SERIALIZATION OF BEHAVIOR DURING CAR FOLLOWING IN OLDER DRIVERS

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Summary: Age-related declines in cognitive functioning can push older adults to adopt strategies that may or may not improve their driving safety. Previous research suggests one strategy involves performing complex driving tasks (e.g., right turn negotiation) in discrete steps ("serialization") rather than fluidly. The current study used simulator scenarios developed to test possible age-related serialization of behavior during complex car following. In all scenarios, participants closely monitored a lead vehicle using sustained attention. During multi-tasking scenarios, drivers performed an additional localization task designed to increase the demands on attention. The results demonstrate that older adults showed general impairments in multi-tasking and vehicle control during car following. Importantly, age-associated changes in task execution were observed, demonstrating older adults also serialize car following behavior under certain conditions. As a result, older drivers withdrew attention from the lead vehicle for several seconds. This pattern of behavior identifies a remediable situation where age-associated impairments may increase crash risk.

INTRODUCTION

Laboratory assessments have demonstrated age-related impairments in allocating attention across multiple behavioral tasks (Kray & Lindenberger, 2000; Mayr, 2001). Similarly, impairments in coordinating complex actions have been observed in the driving domain. In general, when attentional resources are taxed; for example, when a driver must perform secondary or distracting in-vehicle tasks, older adults tend to suffer greater behavioral interference compared to young or middle-aged drivers (Wood et al., 2006; Gaspar, Neider, & Kramer, 2013; Wild-Hall, Hahn, & Falkenstein, 2011). Fortunately, older drivers are often adept at recognizing their cognitive and behavioral limitations and may take steps to optimize performance. For example, individuals who are aware of certain impairments may adopt apparent compensatory strategies to allocate processing resources when task demands rise (Hakamies-Blomqvist, 1994). For example, Fovanova & Vollrath (2011) asked older and younger drivers to perform a difficult lane change maneuver in an on-road vehicle, in the presence of absence of a secondary task. They observed that older adults strategically abandoned a secondary task when mental workload increased and resumed it following a successful lane change maneuver. This strategic abandonment of the non-critical secondary task resulted equivalent levels of vehicle control across age groups.

Related studies using an instrumented vehicle (IV) have elucidated a particular age-specific compensatory strategy. These studies have demonstrated "serialization" of certain vehicle controls in older adults during complex driving maneuvers (Boer et al., 2011; Thompson et al., 2012). In one study, older adults performing right hand turns made steering and speed adjustments in discrete serial stages, whereas younger adults accelerated and adjusted steering

simultaneously (Boer et al., 2011). As a result, serialization led older adults to complete the single fluid action of navigating a turn as a series of distinct component behavioral steps.
The current study examined how age-related serialization strategies may affect driving behavior in a car following scenario. This scenario was designed to assess a driver's ability to coordinate multiple *on-road* tasks that may be performed in conjunction with car following. Car following is a common driving behavior that can be attentionally demanding depending on road culture and surrounding environment. Previous studies often manipulate attentional demands via secondary tasks (e.g., mental math) that are well controlled but uncommon in real world driving. The current scenarios were designed to provide continuous measures of attention and during quasi-naturalistic on-road multi-tasking, as well as quantitative behavioral and vehicle control measures, to test the hypothesis of serialization of vehicle control by older drivers.

METHODS

19 younger adults (ages: 22-46 (M = 30.19, SD = 6.11); 8 females) and 16 older adults (ages: 67-87 (M = 79.25, SD = 5.95); 5 females) participated. All participants were currently licensed to drive and reported driving daily. As part of a larger neuropsychological battery, participants completed the Montreal Cognitive Assessment (MOCA). We found no evidence of cognitive impairment in the older participants. Experimental drives were conducted in a DriveSafety DS-600 fixed-base simulator with five LCD monitors creating a 180° forward field of view. A rear-view and two side-view LCD screens provided a rear-facing traffic perspective. In all scenarios, drivers followed a lead vehicle (LV), throughout the drive. The LV varied its speed between 50, 55, and 60 MPH at random intervals. Drivers were told to adjust their speed to match the LV speed. Feedback was given to participants when they lagged too far (> 3.5 seconds headway) or approached too close (< 1.5 seconds headway). Secondary tasks were included in two scenarios in an attempt to elicit serialization behaviors by increasing the attentional demands on the driver during the car following task (details below).

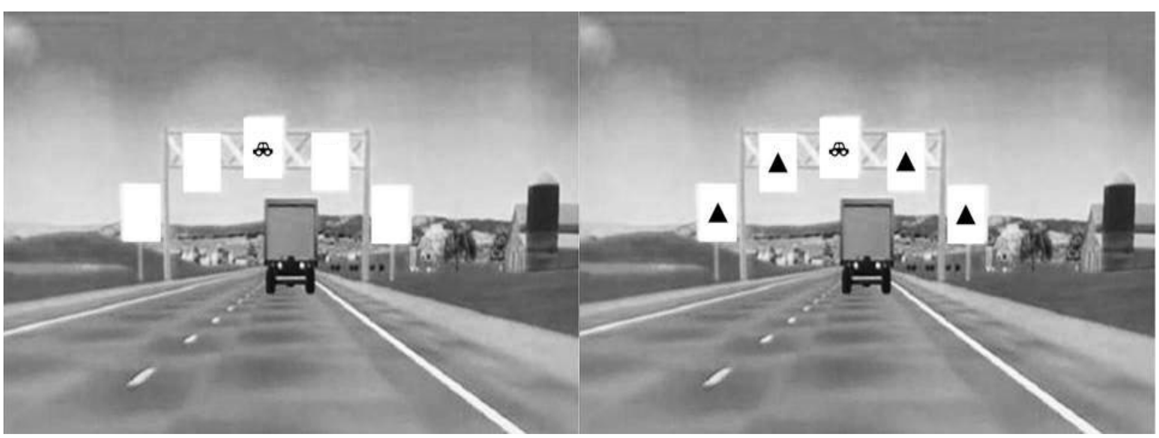

Figure 1. Example of the peripheral sign localization task from the "Locate" and "Ignore" scenarios. Participants followed the LV for the duration of all drive scenarios (see Procedures). Hazard flashes appeared on the LV, illustrating a "target" event. In the Ignore scenario, the peripheral target (small car) appeared among distractor items (black triangles). No distractors appeared in Locate scenario

Follow. During all driving scenarios, sustained attention to the LV was manipulated by asking drivers to monitor the LV's turn signal behavior. In this task, drivers were asked to activate their high beams every time the LV flashed its hazard lights (see Figure 1). A hazard flash event lasted one second, with ten flash events occurring in each driving scenario. Because the task was designed to measure sustained attention, hazard flashes were embedded in the LV's unpredictable turn signal behavior. The LV's turn signals randomly alternated during all scenarios. The turn signals could be active for as little as 50 meters or as much as 1000 meters before switching to the opposite signal (approx. 2 seconds or 40 seconds, respectively; depending on speed).

Follow & Locate. During this scenario, participants performed an additional localization (see Figure 1) task, resembling the challenge of identifying landmark or speed limit signs in the visual periphery.

Follow & Ignore. In this scenario, distractor items (solid black triangles) appeared with the peripheral target object, mimicking cluttered roadway signage. In order to successfully locate the target object, distractor locations needed to be ignored by the driver.

During the Locate and Ignore scenarios, participants spoke the numbered location of a car symbol that appeared on an overhead sign in one of five possible locations (numbered left to right) (Figure 1). The car symbol appeared 3.5 seconds before the participant car would arrive directly under the sign. The car symbol location varied randomly and was displayed for 125 ms for younger adults and 250 ms for older adults. These values were based on pilot testing to determine display times that allowed for adequate levels of accuracy in both age groups. Sign localization points were interspersed approximately every 900 meters. Hazard flashes of the LV did not predict sign events, as peripheral sign locations did not correspond to the hazard flash schedule. Attention to the forward vehicle was calculated using the proportion of correctly detected hazard flashes. Sign localization was calculated as proportion correct. Two common metrics of vehicle control were examined: standard deviation of lane position (SDLP) and coherence (i.e., correlation between driver speed and LV speed).

RESULTS

Follow

Figure 2 shows hit rates for the sustained attention task in all drive scenarios. Age group differences were analyzed with one-way ANOVAs. Performance on the sustained attention task was quantified using a hit rate, where the proportion reflects the number of correctly detected flashes out of the possible ten. In this task, younger participants had a significantly higher detection rate compared to older adults ($F(1,33) = 9.168$, $p = .005$). Significant age-related differences in reaction time (RT) were also observed, younger adults responded faster ($M = 804.27$, $SD = 163.44$) than older adults ($M = 963.06$, $SD = 259.61$; $F(1,33) = 4.847$, $p = .035$). Average SDLP was marginally significantly ($p = .088$) different between younger ($M = 0.146$, $SD = .04$) and older adults ($M = .170$, $SD = .03$). Finally, younger adults ($M = 0.830$, $SD = .18$) showed greater coherence than older adults ($M = .799$, $SD = .10$), but this difference was not significant ($p = .565$).

Follow & Locate

Sustained attention hit rates were again greater in younger adults compared to older adults ($F(1,33) = 19.697$, $p < .001$). RTs were again faster ($F(1,33) = 6.552$, $p = .015$) for younger adults ($M = 901.33$, $SD = 187.63$) than older adults ($M = 1117.90$, $SD = 307.47$). Peripheral localization was quantified as the proportion correct out of the possible ten trial events. Peripheral localization accuracy appears in Figure 3. Localization performance did not differ significantly ($p = .173$) between younger and older adults. Younger ($M = .148$, $SD = .05$) and older adults ($M = .183$, $SD = .05$) did significantly differ ($F(1,33) = 4.21$, $p = .048$) in their ability to maintain lateral vehicle control (SDLP). Coherence was lower in older adults ($M = .82$, $SD = .05$) compared to younger adults ($M = .72$, $SD = .08$; $F(1,33) = 21.735$, $p < .001$).

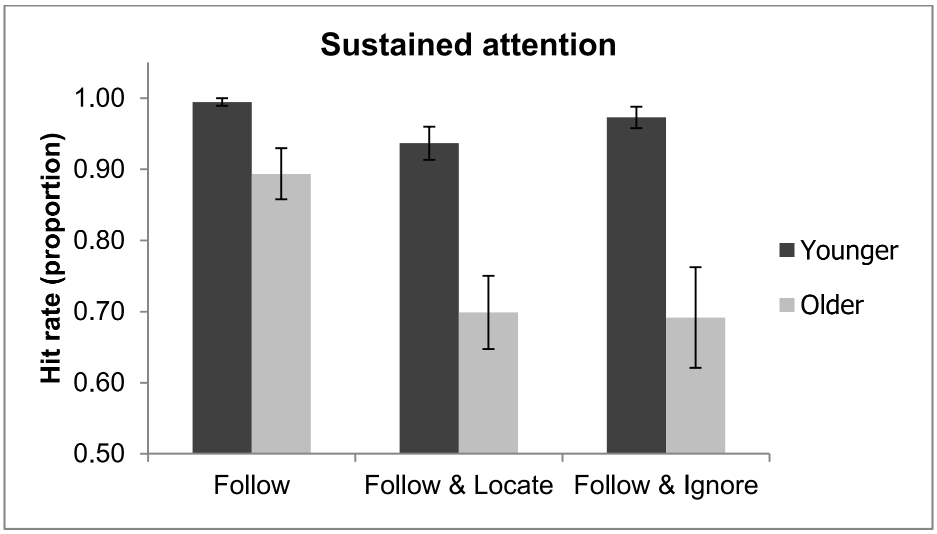

Figure 2. Hazard flash detection performance for all scenarios. Error bars represent standard error estimates

Follow & Ignore

Sustained attention hit rates were again greater in younger adults compared to older adults ($F(1,33) = 17.824$, $p < .001$). RTs were significantly faster ($F(1,33) = 8.738$, $p = .006$) for younger adults ($M = 864.07$, $SD = 176.55$) than older adults ($M = 1067.63$, $SD = 230.64$). Again, Sign localization accuracy did not significantly differ between younger ($M = .96$, $SD = .06$) and older adults ($M = .90$, $SD = .15$; $p =$ ns). SDLP did not significantly differ between young ($M = .16$, $SD = .05$) and older adults ($M = 18$, $SD = .04$; $p =$ ns). Younger adults ($M = .81$, $SD = .06$) showed significantly greater speed coherence ($F(1,33) = 8.188$, $p = .007$) compared to older adults ($M = .74$, $SD = .09$).

Figure 3 suggests that irrelevant distractors in the localization task of the Follow & Ignore scenario did not interfere with performance. Specifically, a 2x2 ANOVA including factors of distractor presence and age group showed a main effect of age ($F(1,33) = 23.81$, $p < .0001$) but no main effect of distractor presence ($F(1,33) = .256$, $p = .617$) or an interaction ($F(1,33) = .571$, $p = .455$). Therefore, we computed a combined "dual-task score" for the sustained attention task during Locate and Ignore scenarios. This averaging allowed us to test for age differences in performing the sustained attention LV task and sign localization simultaneously, versus car following alone. Results showed significant main effects for age group ($F(1,33) = 23.485$, $p < .0001$) and task demand ($F(1,33) = 24.148$, $p < .0001$). There was also a significant interaction between age and task demand ($F(1,33) = 10.72$, $p = .002$). These results indicate older adults show greater impairments in sustained attention task when they also have to perform the secondary localization task.

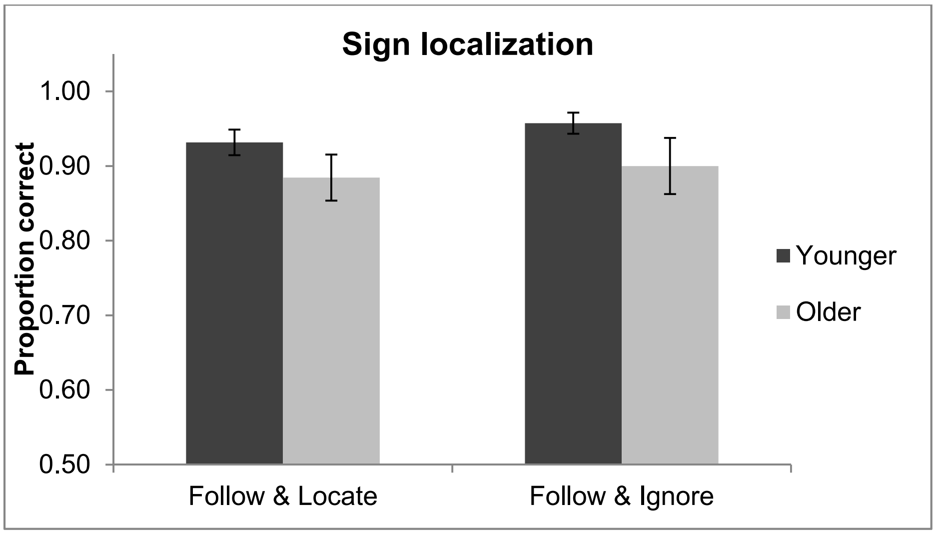

Figure 3. Localization performance for Locate and Ignore scenarios. Error bars represent standard error estimates

Age-related serialization during car following

So far, the results demonstrate that when older adults had to closely monitor the LV and pay attention to the peripheral environment, they showed pronounced impairment in sustained attention to the LV and minimal impairments in localization. This pattern of results is surprising given the importance of monitoring the roadway and LV behavior in driving environments. The decrease in hazard hit rate may reflect an adaptation by the older drivers when they have to cope with additional on-road tasks. Older adults might reduce attention to the LV when a peripheral sign is approaching on the roadway, to allow those processing resources to "shift" to the impending task. If so, sustained attention hit rates should be particularly low when a hazard target flash occurs near a sign point because older adults have maximally reduced attention to the LV and started paying attention to the signs.

To test this hypothesis, we categorized hazard events by their proximity to sign localization points. Sign localization points were approximately 900 meters apart, so hazard flash targets were binned into 300 meter sections, creating "Pre-", "Mid-", and "Post-sign" time windows. Data were then analyzed using a 2x3 repeated-measures ANOVA including factors of age group and time window. (Note: two older adults were removed from this analysis due to chance-level hazard flash detection performance in multiple time windows.)

A main effect of age group ($F(2,62) = 24.139$, $p < .001$) was observed when drivers had to perform both tasks at once; the time window factor was not significant ($F(2,62) = 2.017$, $p = .142$). Results showed a significant interaction between age group and time window ($F(2,31) = 3.623$, $p = .032$). The pattern of behavior suggests young adults can perform the hazard and sign tasks in parallel (see Figure 4). In contrast, older adults showed a general decrement in monitoring the LV and this decrement varied with temporal changes in task demands. As older drivers approached a sign localization point (i.e., the "Pre-sign" zone), demands on attention increased, as a result, older adults switched from LV monitoring to peripheral localization and attention to the LV. Consequently, sustained attention performance fell when LV monitoring was abandoned.

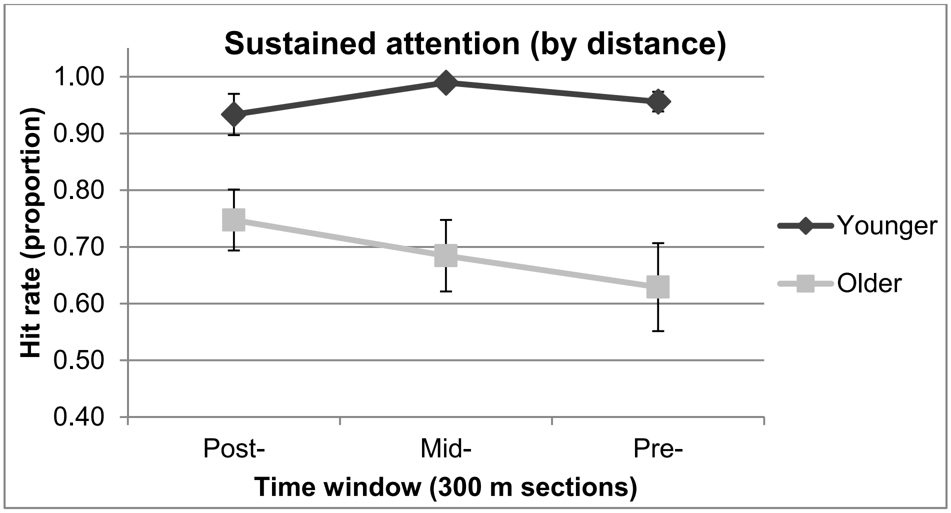

Figure 4. Detection rates when sign localization was also performed. Hit rates were averaged across Locate & Ignore scenarios. X-axis indicates distance from peripheral localization (in 300 m intervals) event. Error bars represent standard error estimates

DISCUSSION

This study provides confirmation and further detail on the serialization of older driver behavior during coordinated complex driving maneuvers. In all scenarios, young adults carefully monitored the LV, resulting in near perfect sustained attention detection performance. Older drivers showed a significant decrease in this task and age-associated response slowing. When drivers had to perform an additional sign localization task, younger drivers again had higher sustained attention performance and greater sign localization accuracy than older adults. In contrast, older adults showed a large decrease in detection, but minimal impairments in sign localization. Also, performing both tasks resulted in some reductions in drivers' ability to match the speed of the LV and maintain lateral vehicle control. Finally, the time window analyses demonstrated the disproportionate impairment in hazard flash detection in older drivers reflects abandonment of forward vehicle monitoring when sign localization also demands attention.

At some level, it is not surprising that older adults have difficulty performing more than one task simultaneously (Kray & Lindenberger, 2000). A consequence of cognitive aging is adoption of strategies to allocate attention more efficiently, rather than dividing limited resources across multiple tasks (Boer et al., 2011; Thompson et al., 2012). In the driving domain, one such strategy involves performing complex driving behaviors in discrete, serial steps. The current experiments demonstrate older adults also serialize car following behavior when the on-road tasks become more difficult. We believe this pattern of results may be of particular real world importance. Subsets of older adults (>70 y.o.) are known to have an increased risk for automobile collisions and on-road fatalities in certain driving contexts (NHTSA, 2009). The current results provide evidence of an environment where this risk may be particularly high. While the current scenarios did not explicitly test crash risk or responses to LV braking behavior, future research will characterize how complex driving behaviors (e.g., unexpected braking) might be impacted by serialization, and how eye-tracking might be used to identify drivers' currently attended on-road task.

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