

Analysis of Visual Demands of In-Vehicle Text Displays Reveals an Age-Related Increase in Time Needed to Reallocate Attention to the Road

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ABSTRACT

The purpose of this study was to evaluate age differences in the visual demands imposed by reading in-vehicle text message displays during simulated driving. Visual demand was operationalized in terms of five eye gaze data parameters. Sixteen young (mean age=20) and 16 older (mean age=77) licensed drivers served as participants. They were required to read variable length text messages from a console mounted display while driving on straight segments on a simulated rural highway. Older drivers required much more time to complete the concurrent text reading task – especially for messages of longer lengths. As hypothesized, most of this age-difference resulted from an increase in the time spent reacquiring the road scene between successive glances to the text display. Lane keeping variability increased and driving speed decreased while reading text for older, but not younger, drivers. This pattern of findings is consistent with prior claims that driving performance in older adults is negatively influenced by problems with attention switching mechanisms.

INTRODUCTION

With the continued advance of technology more and more vehicles on the road today are being equipped with In-Vehicle Information Systems (IVIS). Vehicle occupants can use IVIS technologies for a multitude of purposes such as navigational assistance, browsing the internet, email and entertainment. There may be many benefits to such systems. However, it must not be forgotten that IVIS technology can sometimes serve as a source of distraction. The ultimate safety and utility of these devices depend upon the driver's ability to appropriately divide attentional resources between IVIS and the ever-changing demands of the immediate driving environment. As such devices continue to increase in both popularity and availability, it is essential that steps continue to be taken to understand and quantify the attentional costs of using IVIS while driving and its intrusion upon the driver's ability to operate a vehicle safely and efficiently.

The interaction between the increasing demands imposed by IVIS technology and the diminished capacity of many older drivers is of particular interest for the current study. Crash rates per vehicle mile of travel increase among drivers 70 years of age and older (Cerrelli, 1989). A common finding in the transportation literature involves the over-representation of older drivers in collisions which occur during traffic situations where information processing demands are most pronounced, such as cross-traffic maneuvers and intersections (Schieber, 2000). Researchers have suggested that this unique crash signature can be traced to the aging person's decline in the ability to divide attention efficiently (Ball, et al., 1993; Korteling, 1994). Under dual-task situations that demanded visual attentional resources, Korteling (1991) reported that the performance of older persons was significantly impaired when contrasted with that of younger individuals. Similarly,

Verwey (2000) reported that information processing resources were more constricted for an older group of participants while performing a secondary visual task during real world driving when compared to that of young and middle-aged drivers. Such findings suggest that when attempting to balance the visual demands of IVIS technology with those of the driving environment, the cost of switching attention has the potential to be highly problematic for the senescent driver.

In an earlier pilot study, Schieber, et al. (2000) analyzed eye gaze patterns and vehicular control in an attempt to better understand the cost of switching visual attention between an IVIS display and the roadway during simulated driving. While negotiating four driving scenarios (which included straight-aways, passing maneuvers, work zones, and sharp curves), young (20-25) and older participants (67-82) were asked to read questions presented on an IVIS text display. Message length varied randomly across trials (1-8 lines of text; 20 characters per line). As expected, total elapsed time required to read a text display increased with message length. However, the cost of increasing message length upon total reading time was disproportionately exaggerated for the small sample of older drivers (N=6). Further analysis of the gaze data revealed a surprising explanation for the sizable age-difference in total elapsed time required to read midsize and long text messages. Although some of the age-related increase in total elapsed reading time could be explained by a small increase in the number of glances and longer glance times, a larger proportion of this effect was attributable to the unexpected observation that the older drivers required substantially more eyes-on-the-road time between successive glances to the IVIS text display. Such findings are strongly suggestive of a greater cost for attention switching among older drivers. That is, older drivers may require more time to re-establish awareness of the road-way environment following

off-road glances to IVIS displays. Based upon these preliminary findings, Schieber, et al. (2000) suggested that IVIS messages longer than 2-lines of text may intrude upon simulated driving performance and that such effects appear more pronounced among older adults. They also concluded that measurements of eye gaze behavior representing ratios of time spent with eyes-on-the-road versus eyes-off-the-road may provide a potentially useful metric for measuring age differences in the visual demands of IVIS technologies.

Analysis of the crash data from the pilot study described above also yielded results requiring further consideration. Across the entire experiment young drivers exhibited only a 2% crash rate. However, older drivers had a 46.8% crash rate while reading IVIS messages of varying length. Most of these crashes occurred while negotiating roadway settings imposing exceptionally high demands upon simulated driving skills (i.e., 42% during sharp curves, 46% while performing a passing maneuver, and 75% while navigating a narrow, one lane work zone). The reasons for this artificially high crash rate among older drivers were most likely due to several factors uniquely attributable to the experimental paradigm. First, participants received IVIS message prompts while negotiating critically demanding scenarios such as those noted above. They were instructed to engage in the message reading task regardless of simulated driving demands. However, during real-world driving where the consequences of such actions could be severe, it is expected that drivers would most likely postpone any interaction with an IVIS until the demands of driving decreased to a manageable level. Second, the operational characteristics of the driving simulation software and its interaction with the roadway geometry dramatically increased the overall likelihood of encountering a crash event. That is: Drivers were required to use the right lane of a two-lane road except when passing a slow-moving vehicle. The roadway had no shoulder on the right. As a result, the simulation software detected an exception condition and signaled a crash whenever the wheels of the simulated vehicle touched or crossed the pavement marking delineating the right-edge of the lane. Such lane encroachments are much more likely to be observed among older adults in driving simulation settings.

The present study attempted to remedy the occurrence of extraneous crashes by adding a 3rd lane to each traffic direction. Participants were now instructed to remain in the center lane thus allowing the right lane to serve as a proxy for a roadway shoulder. This dramatically decreased the occurrence of simulator crashes due to lane excursions. Also, to better capture the effects of good judgment most likely to be exhibited during real world driving, IVIS text message prompts were administered only while negotiating straight segments of the roadway that were well clear of high-demand locations along the test route. Finally, during the pilot study it was observed that many participants tended to “skim” longer text messages rather than read them in a word-by-word fashion. In order to ensure that participants were not reading for gist, but rather processed each message thoroughly, drivers were required to read each message aloud. It was believed that by making these adjustments, the previous findings sug-

gesting an increased cost of attention switching for older drivers could be reexamined in a clear and more efficient manner.

METHOD

Participants. Sixteen young volunteers (mean age=20; range=19-21; 6 males) were recruited from introductory psychology classes. Sixteen older volunteers (mean age=77; range=65-85; 7 males) were recruited from community service organizations. All participant's held a valid driver's license and were screened to meet a minimum binocular visual acuity of 20/30 (1.5 minarc) at the test message reading distance.

Apparatus and Materials. Simulated driving scenarios were administered using a Systems Technology STISIM (version 8) driving simulator and event scripting language. Driving scenes were rendered on a color display with a width of 32 deg. Instrument panel text messages were displayed on a LCD panel (4-in wide by 3-in high) mounted approximately 30-deg below the normal line of sight. It displayed 8 lines of 20 characters each. The characters subtended a height of approximately 34 minarc at the nominal viewing distance of 20 inches. Twenty text messages were displayed in a random order during the experimental segment of the study (i.e., 5 message lengths (1, 2, 3, 4 & 6 lines of text) by 4 replications). Two high-resolution video cameras recorded the participant's eyes and face; one was mounted directly in the line of sight (straight ahead) of the driving simulator while the other was mounted adjacent to the text message console. Video from each camera was time stamped and recorded. This multi-channel video was digitized off-line using an SGI workstation and direction of gaze determined via a frame-by-frame analysis using IRIS video editing software. Previous work has established the accuracy of this technique for scoring gaze direction as being either toward the text message console or oriented toward the “outside world” (Schieber, et al., 1997).

Procedure. After completing a university approved informed consent procedure, the participant's visual acuity was screened. Following an initial familiarization session with the driving simulator, the participants drove 11 consecutive laps of a 3 mile long virtual driving circuit. Each lap consisted of a work zone, a small-radius turn and a cluster of slow moving vehicles (forcing a passing maneuver) separated by three straight segments of roadway that were each approximately 1 mile in length. The roadway modeled a low-volume rural interstate with a posted speed limit of 65 MPH. The first lap was driven in single-task mode (no text messages presented), laps 2-3 each contained 3 practice IVIS text messages that were not scored, while the 20 experimental IVIS text messages were presented at the midpoints of the straight road segments on laps 4-11. The onset of each text message was signaled by a loud auditory tone. The participant's task was to read the text message aloud while maintaining proper operation of the driving simulator. Eye gaze behavior during the entire reading epoch was analyzed off-line. Driving performance data was logged in 10 consecutive 200-ft epochs (i.e., 2000 ft) following the onset of each text message to allow

subsequent assessment of the potentially deleterious effects of concurrent reading tasks. Pooled baseline driving (i.e., single-task driving without concurrent reading) performance measures were also collected on straight roadway segments on laps 4, 6, 8 and 10.

RESULTS AND DISCUSSION

Modifications to the experimental protocol, as described above, were effective at reducing the abnormally high number of lane excursions encountered in the previous pilot study. In fact, the overall crash rate while reading IVIS text messages was less than 2%. One older male participant experienced multiple crash events. His data were precluded from the analyses which follow.

Glance behavior for each IVIS text message reading trial was quantized into five summary statistics: (1) latency of 1st glance to IVIS display, (2) total number of glances required to read the IVIS message, (3) mean duration of glances to the IVIS display, (4) total glance time directed toward the simulated road scene during the reading task, and (5) total elapsed reading time (between onset of the warning tone and completion of the IVIS reading trial).

A (2) Age by (5) Message Length split-plot ANOVA (using a Greenhouse-Geisser *df* correction) for **total elapsed reading time** yielded a significant 2-way interaction [$F(1.215, 36.436) = 12.061$, $MSE = 14618.992$, $p < .001$]. This interaction is depicted in Figure 1. *Post hoc* decomposition of this interaction effect revealed that the older drivers required more time to finish reading the six line messages [$F(1,30) = 17.391$, $MSE = 21487.110$, $p < .001$], 4 line messages [$F(1,30) = 13.279$, $MSE = 3238.026$, $p < .001$], 3 line messages [$F(1,30) = 12.815$, $MSE = 1581.199$, $p < .001$], and 2 line messages [$F(1,30) = 7.527$, $MSE = 1321.769$, $p < .01$]. Significant main effects were also identified for age [$F(1,30) = 29.003$, $MSE = 10133.377$, $p < .001$] and message length [$F(1,215, 36.436) = 109.323$, $MSE = 14618.992$, $p < .001$].

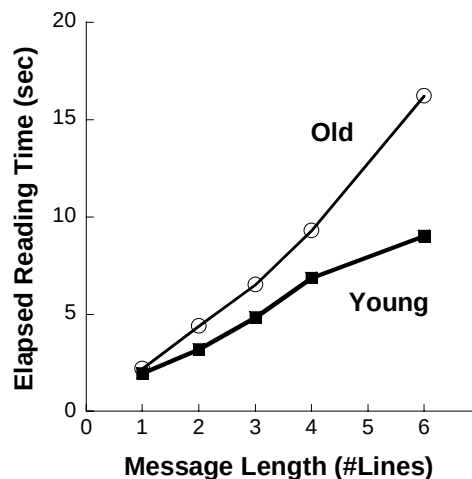


Figure 1. Total elapsed time required to read IVIS text display as a function of driver age and message length.

With respect to the **latency of first glance** towards the IVIS display, a (2) Age by (5) Message Length split-plot ANOVA using a Greenhouse-Geisser *df* correction failed to produce significance with respect to the interaction between age and message length [$F(2.053, 61.583) = .660$, $p = .66$] nor for the main effect of message length [$F(2.053, 61.583) = .787$, $p = .462$]. However, the main effect of age was statistical significance [$F(1,30) = 13.476$, $MSE = 906.842$, $p < .001$] indicating that regardless of message length, older drivers waited longer before reallocating their visual locus from the simulated roadway to the IVIS display. On average, the older group waited an additional half second before initiating a glance to the IVIS display (1.12 vs. 0.54 sec). Such a finding suggests that the older group of drivers may have used this time to prepare for a recognizable dual task situation (e.g. stabilize the vehicle when prompted by the IVIS before glancing away).

Using a Greenhouse-Geisser *df* correction, the (2) Age by (5) Message Length split plot ANOVA for the **total number of glances required to read the IVIS message** yielded a significant age by message length interaction [$F(1.471, 44.144) = 3.902$, $MSE = 1.804$, $p < .039$]. *Post hoc* analysis of simple effects revealed a significant age difference only for 6 line messages [$F(1,30) = 4.781$, $MSE = 3.558$, $p < .037$]. This suggests that older drivers required an additional glance at the IVIS display only while processing the lengthiest of messages (see Figure 2). A significant main effect of message length was also identified [$F(1.471, 44.144) = 173.009$, $MSE = 1.804$, $p < .001$]. However, the main effect of age failed to yield significance [$F(1,30) = 3.110$, $MSE = 2.953$, $p = .088$].

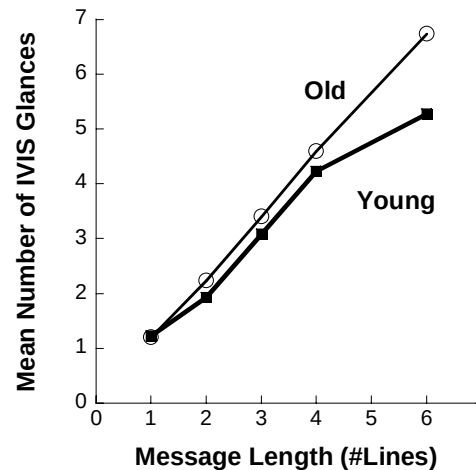


Figure 2. Total number of glances required to read IVIS text display as a function of driver age and message length.

Using **mean glance duration** to the IVIS display as the dependent variable, the (2) Age by (5) Message Length split-plot ANOVA using a Greenhouse-Geisser *df* correction failed to generate either a significant 2-way interaction [$F(2.404, 72.127) = .925$, $MSE = 51.572$, $p = .416$] or an age effect [$F(1,30) = 2.228$, $MSE = 367.157$, $p = .146$], but did identify a significant main effect of message length [$F(2.404, 72.127) = 4.785$, $MSE = 51.572$, $p < .007$]. Young and old drivers alike demonstrated a small but gradual increase in glance duration

while reading IVIS displays of progressively greater length. Average glance time increased from 1.06 sec when reading a 1-line message to 1.25 sec when reading a 6-line message.

The final dependent variable related to gaze behavior involved the **total amount of time spent glancing at the simulated roadway between glances to the IVIS display** during a message reading trial. Using a Greenhouse-Geisser *df* correction, the (2) Age by (5) Message Length split-plot ANOVA yielded significant main effects of both message length [$F(1,241, 37.242) = 39.417, MSE = 8109.169, p < .001$] and age [$F(1,30) = 22.586, MSE = 5560.319, p < .001$], as well as a significant 2-way interaction [$F(1,241, 37.242) = 14.225, MSE = 8109.169, p < .001$]. To further analyze simple effects of age at each message length, one-way ANOVA tests were performed using a Bonferroni adjustment ($\alpha = .05/5 = .01$). The older group of drivers spent significantly more time glancing back at the simulated roadway while in the process of reading 6 line messages [$F(1,30) = 17.577, MSE = 12613.689, p < .001$], 4 line messages [$F(1,30) = 17.797, MSE = 2074.134, p < .001$], 3 line messages [$F(1,30) = 11.376, MSE = 759.099, p < .002$], and 2 line messages [$F(1,30) = 10.578, MSE = 143.932, p < .003$]. These results indicate that the older participants needed to inspect the roadway for significantly longer periods of time between glances to the IVIS display while processing messages of increasing length (see Figure 3). While engaged with the lengthiest of messages, older drivers spent nearly four additional seconds reestablishing roadway awareness within the simulated environment compared to their younger counterparts (7.57 seconds vs. 2.02 seconds). This finding is especially interesting considering that the average time spent visually inspecting the IVIS display, *per se*, was independent of age. To further analyze the effects of this age difference in “eyes on road time”, trend analyses were conducted individually for the old and young age groups using a Bonferroni adjustment ($\alpha = .05/2 = .025$). A significant quadratic trend was identified for the older group of drivers [$F(1,15) = 7.956, MSE = 5262.983, p < .013$], but not the young [$F(1,15) = .775, MSE = 86.756, p = .393$]. Older drivers appear to exhibit greater costs of attention switching when balancing IVIS display demands with those of the simulated driving environment, and these age differences in costs appear to increase in magnitude for messages of greater length.

To analyze the effects of reading the IVIS display upon simulated driving performance, a (2) Age by (6) Message Length by (10) 200-ft Epoch split-plot ANOVA was performed on the following dependent variables: **root mean square (RMS) lane deviation** and **mean driving speed**. Using a Huynh-Feldt *df* correction, the following significant interactions were identified with respect to RMS data: a 3-way age by message length by epoch [$F(11.660, 338.153) = 2.433, MSE = .454, p < .005$], a 2-way length by epoch [$F(11.660, 338.153) = 6.303, MSE = .454, p < .001$], a 2-way age by epoch [$F(3.784, 109.723) = 2.576, MSE = .436, p < .045$], and a 2-way age by length [$F(3.710, 107.604) = 12.598, MSE = .461, p < .001$]. Further analysis of the age by length interaction using one-way ANOVA tests yielded significant simple effects of participant age at 6 line messages ($p < .001$), 4 lines messages ($p < .001$), 3 line messages ($p < .010$), 2 line messages

($p < .001$), 1 lines messages ($p < .003$), and at baseline where no IVIS message was presented ($p < .004$). The simplified representation of the data in Figure 4 suggests that older drivers initially had more variable lane position when compared to young drivers at baseline, and this lateral instability continued to increase as a function of increasing message length.

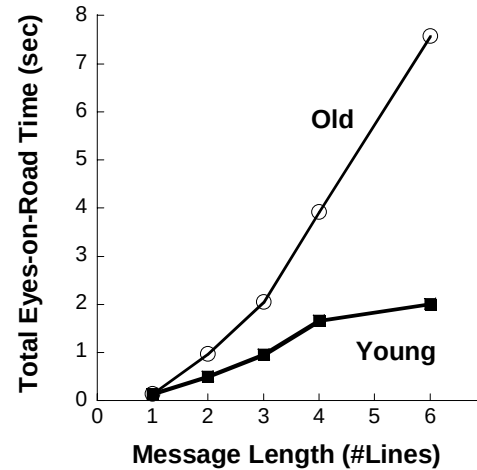


Figure 3. Total eyes-on-road time accumulated between successive glances to IVIS display as a function of driver age and message length

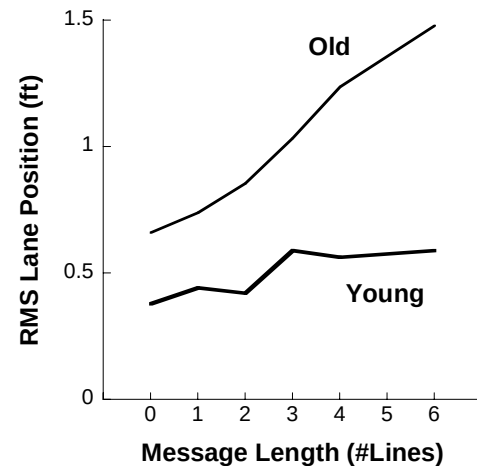


Figure 4. Standard deviation of vehicle lane position as a function of IVIS message length. Baseline driving (no IVIS messages) indicated by message length of zero.

With respect to mean driving speed, use of a Greenhouse-Geisser *df* correction identified the following significant interactions: a 3-way age by message length by epoch [$F(4.924, 142.782) = 5.056, MSE = 13.349, p < .001$], a 2-way length by epoch [$F(4.924, 142.782) = 5.821, MSE = 13.349, p < .001$], and a 2-way age by epoch [$F(2.460, 71.352) = 5.014, p < .006$]. As expected, young drivers exhibited minuscule changes in speed which were independent of both message length and epoch (approximately 60 mph). Older drivers on the other hand, displayed noticeable declines in average speed for message lengths greater than 3 lines of text across trial epoch (from 59 mph at the first epoch to 54 mph at the last epoch).

SUMMARY

Total time required to read IVIS text messages clearly increased for the older drivers in this study. The magnitude of this age-related deficit was strongly influenced by message length. Although no age difference in total reading time was apparent for the shortest message presented, older drivers required 36% and 80% longer to read 2-line and 6-line messages, respectively. However, the most interesting finding of the current study was the diagnosis of the likely mechanism mediating this age effect. Rather than resulting from the need for many more glances or significantly longer individual reading glance times, almost all of the age-related slowing on the text reading task could be attributed to remarkable increases in the total amount of time that older drivers spent looking at the roadway between successive glances to the IVIS display (see Figure 3). This finding replicates and confirms the validity of the unexpected roadway *attentional hysteresis* effect discovered in our previous pilot study. While young drivers required only very brief glances at the roadway to refresh their representations of the travel environment between successive glances to multiline text messages, older drivers found it necessary to dedicate significantly more time to processing information from the road ahead between IVIS task updates. This pattern of results is consistent with prior claims that age-related deficits in driver visual information processing efficiency are strongly related to problems with attention switching mechanisms. Also consistent with the hypothesis of an age-related loss in attention switching efficiency while driving was the finding that the latency between the warning tone announcing the availability of a new text message and the first glance to the IVIS display was about twice as long for the older drivers relative to their younger counterparts. Additional research will be needed to better elucidate the specific nature of these phenomena.

In general, neither mean glance time nor the number of glances required to read the IVIS display varied as a function of driver age. The exception to this general trend was the observation that young drivers tended to need one less glance to read the 6-line message (see Figure 2). This finding suggests that young drivers were able to execute more eye fixation updates during the prolonged gaze periods associated with this reading condition. However, our eye gaze data lacked the spatial resolution to specifically evaluate such a possibility. It should be noted, nonetheless, that the video-based gaze analysis methodology used here was of sufficient spatial resolution to allow the assessment of many important issues regarding driver visual processing demands. This, in turn, provides direct support for the validity of the approach espoused by the Society of Automotive Engineers' *J2396 Recommended Practice* for measuring driver visual behavior (SAE, 2000).

Finally, introduction of the concurrent IVIS reading task had little effect on the simulated driving performance of the young participants. However, very large increases in lane position variability were associated with reading the IVIS text display among the older participants. This clearly suggested that concurrent interaction with the IVIS display (in the eyes-

down configuration used here) intruded negatively upon simulated driving performance. Older drivers apparently tried to compensate for the increased demands by reducing their driving speed during the text reading task. Obviously, this compensatory behavior was not sufficient to prevent intrusion upon lane keeping performance as described above.

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