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Comparing the Glance Patterns of Older versus Younger Experienced Drivers: Scanning for Hazards while Approaching and Entering the Intersection

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Abstract

Older drivers are known to look less often for hazards when turning at T-intersections or at four way intersections. The present study is an extension of Romoser & Fisher (2009) and attempts to further analyze the differences in scanning behavior between older and experienced younger drivers in intersections. We evaluated four hypotheses that attempt to explain the older drivers' failure to properly scan in intersections: difficulty with head movements, decreases in working memory capacity, increased distractibility, and failure to recall specific scanning patterns. To test these hypotheses, older and younger experienced drivers' point-of-gaze was monitored while they drove a series of simulated intersections with hidden hazards outside of the turning path. Our results suggest that none of these hypotheses can fully explain our finding that older adults are more likely to remain fixated on their intended path of travel and look less than younger drivers towards other areas where likely hazards might materialize. Instead, the results support a complementary hypothesis that at least some of the difficulties older adults have scanning intersections are due to a specific attentional deficit in the older drivers' ability to inhibit what has become their prepotent goal of monitoring the vehicle's intended path of travel, thereby causing older drivers to fail to scan hazardous areas outside this intended path of travel.

Keywords

older drivers; intersections; scanning; attention; simulation; eye tracking

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Introduction

After age seventy, crash rates begin to increase, primarily in crashes in intersections where hazards typically emerge from the side of the driver's vehicle (Bryer, 2000; Garber & Srinivasan, 1991; Ryan, Legge, & Rosman, 1998). Left turns through intersections, either across traffic or at a T-intersection, are the most risky for older drivers (Bao & Boyle, 2009; Clarke, Ward, Bartle, & Truman, 2010; Garber & Srinivasan, 1991; Gstalter & Fastenmeier, 2010; Staplin & Lyles, 1991). This is in spite of the fact that older drivers appear to be aware of the problem; in a survey study by Eck and Winn (2002), older drivers reported left turns to be the most difficult maneuver. As with younger inexperienced drivers, a failure to scan appropriately is implicated (Bao & Boyle, 2009).

There is conflicting evidence as to whether older drivers are less likely than younger experienced drivers to glance towards areas where hazards are most likely to develop at intersections. (Except when explicitly noted below, we will use the term 'younger drivers' to refer to younger experienced drivers – usually at least 25 years old.) Three studies will be reviewed. First, a naturalistic study by Keskinen, Ota, and Katila (1998) found no difference between older and younger drivers in the number of glances before making a right hand turn in Japan (the equivalent of a left turn in the U.S.). However, because they discretely videotaped traffic navigating intersections and did not interview drivers in the cars so videotaped, their estimates of drivers' ages were subjective. In addition, they only recorded head movements before the turn at the intersection – but not at either the beginning of the turn (when the driver is moving into cross traffic but has yet to turn the wheel) or while executing the turn. Such head movements are especially critical when the driver is at a stop sign-controlled intersection (T or four-way) – where cross traffic has the right of way, is moving quickly, and is possibly obscured (e.g., by a bend in the road).

Second, Bao and Boyle (2009) used in-vehicle cameras to monitor drivers' head movements during right and left hand turns and straight-through driving maneuvers at two different four-way stop sign-controlled intersections. Each intersection was a major 4-lane expressway with a median strip intersected by a 2-lane rural road. The older drivers approached the intersection on the 2-lane road, which contained a stop sign. Separate analyses were undertaken for the drivers' head movements before the intersection, during the approach to the median, and after exiting the intersection. The visual scanning behavior was inferred from head movements. They found that the scanning behavior of drivers aged 65 to 80 was primarily confined to an area directly in front of their vehicle before the intersection, while executing the turn and after exiting the intersection. In all that follows, we will refer to gazing at the future path of the vehicle as 'looking straight ahead'. Bao and Boyle noted that one of the intersections had a higher rate of crashes – an average of five per year as compared to only one per year for the other. For the high-crash intersection, the difference in crash rates between the two intersections coincided with the presence of obscuring features that blocked the drivers' view of oncoming traffic such as horizontal curvature on the cross road. Additionally, the intersection with the higher crash rate had a speed limit of 55 mph as compared to 35 mph for the low crash intersection (Bao and Boyle, 2008). They also found that higher traffic volume did have an effect on drivers scanning to the left, but only on the approach to the intersection. The study is important because it is the first one to compare the proportion of time that older and younger experienced drivers spend scanning to the left, ahead and to the right as they approach, enter and exit an intersection. However, because it was a field study it was not possible easily to evaluate the various hypotheses that have been put forward to describe why the observed decreases in the scanning behavior of older drivers actually occur. As such, a further study is warranted in which one can better control the built and natural features of the environment at intersections and thereby rule out various competing explanations of older drivers' failure to scan to the sides.

Third, Romoser and Fisher (2009) conducted a training study aimed at improving older driver scanning in intersections at the onset of the turn. They focused on what they termed secondary glances, which were glances made when the driver begins to roll into the intersection and while in the intersection. They found that older drivers, prior to training, made a secondary glance toward hazardous regions only 35% to 40% of the time both in a simulator and in the field (scanning behavior in the field was inferred from head movements, on the simulator from eye movements). An earlier study done on a driving simulator (Romoser, Fisher, Mourant, Wachtel, & Sizov, 2005) found that younger drivers took secondary glances to the far left 72% of the time compared to only 44% of the time for older drivers when making a right turn at a T-intersection with a hill to the left obscuring oncoming traffic approximately 3 seconds away. However, in both Romoser et al. (2005) and Romoser & Fisher (2009), the authors studied secondary glances only as a binary variable – either the driver took a secondary glance or they did not. As a result, the subtle differences of scanning behavior such as the duration and location of glances could not be determined.

The present study is a follow up to Romoser & Fisher (2009) and attempts to further investigate the differences in scanning behaviors between experienced older and experienced younger drivers in intersections, especially when the intersection does not contain distractions but does contain features that obscure oncoming traffic. We investigate examples of three different intersection types (that also require different driving maneuvers) that have proven to be especially dangerous for older drivers: right turns at T-intersections, left turns across traffic in signalized intersections, and straight through maneuvers when cross traffic has the right away. Specifically, our analyses are of the glance protocols (viewing direction at each point in time during a turn) of older (ages 72–87) and younger (ages 25–55) experienced drivers when negotiating intersections during an interval extending from 8 seconds prior to when they cross into the intersection to 5 seconds after that moment. To date, most research investigating the road scanning of older drivers has coded data as "looked" or "did not look" decisions within a time window of a few seconds after drivers enter an intersection (see Romoser & Fisher, 2009) or grouped glances into large spatial "bins" at various angles relative to the car at a specific points in the turning maneuver (see Bao & Boyle, 2009; Staplin, Gish, Decina, Lococo, & McKnight, 1998). So far, however, no studies have compared how long older and younger drivers spend glancing at areas of visual interest as small as 15 degrees as a function of time intervals as small as one-third of a second.

This particular set of intersection scenarios and more fine grained analysis will allow us to evaluate four different hypotheses of why it is that older drivers fail to scan for threats at intersections as frequently as do younger drivers. The first is the hypothesis that older adults are less likely to scan because it is more difficult for them to turn their heads (e.g., Eby, Trombley, Molnar & Shope, 1998; Janke, 1994). The second is the hypothesis that the known decreases in the capacity of working memory of older adults (see Zacks, Hasher, & Li, 2000 for review) cause them to forget to scan at intersections more often than their younger counterparts. The third is the hypothesis that older adults spend less time scanning for potential threats than younger adults because they are more easily distracted by irrelevant stimuli (Bolstad & Hess, 2000; Gamboz, Russo, & Fox, 2000; Kramer, Hann, Irwin, & Theeuwes, 1999; Nieuwenhuis, Ridderinkhof, Jong, Kok, & van der Molen, 2000),. Finally, the fourth is the hypothesis that older drivers have forgotten a specific scanning routine.

Method

Participants

Eighteen older drivers (age 72 to 87; mean = 77.7; SD = 4.6) and eighteen younger experienced drivers (age 25 to 55; mean = 35.0; SD = 9.0) were recruited. All participants had at least 10 years driving experience, were healthy and living independently, drove at least 5,000 miles per year, and had valid driving licenses with no medical or time-of-day restrictions. Participants were administered a Snellen eye test and all had 20/20 corrected vision (minimum requirement was 20/30). All participants scored within plus or minus one standard deviation of the population mean in their respective age groups (Tombaugh, 2004) for the Trail Making B test, a widely used measure of visual scanning, speed of processing, and executive functioning. Finally, all participants were administered a flexibility test used by Romoser (2008) in which they had to grab the base of a chair and look around at a target on a screen. Only those scoring a 4 or 3 out of a possible 4 points (could easily turn to read sign while holding on to chair with both hands or letting go with just one hand) were allowed to participate in the experiment.

Materials and apparatus

The simulator used for this experiment was the advanced driving simulator at the University of Massachusetts Amherst. The simulator consists of a full body Saturn sedan cab with an automatic transmission gearshift with three large screens that subtend 135 degrees of visual angle. The roadway was virtually projected onto the screens and was refreshed at 30 Hz.

An ASL 5000 eye tracker was used to measure the participant’s point-of-gaze and head position while driving the simulator. It sampled eye position at 60 Hz. The point-of-gaze was overlaid upon the driving scene – a fixed video channel from the simulator that moved relative to the car – and recorded for later analysis.

Procedure

After receiving an introductory tour of the simulator and a practice drive, participants received instructions to drive normally assuming there was a speed limit of 30 miles per hour. They were told that they would be following a lead vehicle through the virtual environment in order to know where to turn. They, however, were not told that the lead vehicle also served to aid with the timing of the traffic scenarios (described below) by ensuring that the participant entered the intersection at a time soon after other vehicles traversed the intersection indicating to participants the potential for hidden threats when they themselves navigated the intersection.

The experimental session lasted approximately 45 minutes. After receiving informed consent, participants were administered the Trail Making B test, Snellen eye test and the flexibility test. Afterward, participants were allowed up to two practice drives each lasting 5 min to get used to driving the simulator. If a participant displayed signs of simulator sickness after the practice drive, he or she was dismissed. At this point 31% of older participants and no younger participants were dismissed for simulator sickness after the practice drive. Older participants who dropped out were replaced in the study. After the practice drive, the participant was fitted with the eye tracker. The participant then drove three counterbalanced experimental drives; each contained one of the three intersection scenarios outlined below. Each drive lasted approximately from 3 to 6 minutes with 2 to 3 minute breaks between drives. Afterward, the participant was helped out of the simulator and debriefed.

Simulator scenarios

Participants drove a series of virtual drives containing three intersection scenarios where observations were recorded using the eye and head tracker. The intersections and maneuvers that were performed by the participants were representative of those where older drivers are more at risk (Garber & Srinivasan, 1991; Gstalter & Fastenmeier, 2010; Staplin & Lyles, 1991). Each scenario contained features (e.g., sharp vertical or horizontal curves in the roadway) that could hide moving vehicles that were three seconds away from the center of the intersection if they traveled at the posted speed limit. The maneuvers and intersections used in this study consisted of (a) turning left across oncoming traffic at a four-way intersection with a two-way stop on the side roads (the driver did not have to stop), (b) turning right from a stop at a T-intersection, and (c) going straight through a four-way intersection with two-way stop (the driver had to stop).

Dependent Variables

The horizontal angle of the driver's point-of-gaze relative to the centerline of the vehicle at successive points in time was the variable of interest. Eye tracker tapes were scored by hand, with the angles being measured by overlaying a grid on the video image and recording the angular deviation from the centerline of the vehicle every one-third of a second[1]. Comparisons of glance angles were made between the two age groups. Of primary interest was the amount of time each participant spent looking 1) toward an area from which the most probable hazard could emerge and 2) toward an area along the projected path of the vehicle through the intersection – be it a turn or straight.

Results

For all three intersection scenarios, $time_0$ (time zero) is defined as the moment at which the driver crosses into the intersection at the point where the roads cross. The total interval of time examined extended from eight seconds before $time_0$ to five seconds afterwards. Eye position was sampled every one-third of a second and the driver was scored as fixating the region for the 333 ms sample interval. In the discussion below, an interval includes the left endpoint but not the right endpoint; thus, for example, the 0 to +1 second interval contains the observations at 0, +1/3, and +2/3 seconds.

Left turn across traffic scenario

In this scenario, the driver turned left across traffic onto a side street at a two-way stop sign-controlled intersection (see Figure 1). The driver's vehicle does not have to stop. As cross traffic must stop, the major threat is that the driver's car could come into conflict with oncoming traffic during the left turn. Moreover, there was a hill that blocked the driver's view of oncoming cars across the intersection until these oncoming cars were within three seconds of the intersection. The location critical for scanning (i.e., the region in which a potentially threatening vehicle could appear) fell in a central area approximately −10 to +10 degrees relative to the driver's car before the turn and early in the turn.

The glance data are presented in Table 1, with glance angle collapsed into five categories: *far left* (−27 degrees or more to the left); *near left* (−11 to −26 degrees); *central* (−10 to +10 degrees); *near right* (+11 to +26 degrees); or *far right* (+27 degrees or more to the right). As can be seen in Table 1, there was no significant difference between the two groups in the

[1]A more frequent sampling rate perhaps would have revealed more information. However, the actual pattern of eye movements were quite complex, being a mixture of fixations, smooth pursuit movements (following a fixed target moving with respect to the driver) and saccades. It was clear during the analysis effort that the sampling rate captured all the major fixations during the intersection. Moreover, as will be seen, our sampling method indicated clear differences between the groups.

period from −8 s to −2 s, but a significant difference in the period from −2 s to +1 s. Averaged over this interval, younger drivers spent significantly more time than older drivers looking at the central region (where the potential threat vehicle might appear), $t(34) = 3.72$, $p < .001$. In the interval +1 to +3 s, there was a suggestion of the difference observed in the −2 s to +1 s interval, but no differences after that. As we will see with the other two scenarios, the period that distinguishes the groups most clearly is the one from −2 s to +1 s. Also of interest is whether the behavior of the groups during what appears to be the critical −2 s to +1 s interval is different before and after entering the intersection. As Table 1 indicates, the younger drivers were looking at the central region significantly more in both the −2 s to 0 s interval and the 0 s to +1 s interval.

The next obvious question is whether there was a preferred region that the older drivers were tending to look during this critical interval. The answer is "yes": the future path of the vehicle (see Figure 2). In the −2 s to 0 s interval (i.e., before beginning the turn), the older drivers are fixating more on the two left regions, significantly so on the far left region (see Table 1). Moreover, if one combines the far left and near left glances, there were significant differences between the two groups for both the −2 s to 0 s, $t(34) = -2.982$; $p < 0.01$, and 0 s to +1 s, $t(34) = -3.110$; $p < 0.01$, intervals.

To summarize, the patterns of glances between the two groups did not differ much until they were within 2 seconds of entering the intersection. Before 2 seconds, both groups were primarily looking in the direction of travel (straight ahead). After this time and up until 1 second after entering the intersection, the older drivers' glances were largely concentrated on the roadway to the left towards which they were turning (i.e., the direction of travel) whereas the younger drivers did divide their attention more between this region and the region from which a hazard might emerge. There was a suggestion of a difference between groups in the +1 to +3 second interval, but after that, both groups were looking in the direction of travel (straight ahead). We will defer a complete discussion of the implications of these data until after presenting the other two scenarios. However, one point seems worth making now. Given that the "correct" response is maintaining a glance straight ahead before the turn and early into the turn, it seems unlikely that the failure of the older drivers to monitor this area is due to motor problems in turning the head.

Right Turn at T-Intersection

In this scenario, the driver approached a T-junction (Figure 3) and was supposed to stop. Cross traffic on the top part of the T had the right of way. The driver's task was to make a right turn, and thus merge with the cross traffic. As with the prior scenario, the "sightline" for the cross traffic was limited. In this scenario, there was a hill three seconds away from the intersection to the left such that a vehicle approaching the intersection going 35 mph would not be visible until it was three seconds from the middle of the intersection. The lead vehicle was programmed to begin its right turn when the participant was within 10 yards of its rear bumper. Thus, the right turning lead vehicle may have served as a visual attractor.

The most plausible potential threat in this scenario was a car coming from the left, and as a result, the zone that should be monitored most closely for potential hazards was the far left when the driver approached the intersection and started the right turn. As can be seen in Table 2, the time course of differences between groups was the same as in the first scenario. That is, there were no differences between groups that approached significance either before −2 s or after +1 s, but clear differences between the two groups in the critical −2 s to +1 s interval. Averaged over the entire interval, the older drivers were looking into the far left (potential danger) region much less than the younger drivers, $t(34) = 2.717$, $p < .01$, but looking to the near right (in the direction of their turn – see Figure 4) much more, $t(34) = -3.224$, $p < .01$. As with the first scenario, we also wanted to determine whether the difference in scanning behavior between the groups was different both before entering the intersection and after entering it. As seen in Table 2, the differences between groups in both the potential hazard zone (far left) and the future path of the vehicle zone (near right) were significant in both the −2 s to 0 s and 0 s to +1 s intervals.

To summarize, as in the left turn scenario, the pattern of glances did not differ much between the two groups until they were within 2 seconds of entering the intersection, whereas in the −2 s to +1 s interval, the older drivers' glances were largely concentrated on the roadway ahead or to the right (i.e., where their vehicle was about to go) while the younger drivers' glances were significantly more likely to be concentrated on the near or far left (where the most probable hazard was likely to appear). We should note that although the patterns of behavior of the two groups at the conceptual level were similar to that in the prior scenario, the actual physical behaviors were quite different: in this scenario, monitoring the danger involved a large head movement to the left, whereas in the first scenario, monitoring the danger consisted of looking straight ahead of the vehicle.

Straight through intersection

The final scenario (see Figure 5) was one in which the driver approached a four-way stop sign-controlled intersection, stopped, and then proceeded straight through. As with the right turn merge scenario, the driver had a stop sign and cross traffic did not have to stop. In this scenario, the line of sight for the driver was limited both to the right and left with cross traffic from both directions not visible until it was three seconds from the center of the intersection. Thus, a careful driver should have been continually monitoring both right or left, as traffic could have emerged from around roadway curves unexpectedly in either direction. In addition, there was no traffic approaching in the opposing lane as a potential threat.

A striking difference between data in this scenario and those in the other two is that there were significant differences between groups even in the −8 s to −2 s interval (see Table 3). Younger drivers spent more time looking to both the far left and the far right than the older drivers even during this early interval (a total difference of .667 s), $t(34) = 2.651$, $p < 0.02$. However, the older drivers did look to the near left region significantly more during this interval than the younger drivers, so that most of the difference between the groups was in looking to the right. However, as Table 3 indicates, the difference between the groups was again most striking in the −2 s to +1 s interval, with the younger drivers glancing both to the far left and far right much more than the older drivers, $t(38) = 3.692, 3.695$, respectively, $ps < .002$. Moreover, as with the prior two scenarios, the younger drivers were looking at these regions significantly more both in the −2 s to 0 s and 0 s to + 1 s intervals. Also, as in the prior two scenarios, the older drivers were looking in the center zone – the direction of travel (which was straight ahead throughout) – significantly more than the younger drivers in the −2 s to +1 s interval, $t(38) = -5.005$, $p < .001$. Indeed, the older drivers were still looking significantly more to the center region even in the +1 s to +3 s interval (see Table 3).

The above analyses, however, may not fully capture the difference between the groups as the "correct response" isn't looking either to the left or right, but looking both to the left and right within a relatively narrow time window. We think that the following statistics for the percent of participants in a group that looked both to the left and right during an interval are quite revealing, especially in the critical −2 s to +1 s interval. Whereas 77.7% of the younger drivers looked both to the far left and far right during this interval, only 44.4% of the older drivers did, $t(34) = 2.968$, $p < 0.01$. It is hard to apply this measure to short intervals because it takes some time to move the eyes (and usually the head) to both the left and right; however, this huge disparity between groups in looking both ways persists both before and after $time_0$. For the interval −5 s to 0 s, all the younger drivers looked both to the far left and far right at least once whereas only 72.2% of the older drivers did, $t(34) = 3.402$, $p < 0.01$, and for the interval 0 s to +5 s, 72.2% of the younger drivers looked both far left and far right whereas only 5.5% of the older drivers did, $t(34) = 4.388$, $p < 0.001$.

In summary, the difference between the two groups was most pronounced in the −2 s to +1 s interval: the older drivers looked far more towards the forward path of the vehicle than the younger drivers, but far less at the regions in which a hazard might appear. However, unlike the other scenarios, this pattern was not restricted to this interval. The younger drivers were looking to the far left and far right significantly more even in the −8 s to −2 s interval. Moreover, although there was a suggestion in the prior two scenarios that the older drivers were still looking at the direction of travel more than the younger drivers even in the +1 to +3 sec interval, the difference between groups in the third scenario was significant. The proper response is to continue monitoring both the far left and far right continually, and because it takes appreciable time to do both, this appropriate monitoring has to start earlier and possibly continue even later.

Overall Error

Because of the large number of temporal and spatial bins we used for our analyses, we have reported many tests. It is important to note that the significance criterion of 0.05 was not adjusted to accommodate these multiple t-tests. As a result there is a probability greater than 0.05 over the entire experiment of any one result being significant by chance alone. However, interestingly we observed the same consistent trends within each intersection type. The likelihood is small that all three results would together be significant by chance.

As a means of addressing concerns regarding the significance of the results, rather than considering the time spent looking in various spatial bins around the vehicle, one way of increasing the power of the analysis would be to compare the percentage of time drivers in both cohorts spend fixating the path of the vehicle through the intersection during the critical interval of −2s to +1s. When this is done, there are three analyses to consider, necessitating correcting the criterion for significance to $p = .0165$ using the Bonferroni method. Using this criterion, older drivers still fixated the path of the vehicle during the critical interval significantly more often than middle-aged drivers. For the straight through intersection, older drivers fixated the vehicle's path through the intersection 66.7% of the time, compared to 31.7% of the time for middle aged drivers, $t(34) = 4.89$, $p \ll 0.001$. Similar significance existed for the Left Turn at Light intersection (77.8% older; 54.4% middle aged, $t(34) = 3.407$, $p < 0.01$) and Right Turn at T-intersection (66.1% older; 46.1% middle aged, $t(34) = 2.633$, $p = 0.0126$). As can be seen, the trends reported in the analyses in previous sections are seen again here, which we believe means the results can be used with confidence.

Discussion

The pattern of data is remarkably consistent across the three scenarios in spite of the differences between both the geometry of the scenario and what the driver needs to do to successfully negotiate it. For all three scenarios, the major difference between groups is in the −2 s to +1 s interval. On some level, that may just be reinforcing common sense, as these are all intersections where a careful driver should be looking for a vehicle coming from the threat region (or regions) and this is the time that it is most critical to do so. Looking later is likely to be too late in many circumstances and looking earlier is likely to be irrelevant as a vehicle hidden in the threat region prior to 2 seconds before the driver reaches the intersection is likely to become fully visible as the driver comes to the intersection (especially as the driver is going slowly). Nonetheless, although this is a priori the critical time interval for making glances toward the threat region, it is not trivial that this is mainly where the older drivers' scanning performance is worse than the younger drivers and makes it plausible that this difference is a significant contributor to their increased crash rates at intersections.

The results also rule out the four explanations of why older drivers are scanning for potential threats less often at intersections. First, it has been hypothesized that older adults fail to scan in the direction of potential threats because it requires head turns and head turns are more difficult for older adults. We don't deny nor would we deny that in general head turns are more difficult for older adults. However, this problem cannot explain our data. Specifically, in the second and third scenarios, large head turns are required to achieve the appropriate scan (this is similarly the case with the Bao & Boyle, 2009, scenarios). Thus, for these scenarios, one might argue that older drivers, having motor impairments of various kinds (McPherson, Michael, Ostrow, &, Shaffron, 1988), are unwilling or unable to make sufficiently rapid head turns to accomplish an effective scan of the hazardous region. However, in the first scenario in this experiment, the correct response is gazing straight ahead at least part of the time, which does not require any head movements in the −2 s to 0 s interval. This makes it unlikely that motor impairments are a major cause of the scanning deficits we observed. Also, as indicated above the older drivers in this sample were screened to have adequate flexibility and motor abilities.

Second, it is known that there are decreases in working memory capacity in older adults (Zacks, Hasher, & Li, 2000). It is reasonable to hypothesize that these decreases may explain why older adults scan less at intersections. But consider our results, specifically the finding in the present study that the scanning decrement for the older drivers occurs both in the −2 s to 0 s interval and the 0 s to +1 s interval, with the decrement being roughly equal for the three scenarios. This indicates that the specific driving demands of the moment are not a major contributor to the scanning decrement for the older drivers. That is especially true for the second and third scenarios, where the driver is merely coming to a stop indicated by the stop sign. (In the second scenario, there could be some preparatory wheel turning during this interval, but this does not seem particularly demanding as it requires no coordination with any other part of the driving act.) We think this makes it unlikely that the scanning decrements we have observed in these three scenarios are likely to be caused by the older drivers having a smaller short-term memory capacity that cannot handle both the motor act of driving and the perceptual act of scanning.

Third, it is known that older adults are more easily distracted by irrelevant external events (e.g., Hasher & Zacks, 1988; Kramer, Hann, Irwin, & Theeuwes, 1999). If this were the sole explanation of why older adults scanned less frequently, then one would hypothesize that there should be no difference between the scanning patterns of older and younger drivers at intersections. We think the present data rule out this hypothesis in a rather straightforward fashion because all of the scenarios investigated had no distracting events. As the driver approached the intersection in the interval −2 sec to 0 sec, nothing other than the lead vehicle was moving and there was no significant stimulus to compete with investigating the danger zone. (In scenarios two and three, cars went through the intersection well before the driver arrived at the intersection to clearly indicate that the vehicles coming across had the right of way.)

Fourth, the large differences across scenarios also rule out another possible cause of why the older drivers' scanning patterns deteriorated: that they forgot a specific routine. That is, if the scanning pattern was part of a skilled act for each intersection scenario, it seems unparsimonious to posit that the older drivers were simultaneously losing their memories of how to scan in each of these quite different situations. Instead, it seems more parsimonious to posit that something more general is being lost. We will return to this point below.

Other Possible Contributors to Older Drivers' Failures to Scan

Although the failures to scan documented here quite plausibly are a major contributor to increased crash rates, there are other declines in mental and physical abilities in older adults that also plausibly lead to increased crash rates, such as having less control over the vehicle. Here, we consider the narrower question of whether these other declines are important causes of the scanning deficits observed here. These other, "higher", deficits, that are somewhat more plausible as explanations for scanning deficits include: (a) having a reduced useful field of view (UFOV) (Ball, Beard, Roenker, Miller, & Griggs, 1988; Ball & Owsley, 1991) and (b) having a compromised control of executive function (Braver & West, 2007).

Consider first the possibility of a decrease in UFOV contributing to the scanning deficits. In our scenarios there are no threat vehicles present as a driver navigates an intersection. Thus, decrements in UFOV that might impact turning maneuvers when threat vehicles are present cannot be the source of decreases in older drivers' scanning at intersections. However, information present in the periphery before the intersection may be harder for older drivers to register if there are decreases in UFOV. In both the second and third scenarios, older drivers will obtain less information in the periphery than younger drivers if they are also focusing on some central task (perhaps the lead vehicle). Thus, they may miss the fact that the road curves out of sight and therefore be less likely to scan. However, it is hard to understand how failures to scan for threats in the first scenario could be explained by decreases in the UFOV since the threat zone was centrally located, both as the driver approached the intersection and as the driver entered the intersection. Regardless, there is enough uncertainty here to believe that decreases in UFOV may have a role to play in our scenarios.

Consider second the possibility that executive control is compromised. There is nothing in the present data that rules out this possibility. However, we think the training study of Romoser and Fisher (2009) does so. Their sample of older drivers was similar to those of the present study and they compared groups with two types of training regimens to a group with no training. Older drivers in all three groups were initially filmed prior to training inside their vehicle as they navigated turns in their normal course of driving both in the simulator and on the open road. Participants in the *passive training* group received a classroom-style lecture in which they were informed that older drivers tended not to look around correctly when dealing with intersections such as those in the above three scenarios and received a demonstration of proper scanning behavior. In essence, they were told that older drivers failed to monitor regions such as the ones we have analyzed. This passive training group, however, scored no better six to eight weeks later on a post-test in the driving simulator than a group of older drivers who received no training. In contrast, the *active training* group both (a) got feedback from the videotape of their simulator and on-road drives that clearly showed them that they (in contrast to older drivers in general) were failing to monitor hazardous regions and (b) practiced increased scanning in a driving simulator. The improvement in the older driver group was quite pronounced. Although the data were scored somewhat differently from our coding in the present study, the proportion of intersections in which drivers in the active learning group made large, extra looks toward areas where hazards could emerge nearly doubled. It is hard to see how this training could have increased general executive control. Also, more generally, the above results are consistent with our conclusion that neither decreases in working memory nor decreases in flexibility can explain the results in our scenarios. Specifically, it is not obvious how a training program that lasted only two hours and focused on skills not obviously relevant to working memory could have helped restore decreases in working memory capacity. It is equally not obvious, given that there was no attempt to remediate motor problems that older adults might have turning their head in the training, how trained older drivers could have increased their head turning so dramatically if their major problem was difficulty turning their head.

Again, we are not claiming that we have ruled out any of the hypotheses above as explanations for the scanning differences between older and younger drivers in all intersection scenarios. Rather, they do not appear to be explanations for the scanning differences we find in our scenarios. For example, consider scenarios where threat vehicles were present. UFOV problems may well come into play when older drivers scan successfully for a threat vehicle. That is, some of the time when older drivers scan successfully (i.e., point their eyes toward the danger zone), UFOV problems may prevent them from actually perceiving the problem. Moreover, we realize that with a different, more impaired population of older drivers one or more of the above explanations that we have ruled out for our population of older drivers may well be required. For example, older drivers with more severe vision, motor, and attentional problems would almost definitely make fewer scans than younger drivers.

A Hypothesis for Older Drivers' Scanning Difficulties: Oversimplification of the Driving Task

There is another type of "distraction", however, that appears to be a plausible explanation for the poorer performance of the older drivers: they are, in some sense, too fixated on the section of the roadway toward which they are turning and, as a consequence, fail to monitor the regions from which hazards may appear. The question, then, is why are older drivers fixating on the projected path of their vehicle through the intersection at the expense of monitoring hazards outside of their vehicle's path? We think that the most likely answer to this question is that many older drivers have, in some sense, acquired something like a bad habit. This "bad habit" is to oversimplify the task of dealing with potential hazards so as to be sure not to hit anything which includes both looking straight ahead and slowing overmuch in potentially threatening situations – but not being sure enough that some vehicle won't hit you. If so, there are two obvious issues that need to be addressed: (a) how did the older drivers acquire the habit? and (b) how does a very modest amount of training get them to lose it?

First, consider how the older drivers could have acquired such a habit. We think it is likely that many older drivers believe (whether rightly or wrongly) that they have diminished resources available to apply to the driving task, and thus they concentrate on what is plausibly the primary goal of a careful driver: to be sure not to hit anything with one's vehicle. To this end, they basically focus on two things: (1) monitoring the road in front of them and (2) making sure not to drive too fast so as to give themselves plenty of time to stop in case something does unexpectedly appear ahead of their vehicle or the vehicle ahead of them (i.e., our lead car).

Such a habit probably supports safe driving in most circumstances, and the available evidence is that older drivers are not overinvolved in most types of crashes (i.e., those not involving a vehicle hitting them from the side; Bryer, 2000; Garber & Srinivasan, 1991; Ryan, Legge, & Rosman, 1998). This raises the question of why older drivers are not generally more involved in crashes where they might hit something coming from the side; they are only more likely to be in crashes in which they are hit from the side by another vehicle. An example of the former scenario occurs when the driver is passing a truck that is stopped in the parking lane immediately in front of a mid-block pedestrian cross-walk. Clearly this requires careful scanning away from the forward roadway (in this case, being sure to look around the front of the truck for a pedestrian or cyclist) in order to minimize crashes. One possibility is that the truck in the central field of view serves as a clear signal that vision is obscured and so older drivers initiate a scan to the side, something that they do not do at intersections where there is no obvious cue. Another possibility is that older drivers respond to such situations by slowing down more than younger drivers, thus making up for scanning less. Obviously, more data is needed on such non-intersection scenarios.

This habit, however, is quite non-optimal at intersections. This is true, not only because the driver may fail to monitor hazards such as those in the three scenarios we have discussed, but also because the policy of driving more slowly though an intersection may expose the vehicle to a longer window of getting hit by another vehicle when the intersection is being navigated. Moreover, because crashes are fairly rare events (and to the best of our knowledge, the older drivers in our study were not involved in such crashes recently), this habit has likely been reinforced as a safe strategy in the minds of these drivers over many “learning” trials at intersections.

A possible factor that may help to explain why such a habit could develop in older drivers is that there is evidence that older people may have more difficulty inhibiting a globally stronger or *prepotent* response. For example, in numerous studies older and younger adults were equally good at making saccades toward a peripheral stimulus (a natural response), but older adults had a specific deficit in making eye movements away from the peripheral stimulus (an “antisaccade”) (Butler & Zacks, 2006; Butler, Zacks, & Henderson, 1999). To execute the “antisaccade”, the participant must restrain the prepotent response in favor of a less preferred response (Butler & Zacks, 2006). In driving, the prepotent response is to monitor the roadway ahead. As a result, the “bad habit” pattern of not scanning at intersections may result from a failure to inhibit the globally dominant action pattern when a weaker, but more situationally appropriate, action pattern is called for (Hasher, Zacks & May, 1999).

In addition, evidence from the memory literature indicates that previously well-learned responses can be easily re-learned given the proper training. Theories of spaced practice suggest that although a memory may not be accessible immediately, it is still present and accessible if during learning the person is made aware of this fact, thus creating new access routes for this memory (Bjork & Bjork, 2006; Storm, Bjork & Bjork, 2008). The active training procedure reported in Romoser and Fisher (2009) optimizes such learning by making the older drivers’ aware that this old habit has disappeared and helps them to create new cues to help them make the old habit more easily retrievable (such as the act of beginning to enter an intersection serving as a cue to execute a secondary glance toward a hazardous region). Moreover, this memory literature indicates that such learning trials can lead to long-term effects such as those observed in Romoser and Fisher (2009). Finally, the memory literature helps to explain why passive training is quite ineffective. If older drivers have not been in any crashes at intersections, they have “learned” that their strategy of dealing with intersections is a successful one; thus hearing that older drivers have some sort of problem with intersections is an ineffective learning experience because there is no direct evidence to the older driver that they themselves have a problem.

Summary and Conclusions

This current study along with the training data from Romoser and Fisher (2009) provide valuable insights on older drivers’ behavior at intersections. First, failures of the older drivers we studied at intersections appear to be tied to a very particular behavioral problem. Specifically, it appears that healthy older drivers are redefining their driving task, possibly because of fears of declining capabilities rather than actual declining capabilities. Second, we find that many of the possible physiological and cognitive explanations do not account for healthy older drivers’ failure to scan for hazards at intersections where distractions are not present. However, that said, we do not claim that we have ruled out these explanations. In the case of more pronounced declines in cognitive and physical health and in many high-demand driving situations, these explanations have been shown to be robust. Our study looks at a very specific domain in which older drivers are at higher risk: navigating intersections. What we do argue is that the evidence in our study and that from the training study of Romoser and Fisher (2009) is consistent with only one of those explanations: that older drivers may develop a habit that causes them to not perform a response of which they are perfectly capable and only need to reinstate.

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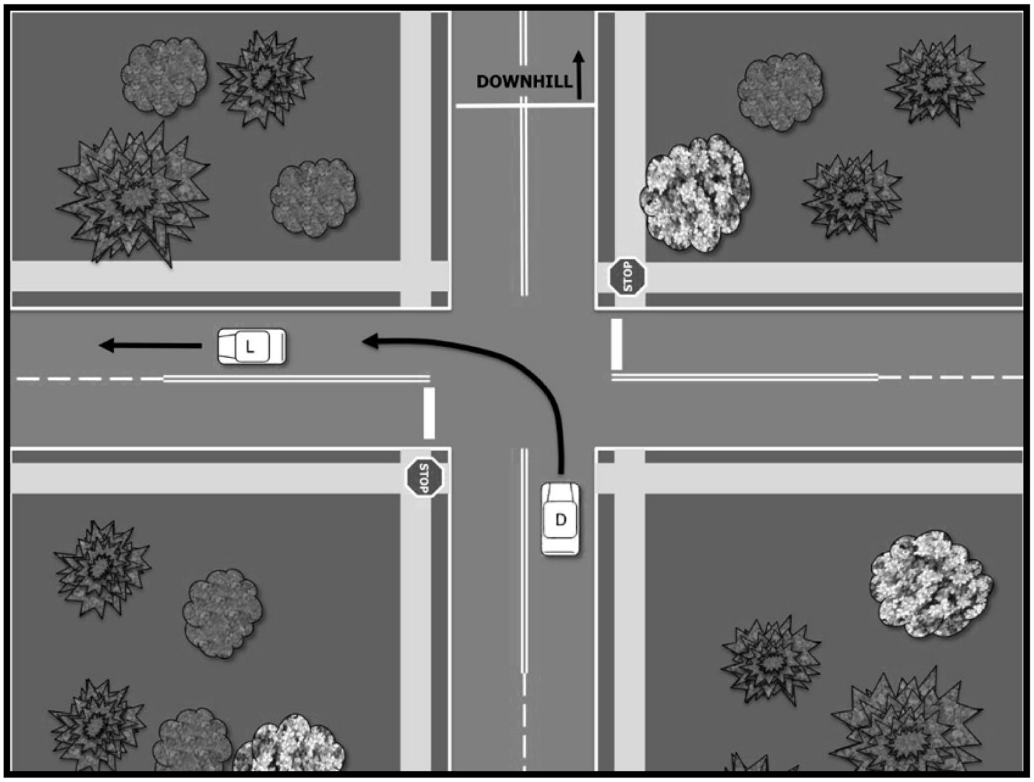

Figure 1.
Left Turn Across Traffic Scenario: Driver (D) turns left at 4-way stop sign-controlled intersection on to side street following lead vehicle (L). Side streets have stop signs, the driver does not. Three seconds beyond intersection road curves away down hill.

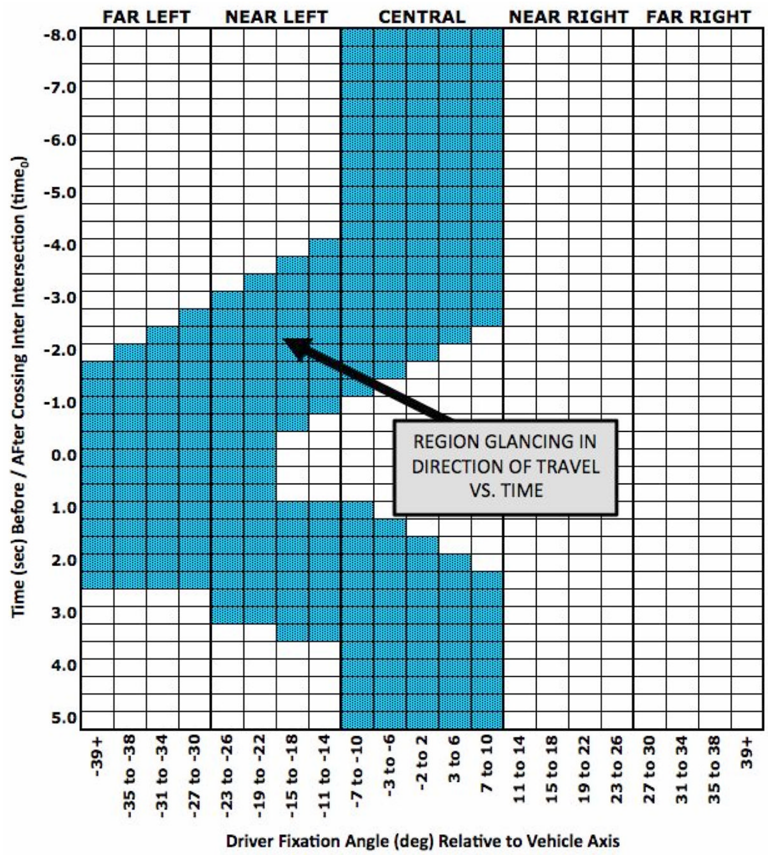

Figure 2.

Left Turn across Traffic Scenario: Definition of the region "looking into the future path of the vehicle".

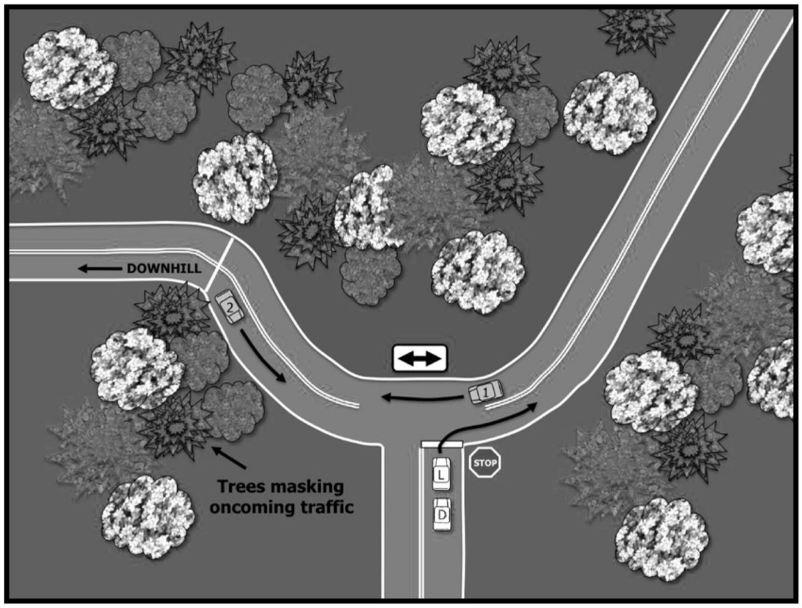

Figure 3.
Right Turn at T-Intersection: Driver (D) turns right at T-intersection following lead vehicle (L). Prior to turn two cross traffic vehicles (1 & 2) proceed through intersection to reinforce that cross traffic does not stop. Three seconds the left, the road bends away to the left and proceeds downhill.

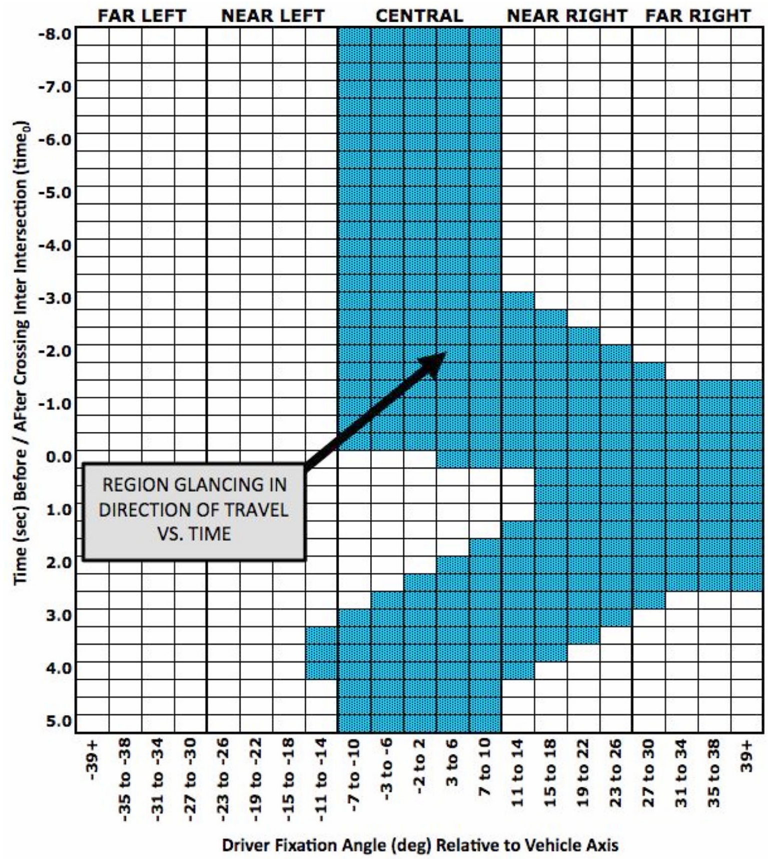

Figure 4.

Right Turn at T-Intersection scenario: Definition of the region "looking into the future path of the vehicle".

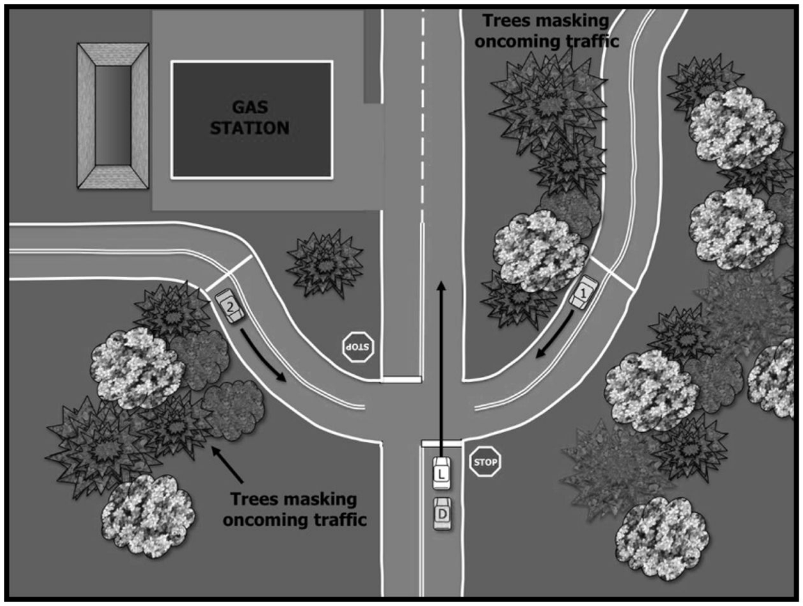

Figure 5.
Straight Through Intersection: Driver (D) proceeds straight through 4-way stop intersection following lead vehicle (L). Prior to entering intersection, two cross traffic vehicles (1 & 2) proceed through intersection to reinforce that cross traffic does not stop. Three seconds to both right and left, road bends away hiding oncoming vehicles.

Table 1

Left Turn Across Traffic Scenario: Average amount of time (sec) spent in each region; older and younger drivers compared

		Region (relative to driver's car)				
Time Range	Age Cohort	Far Left (−27° & left)	Near Left (−11° to −26°)	Central (−10° to +10°)	Near Right (+10° to +26°)	Far Right (+27°& right)
−8 to −2 sec	Older (70–89)	0.185	0.556	4.741	0.278	0.241
	Younger (25–55)	0.370	0.370	4.556	0.407	0.296
	DIFFERENCE	0.185	−0.186	−0.185	0.129	0.055
	t (df = 34)	1.572	−1.049	−0.566	1.030	0.465
−2 to 0 sec	Older (70–89)	1.000	0.519	0.370	0.019	0.093
	Younger (25–55)	0.815	0.204	0.796	0.056	0.130
	DIFFERENCE	−0.185	−0.315	0.426	0.037	0.037
	t (df = 34)	−1.271	−2.528*	3.098**	1.047	0.398
0 to +1 sec	Older (70–89)	0.704	0.222	0.074	0.000	0.000
	Younger (25–55)	0.500	0.130	0.296	0.056	0.019
	DIFFERENCE	−0.204	−0.092	0.222	0.056	0.019
	t (df = 34)	−1.882	−1.029	2.838*	1.844	1.000
+1 to +3 sec	Older (70–89)	0.741	0.889	0.370	0.000	0.000
	Younger (25–55)	0.630	0.667	0.667	0.019	0.019
	DIFFERENCE	−0.111	−0.222	0.297	0.019	0.019
	t (df = 34)	−0.564	−1.531	1.679	1.000	1.000
+3 to +5 sec	Older (70–89)	0.000	0.259	2.000	0.019	0.000
	Younger (25–55)	0.056	0.333	1.926	0.019	0.000
	DIFFERENCE	0.056	0.074	−0.074	0.000	0.000
	t (df = 34)	0.000	0.555	−0.449	0.000	0.000

* $p < 0.05$,

** $p < 0.01$,

*** $p < 0.001$

Table 2

Right Turn at T-Intersection: Average amount of time (sec) spent in each region; older and younger drivers compared

		Region (relative to driver's car)				
Time Range	**Age Cohort**	**Far Left (−27° & left)**	**Near Left (−11° to −26°)**	**Central (−10° to +10°)**	**Near Right (+10° to +26°)**	**Far Right (+27° & right)**
−8 to −2 sec	Older (70–89)	0.889	0.148	4.259	0.259	0.444
	Younger (25–55)	0.722	0.148	4.167	0.259	0.704
	DIFFERENCE	−0.167	0.000	−0.092	0.000	0.260
	t (df = 34)	−0.754	0.000	−0.294	0.000	1.760
−2 to 0 sec	Older (70–89)	0.611	0.111	0.481	0.389	0.407
	Younger (25–55)	1.000	0.074	0.407	0.167	0.352
	DIFFERENCE	0.389	−0.037	−0.074	−0.222	−0.055
	t (df = 34)	***2.247****	−0.583	−0.603	***−2.030****	−0.421
0 to +1 sec	Older (70–89)	0.204	0.000	0.093	0.352	0.352
	Younger (25–55)	0.389	0.019	0.111	0.148	0.333
	DIFFERENCE	0.185	0.019	0.018	−0.204	−0.019
	t (df = 34)	***2.243****	1.000	0.313	***−2.21****	−0.164
+1 to +3 sec	Older (70–89)	0.019	0.019	0.463	0.796	0.704
	Younger (25–55)	0.093	0.000	0.593	0.741	0.574
	DIFFERENCE	0.074	−0.019	0.130	−0.055	−0.130
	t (df = 34)	1.196	−1.000	0.841	−0.336	−0.854
+3 to +5 sec	Older (70–89)	0.000	0.074	2.000	0.204	0.056
	Younger (25–55)	0.000	0.037	2.111	0.111	0.074
	DIFFERENCE	0.000	−0.037	0.111	−0.093	0.018
	t (df = 34)	0.000	−0.741	0.687	−0.855	0.232

* $p < 0.05$,

** $p < 0.01$,

*** $p < 0.001$

Table 3

Straight Through Intersection Scenario: Average amount of time (sec) spent in each region; older and younger drivers

		Region (relative to driver's car)				
Time Range	**Age Cohort**	**Far Left (−27° & left)**	**Near Left (−11° to −26°)**	**Central (−10° to +10°)**	**Near Right (+10° to +26°)**	**Far Right (+27° & right)**
−8 to −2 sec	Older (70–89)	0.574	0.500	4.130	0.352	0.444
	Younger (25–55)	0.778	0.222	3.741	0.352	0.907
	DIFFERENCE	0.204	−0.278	−0.389	0.000	0.463
	t (df = 34)	1.117	***−2.349******	−1.325	0.000	***2.567****
−2 to 0 sec	Older (70–89)	0.426	0.037	1.130	0.130	0.278
	Younger (25–55)	0.630	0.056	0.630	0.111	0.574
	DIFFERENCE	0.204	0.019	−0.500	−0.019	0.296
	t (df = 34)	1.748	0.470	***−2.862*****	−0.277	***2.396****
0 to +1 sec	Older (70–89)	0.074	0.093	0.815	0.000	0.019
	Younger (25–55)	0.407	0.037	0.259	0.056	0.241
	DIFFERENCE	0.333	−0.056	−0.556	0.056	0.222
	t (df = 34)	***4.343******	−0.951	***−5.190******	1.844	***3.987******
+1 to +3 sec	Older (70–89)	0.093	0.019	1.870	0.000	0.019
	Younger (25–55)	0.167	0.148	1.537	0.056	0.093
	DIFFERENCE	0.074	0.129	−0.333	0.056	0.074
	t (df = 34)	0.708	1.859	***−2.564****	1.844	1.518
+3 to +5 sec	Older (70–89)	0.019	0.019	2.278	0.019	0.000
	Younger (25–55)	0.037	0.019	2.278	0.000	0.000
	DIFFERENCE	0.018	0.000	0.000	−0.019	0.000
	t (df = 34)	0.447	0.000	0.000	−1.000	0.000

* $p < 0.05$,

** $p < 0.01$,

*** $p < 0.001$