable driving population. It is, however, difficult to identify which resultant engineering and policy interventions are efficacious. Potentially, one such helpful intervention has been the introduction of voice-enabled driver vehicle interfaces into OEM in-vehicle infotainment systems.

Studies broadly agree that the use of both voice and visio-manual interfaces carry attentional demands and concurrent risk of excessive workload. Using either draws on many of the same attentional resources as driving itself (Wickens, 2002), and so limits the stable load level a driver may sustain over time (Hancock & Warm, 1989). Voice systems potentially demand fewer attentional resources than their visio-manual counterparts (Carter & Grahm, 2000; Dobres et al., 2016; Chiung et al., 2004; Mehler et al., 2016; Reimer & Mehler, 2013), but how and whether this adaptive compensation helps is still a matter of debate. Such contention may in part be a reflection of the present diversity in voice interfaces. The vocal modality is commonly paired with visual and haptic demands (see Sawyer et al., 2014; Reimer et al., 2014) to create what might reasonably be termed an auditory-vocal-visual-manual and cognitive interface (as described in Reimer et al., 2014). Such hybridization of modality is the result of practical user interface (UX) realities, but also means that in-vehicle "voice" systems tend to stray from a popular characterization of "eyes-free" or "hands-free" (Reimer et al., 2014). Therefore, a more appropriate way to think of a voice interface is as a component of a multi-modal user interface that, when properly implemented, may incur less demand than alternatives. Specifically, glance patterns show promise as an effective measure to evaluate the complex strategic attentional allocation changes which the incorporation of voice interface may effect in the driver. For example, although gaze patterns while accessing a vocal interface are not identical to those while just driving, they can result in more time with eyes directed toward the forward roadway (Dobres et al., 2016, Mehler et al., 2016) and a distribution of glances across regions more similar to just driving than during a primary visual-manual interaction (Muñoz et al., 2015).

The etiology of older driver collisions specifically suggests a lack of roadway situational awareness. Older drivers are especially prone to angle collisions, more likely to be operating the struck vehicle, and less likely to have made any evasive maneuver (NHTSA, 2009). Visual attention is here clearly implicated, and is vital to building and maintaining the strong situational awareness necessary for defensive driving. Forward attention of older drivers is discussed in a number of studies (see Johnson & Keltner, 1983; Owlsley & Ball, 1993; Morgan & King, 1995), but there is a relative paucity of literature investigating the effects of aging on rear directed attention. Mirror checks are the primary driver accesses to information about the rearward roadway, and all events behind forward and peripheral vision. The link between adequate mirror checking and safety has long been noted (see, for example, Quenalt 1967, 1968). Novice drivers check their mirrors less frequently than experienced drivers, leading to impoverished situational awareness (Underwood et al., 2003). No fully equivalent evaluation has yet been made for older drivers. Indeed, skill-based changes, such as the transition from novice to expert driver, may bear little resemblance to the way driving behaviors change over lifespan. Anecdotal evidence suggests that older drivers seldom check their mirrors (Lee, 2003), an assumption potentially supported by more limited head mobility related to age (Morgan & King, 1995). Simulator-based observations of lane-changing behavior carried out by Lavallière and colleagues (2011a) showed older adults less likely to check the side mirror prior to a maneuver, a finding not supported by a later roadway effort (Lavallière et al, 2011b). When they do glance, there is experimental evidence that overall older adult gaze time is longer (Dobres et al., 2016). Given the vital nature of mirror checks for driver situational awareness and resultant safety, it is striking that a more complete picture of such older driver behavior is not available.

As such, the present study compared older and younger drivers in terms of mirror check behavior, to include both glances to the rearview mirror and total gaze time devoted. Drivers engaged in a baseline "just driving" condition, as well as both simple and complex multitasking conditions involving the infotainment system. Simulated driving has been argued appropriate for evaluations of older drivers (Lee, 2003), but the present study's focus upon glance patterns necessitated a more naturalistic driving (as argued in Dobres et al., 2016) and so data gathered through an instrumented vehicle study on an open highway was leveraged (see Reimer et al., 2013 for experimental details).

Given the above, it was hypothesized that older participants would show: (1) fewer glances to the mirrors, but (2) more time attending to mirrors overall. It was further hypothesized that the multitasking conditions would result in decrements to mirror check frequency (3) and duration (4) relative to baseline driving. The voice-enabled interface was expected to partially mitigate these losses, both in terms of glance frequency (5) and duration (6). Given that driver vehicle interfaces are explicitly developed to be population agnostic, no specific interaction between age and voice interface was assumed for purposes of hypothesis testing; it was expected that the interface would serve all drivers well.

METHOD

Participants

Two gender-balanced cohorts of 30 participants each, 20-29 and 60-69 years of age, were recruited from the greater Boston area. Five of these participants could not be coded for glances due to problems with ambient lighting, one had their eyes out of the video frame, and one was tall enough to result in difficulties in coding and a high number of unclassifiable glances. These seven participants were dropped from the present analysis, resulting in a sample of 15 younger male (*M* = 24 yrs, *SD* = 2.7 yrs), 14 older male (*M* = 66.6 yrs, *SD* = 2.5 yrs), 15 younger female (*M* = 24.73 yrs, *SD* = 3.0 yrs), and 9 older female participants (*M* = 65.4 yrs, *SD* = 2.2 yrs). It is notable that the younger cohort was not composed of novices, and all participants were required to have at least three years driving experience with license, to have driven at least three times a week, and were required to attest to not having been involved in police reported accidents in the past year. Participants were likewise required to speak and understand English well. We screened for self-reported good health, rejecting participants with neurological or cognitive impairment such as Parkinson's, Alzheimer's, dementia, or psychiatric illnesses, as well as physical impairment including cardiac disease, diabetes, or hospitalization in the past six months. Participants were compensated $90 for time involvement of up to four hours and thirty minutes, including two hours of on-road driving. All participants provided informed consent, consistent with guidelines set forth by the Massachusetts Institute of Technology's Institutional Review Board. Further details can be found in Reimer et al., 2013.

Apparatus

Participants drove a 2010 Lincoln MKS and utilized its' OEM in-vehicle infotainment system. The voice-enabled interface was engaged by pressing the "Push to Talk" button (see Figure 1). This interface was an excellent example of voice being used in conjunction with other modalities, as in addition to a manual button press, visual attention to the center stack screen was necessary for prompts and feedback (and see Hancock, Sawyer & Stafford, 2015). Redundant traditional controls existed for many systems. For example, the radio could be manually controlled through dial and button operation alone.

A variety of sensors were directed at the driver and environment, including vehicle telemetry recording, front facing scene cameras, a driver-facing face camera, and a microphone. Glance data in the present work was manually coded (double coded and mediated) from the driver-facing face camera footage, recorded at 15FPS with an AVT Guppy F033C/Kowa LM6NCM fitted with a 6mm lens. In addition to electronic monitoring, the driver was monitored by an experimenter in the rear of the vehicle. This individual, in accordance with an experimental protocol, triggered audio clips guiding the participant through tasks and provided driving directions. They were also responsible for verifying participants' "understanding and compliance" with these instructions and ensuring safety.

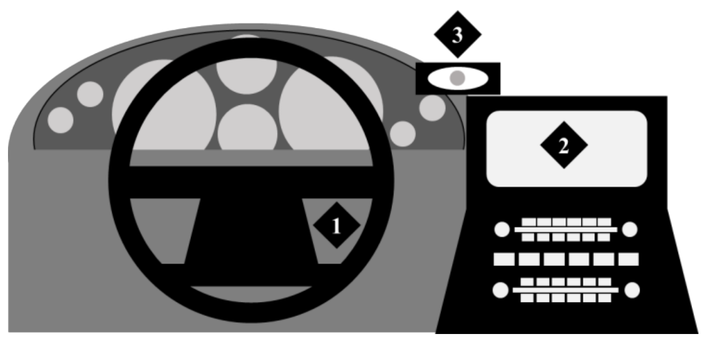

Figure 1. In the 2010 Lincoln MKS used in the present study, accessing the voice interface for radio tuning involved pressing the "push-to-talk" button (1), speaking commands, and listening and/or watching the center stack display (2) for confirmation and prompts. Accessing the visio-manual interface for radio tuning involved pressing two physical buttons, a touchscreen contact, and rotating a tuning knob, all on the center stack (2). Glances were coded from driver-facing camera (3) footage.

Procedure

Before arriving, participants completed a basic demographic survey. Participants were extensively trained on the voice-enabled and visio-manual interfaces of study (see Reimer et al., 2013 for details). Approximately 30 minutes of urban and highway driving was necessary for participants to reach a loop of high speed, divided highway segments outside the greater Boston area which served as the highway testing environment. The adaptation period allowed drivers to become familiar with the vehicle. Over two subsequent 40 minute drives, multiple in-vehicle tasks were assessed. The present analysis focuses upon epochs of time involving driving while engaging in visio-manual and voice-enabled radio tuning, or "just" driving.

When just driving, participants were not operating under any instructions to interact with subsystems of the automobile. The period was intended to be a reference baseline.

When using the radio, "Simple" (i.e., preset station selection) and "Difficult" (i.e., fine tuning) radio tasks were presented, and participants' use of voice or manual systems was isolated to alternating segments, and counterbalanced across the sample. The visual-manual radio tasks were based on the approach taken by the Crash Avoidance Metrics Partnership (CAMP) Driver Workload Metrics project (Angell et al., 2006). The simple visual-manual radio preset tasks consisted of a single button press (preset 1 or preset 5). The difficult visual-manual radio tuning session consisted of four steps accomplished on the center console radio controls. Participants would: 1) turn on the radio by pressing the Volume button, 2) press the Radio button, 3) select a specified radio band using a software touchscreen button (from among AM, FM1, FM2, Sat1, Sat2, and Sat3), and finally, tuning the system to the desired station by rotating the tuning knob.

Voice radio preset tasks consisted of three steps: 1) press the "push-to-talk" button located on the steering wheel, 2) speak "Preset 1" (or Preset 5), and 3) speak "Yes" to confirm the selection. At each step in this process the driver would receive auditory feedback and prompts; for example, a press of the "push-to-talk" button resulted in the auditory prompt, "Please say a command". A given voice radio tuning session consisted of four steps. Participants would 1) press a hardware "push-to-talk" button, 2) speak "Radio," 3) speak the desired station frequency (for example, "100.7"), and finally, 4) speak "Yes", confirming the selection.

Analysis

Eye glance measures were quantified following ISO standards (ISO 15007-1, 2002; ISO 15007-2, 2001) with a glance to a region of interest defined to include the transition time to that object. Glance data reduction was computed from the driver-facing face camera based upon methods initially proposed in Smith, Chang, Glassco, Foley, and Cohen (2005), implemented in Angell et al. (2006 see especially Appendix P). Details on the implementation are provided in Reimer, Mehler, Dobres, et al. (2013, Appendix G), in short, two independent raters coded each epoch of interest according to glances directed to road, center stack, instrument cluster, rearview mirror, left mirror, right mirror, and other areas. Such coding was then compared for discrepancies, and any found were submitted to a third, arbitrating rater, who would produce a final decision. In the present analysis, data from mirror glances was compared to non-mirror glances, and percentages of both count and total time compared to overall values. Specifically, rearview mirror, left mirror, and right mirror glances were summed and divided by total glances to produce the "Mirror Checks as a Percentage of Total Glances" metric (i.e. a time adjusted frequency measure), while time devoted rearview mirror, left mirror, and right mirror glances were summed and divided by total time to produce "Mirror Checks as a Percentage of Total Gaze Time".

RESULTS

The present analysis compared percent of total glances directed to all mirrors and percentage of total gaze time between two populations interacting with two radio tuning interfaces under three load conditions. The resultant experiment produced a 2 (age group: younger, older) x 2 (interface: manual, voice) x 3 (condition: just driving, simple, difficult) within-between design.

There was a significant interaction between condition and age group (Figure 2), Wilks' Lambda = .88, $F(4, 202) = 3.27$, $p = .01$, $\eta^2_p = 0.06$. Univariate ANOVA results were therefore interpreted, revealing the interaction was significant in mirror checking percentage of total gaze time: $F(2, 102) = 6.56$, $p < 0.01$, $\eta^2_p = 0.11$.

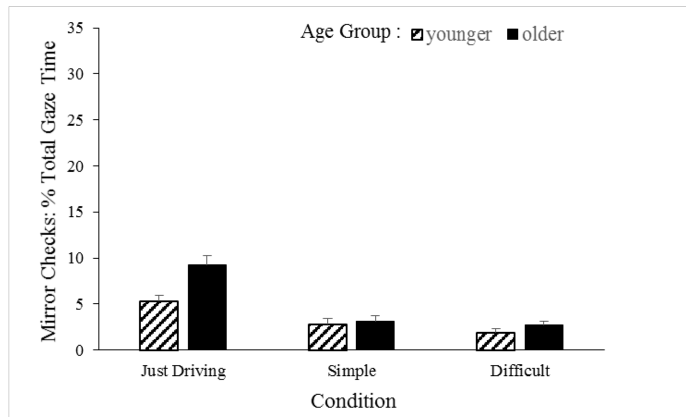

Figure 2. Older experienced drivers, while just driving, devoted a greater amount of gaze time to mirrors than did younger experienced drivers. This is a potentially strategic behavior to maintain rearward situational awareness. Under conditions of multitasking, total gaze time for the older group fell to levels similar to the younger group. Error bars for both figures represent within-participants confidence intervals (Cousineau, 2005).

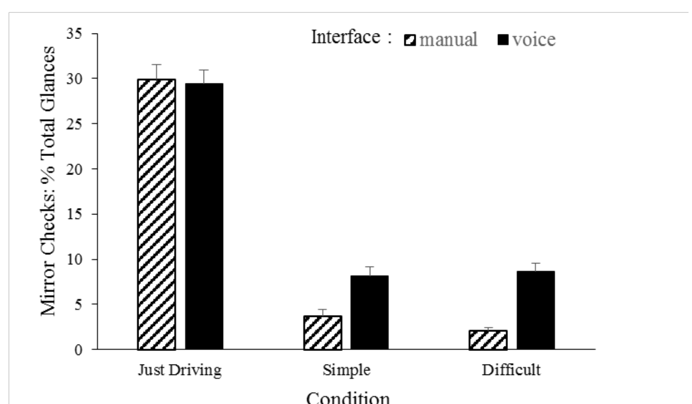

Figure 3. While the drop in proportion of glances devoted to mirror checks is evident, under conditions of multitasking, the voice-enabled interface resulted in drivers maintaining a greater amount of such attention. Error bars for both figures represent within-participants confidence intervals (Cousineau, 2005).

There was also a significant interaction between condition and interface (Figure 3), Wilks' Lambda = .89, $F(4, 202) = 3.19$, $p = .01$, $\eta^2_p = 0.06$. Univariate ANOVA results were therefore interpreted, revealing the interaction was significant in percentage of total glances to mirrors: (violations of sphericity were indicated by Mauchly's Test $\chi^2(2) = 12.24$, and therefore degrees of freedom have been adjusted using the Greenhouse-Geisser (1959) correction, $\varepsilon = 0.82$) $F(1.64, 83.80) = 6.24$, $p = 0.01$, $\eta^2_p = 0.11$.

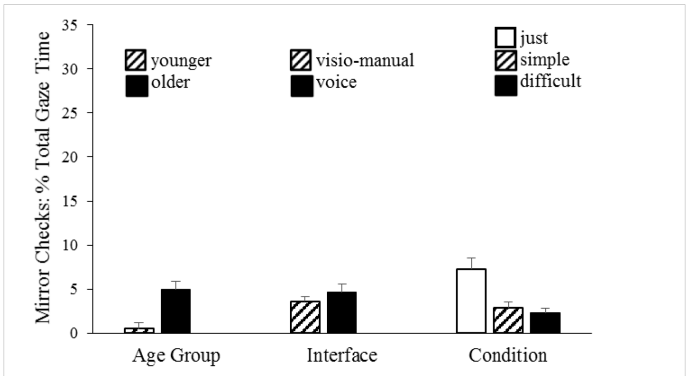

Figure 4. A greater percentage of total gaze time was devoted to mirrors for older drivers, drivers using the voice enabled interface, and under the baseline 'just driving' condition. Error bars for both figures represent within-participants confidence intervals (Cousineau, 2005).

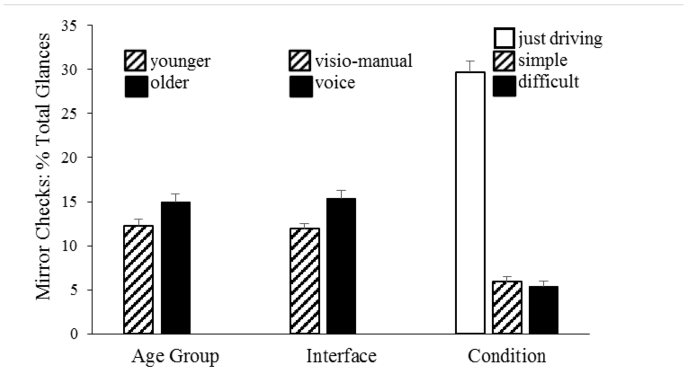

Figure 5. A greater percentage of total glances was devoted to mirrors for older drivers, drivers using the voice enabled interface, and under the baseline 'just driving' condition. Error bars for both figures represent within-participants confidence intervals (Cousineau, 2005).

There was a significant main effect of age group, Wilks' Lambda = 0.87, $F(2, 50) = 3.77$, $p = 0.03$, $\eta^2_p = 0.13$. Between-subjects ANOVA results were therefore interpreted, revealing the effect to be significant as related to both variables: percentage of total glances to mirrors, $F(1, 51) = 5.45$, $p = 0.02$, $\eta^2_p = 0.10$ and percentage of total gaze time $F(1, 51) = 7.00$, $p = 0.01$, $\eta^2_p = 0.12$.

There was a significant main effect of interface, Wilks' Lambda = 0.76, $F(2, 50) = 7.86$, $p = 0.01$, $\eta^2_p = 0.24$. Univariate ANOVA results were therefore interpreted, revealing the effect to be significant as related to both variables: percentage of total glances to mirrors, $F(1, 51) = 15.73$, $p < 0.01$, $\eta^2_p = 0.24$ and percentage of total gaze time $F(1, 51) = 4.90$, $p = 0.03$, $\eta^2_p = 0.09$.

There was a significant main effect of condition, Wilks' Lambda = 0.11, $F(4, 48) = 102.43$, $p < 0.01$, $\eta^2_p = 0.90$. Univariate ANOVA results were therefore interpreted, revealing the effect to be significant as related to both variables: percentage of total glances to mirrors, (violations of sphericity were indicated by Mauchly's Test $\chi^2(2) = 26.79$, and therefore degrees of freedom have been adjusted using the Greenhouse-Geisser (1959) correction, $\varepsilon = 0.71$) $F(1.41, 72.09) = 289.46$, $p < 0.01$, $\eta^2_p = 0.85$ and percentage of total gaze time (violations of sphericity were indicated by Mauchly's Test $\chi^2(2) = 14.45$, and therefore degrees of freedom have been adjusted using the Greenhouse-Geisser (1959) correction, $\varepsilon = 0.80$) $F(1.60, 81.54) = 49.37$, $p < 0.01$, $\eta^2_p = 0.49$.

DISCUSSION

Perhaps the most interesting finding at hand is that older participants, contrary to this paper's first hypothesis (1), engaged in more mirror checks than younger drivers, as well as devoting more gaze time to mirrors, as hypothesized (2). This is important new information, and it seems likely that our older drivers' (60-69 years in this sample) challenges in vision and mobility might drive these increases in mirror checking to better maintain rearward situational awareness. We suggest that increased mirror checking behavior in older adults is compensatory, but further research will be necessary to support that supposition. The present data do not tell us if this difference in attention allocation is adaptive or maladaptive, and we know of no work identifying ideal levels of mirror checking for optimal situational awareness that might clarify the finding.

In support of our third and fourth hypotheses, both multitasking conditions resulted in strong decrements to mirror check frequency (3) and duration (4) relative to the baseline "just driving" condition. The present age x condition interaction sheds additional light on this pattern; older drivers not multitasking with the infotainment system show a much higher gaze time devoted to mirrors, but once interacting with either modality interface in our radio tuning task that time falls far closer to the younger cohort. We suggest that, in the face of increased load, such strategic increases in maintaining situational awareness fall largely by the wayside.

It is therefore notable that the number of glances devoted to mirrors in the interface x condition interaction shows a potentially compensatory pattern: under conditions of multitasking, users of the voice interface devote more time to rearward attention. This upholds both the final hypotheses (6), and may be interpreted as the freeing of resources, allowing longer glances and enhanced maintenance of rearward situational awareness. Here a trend, but no significant effect, was seen for glance number (5). In sum, our present data show that the voice-involved interface supporting enhanced attention to mirrors, as measured by total gaze time. This is a benefit which older drivers may very much need.

What remains unclear from the present "glance based" analysis is the degree of meta-cognitive awareness that drivers have of the costs imposed by multitasking. The values presented here, therefore, are the product of strategic behavioral compensation, the exact nature of which is unknown and which is only minimally explored in the scope of the present work. Indeed, the present work treats all mirrors as a single 'channel', a methodological choice that may mask patterns of visual search. A related concern is that the time adjusted measures employed here do not consider time on task. For example, mean time for completion of the simple task was 7.7 seconds, compared to 24.9 seconds for the complex task. The unbalanced sample in the present study may have limited the sensitivity of statistical inferences, and the interpretation of the dependent variables, glance count and duration, is based upon a very new and incomplete understanding of rearward driver situational awareness. Future work should work to mitigate these limitations, as well as expand these identified areas of knowledge.

What is clear is that multi-tasking and age drive changes in attentional allocation to the rear of a vehicle while driving on a highway. To the extent that we can generalize from this sample, older drivers devote more temporal attention allocation to building rearward situational awareness through mirror checks than do younger drivers until they are faced with the added load of multitasking. They then experience a proportionally more severe version of the decrement all drivers suffer. When multitasking is necessary, a voice-enabled interface such as that tested in the present study can support a reduced detriment to mirror check frequency and length, and so likely better preserve rearward situational awareness. This apparent advantage is seen for all age groups, and is potentially most vital to older drivers, who are stripped by multitasking of what may be an adaptive increase in rearward attention. This is important new evidence, and the fact that it contradicts previous simulator-based findings should serve as a wake-up call in regard to how little is understood about the patterns of naturalistic roadway attention allocation that develop over lifespan.

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