Age-related differences in visual scanning at median-divided highway intersections in rural areas

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Abstract
The objective of this study was to examine age-related differences in visual scanning as drivers performed three separate maneuvers (going straight across, making a left and right turn) at two median-divided highway intersections with different crash frequencies. An on-road study was conducted with 60 drivers in three age groups: younger (18–25), middle-aged (35–55), and older (65–80). The study consisted of two between-subject (age and gender) and two within-subject variables (drive maneuver and intersection type). Drivers’ behavior was measured by the proportion of time they visually sampled towards the left, right and rearview mirror, and by an entropy rate representative of randomness in visual scanning. The results showed that older and younger drivers do not utilize their full scanning range when compared to middle-aged drivers, as indicated by lower entropy rate and the tendency to check fewer areas before executing a maneuver through the intersections. This trend was more obvious during left and right turn maneuvers indicating a greater likelihood to miss an unexpected event. Older drivers had a significantly smaller proportion of visual sampling to the left and right during intersection negotiations when compared to younger and middle-aged drivers. Older and younger drivers checked the rearview mirror significantly less when compared to middle-aged drivers.

1. Introduction
Driving is a highly visual and complicated task. It has been reported that about 90% of driving information is captured through the eyes (Robinson et al., 1972) although the precise percentage of visual input while driving has been subject to debate (Sivak, 1996). Most studies do concur that visual information plays a significant role in driving (Green, 2002; Robinson et al., 1972; Sivak, 1996; Van Houten and Retting, 2001). Therefore, maintaining safe driving requires persistent and accurate scanning of the environment for critical information.

Visual scanning is of great importance in understanding and determining drivers’ performance, especially at intersection negotiations due to complicated geometric features and traffic from multiple directions. Intersection negotiations, particularly in rural areas, often involve significant speed differences and higher rates of non-stopping traffic on the major roads (Chan, 2006; Laberge et al., 2006). Drivers need to continuously observe the environment and be aware of any potential threats from several locations in order to execute an intersection maneuver without a safety critical incident.

Crash rates at intersections, especially at rural non-signalized intersections are comparatively high and encompass a significant portion of fatalities each year (Burgess, 2005). Difficulties at intersections are typically related to the visual domain and include a failure to see relevant traffic signs or signals (McGwin and Brown, 1999), to perceive cross traffic (Caird et al., 2005), or appropriately judge the distance or speed of oncoming traffic (Guerriera et al., 1999). Failure to observe oncoming traffic was also identified as the most significant causal factor for intersection crashes in a New Zealand study (LandTransport, 2005). Differences in drivers’ visual attention has also been observed at T-intersections with drivers having significantly more head movements toward the right before executing left turning maneuvers when compared to right turning maneuvers (Summala et al., 1996).

Age is also a factor in intersection negotiations with older drivers frequently cited as having more difficulty (AAA, 2001; Preusser et al., 1998) for several reasons related to declining cognitive abilities (e.g., inability to attend to or perceive potential threats) (Hakamies-Blomqvist, 1994). Studies show that older drivers made less glances towards their peripheral area than their central visual field and significantly longer mean fixation durations (Maltz and Shinar, 1999) and more search errors (Ho et al., 2001) than younger drivers. Younger drivers have better visual acuity than older drivers (Wood and Mallon, 2001) and are able to judge imminent collisions better (Delucia et al., 2003). However, they have also been shown to...
comply less often to stop-signs (Yagil, 2001) which are the most prevalent traffic control devices at rural expressway intersections (Maze et al., 2006). In a study by Bao and Boyle (2008), older and younger drivers were observed to brake significantly later on the approach to a stop-sign when compared to middle-aged drivers.

The majority of observational studies at intersections (Keskinen et al., 1998; Summala et al., 1996) are limited in their ability to observe changes in visual scanning behavior. However, older and younger drivers may spend less time looking appropriately to both sides of traffic while executing maneuvers at intersections that include a median-divided highway when compared to middle-aged drivers. This may result in an improper assessment of the traffic conditions. Examining driver’s visual scanning under complex situations (e.g., two-way stop-controlled intersections) can provide insights on what is appropriately attended to while executing a maneuver at intersections. In previous work, Bao and Boyle (2007) examined the differences in visual search durations between older and middle-aged drivers prior to executing an intersection maneuver at rural median-divided highway intersections, also referred to as rural expressway intersections (Maze et al., 2004). The results showed that older drivers used significantly less search time to prepare for a driving maneuver when compared to middle-aged drivers. As stated earlier, studies already show that older drivers have greater crash risks at intersections. The goal of this study is to provide some greater insights into this issue by segmenting the maneuvers into different stages and understanding which areas are attended to more often. This study also extends the previous findings of Bao and Boyle (2007) by examining younger drivers in addition to middle-aged and older drivers.

2. Methodology

2.1. Participants

Sixty drivers from three age groups participated in this study. Younger drivers were between 18 and 25 years old ($M = 21, \text{ S.D.} = 2.1$), middle-aged drivers were between 35 and 55 years old ($M = 46, \text{ S.D.} = 4.8$), and older drivers were between 65 and 80 years old ($M = 73, \text{ S.D.} = 5.2$). Each group consisted of 10 males and 10 females. All participants were recruited through an advertisement in a local newspaper and required to be active drivers with a valid US driver’s license and have a safe driving record (i.e. no crash records within recent 3 years of participation). Participants were compensated $20 for their time in the study.

2.2. Apparatus

This study was conducted with a 2002 Ford Taurus instrumented sedan. Two LP-850W weather proof cameras and four MB-750 pinhole lens cameras were installed in the vehicle to capture foot movements, face views, hand steering position, and vehicle to lane position. The four pinhole cameras were located inside the car and the two weather proof cameras were located under the left and right outside mirrors, and all cameras were completely unobtrusive to the drivers. The video was captured with a sample frequency of 15 Hz. A Garmin GPS-17N GPS receiver provided information on the driver’s position at all times.

Driving performance measures included the driving speed, brake force, and throttle position, by GPS location. The video cameras were time synchronized to all performance measures recorded from the vehicle. All data was automatically recorded using National Instrument Labview software and saved onto a computer that was located in the trunk of the instrumented vehicle and later transferred to a personal computer for analysis.

2.3. Procedure

The experiment took place at two rural median-divided highway intersections located in Linn County, IA. One intersection had an average of five crashes per year while the other intersection had less than one crash per year as defined by the Iowa Department of Transportation (DOT) crash data from the past 4 years (2002–2006). The mean traffic volumes for this same period were 16,850 vehicles per year at the low crash intersection and 18,225 per year at the high crash intersection. Both were two-way stop-controlled intersections, with a major expressway and a minor rural road (see Fig. 1). The major expressways were divided highways with two lanes of traffic on each side. The posted speed limit of the expressways was 65 mph (or 105 km/h). The rural road at the high crash intersection was a two-lane road with a posted speed limit of 35 mph (or 56 km/h) while the rural road at the low crash intersection was a two-lane road with 55 mph (or 89 km/h) posted speeds.

All drivers were asked to execute three driving maneuvers at both intersections: a left turn and right turn from the minor rural road onto the major expressway, and a straight across maneuver through the intersection. Each participant started the drive at the same place. To minimize the effect that may occur due to the type of intersection that was encountered first, half of the participants from each age group drove the route in a clockwise direction, while the other half drove in a counter-clockwise direction. The order of the three driving maneuvers was also counter balanced. All participants were told to drive normally and safely (i.e. asked not to violate the traffic regulations and adhere to posted speed limits) and to follow the instructions from the researcher, who sat in the front passenger seat. All experiments were conducted on dry roads, clear days, and non-peak hour times.

2.4. Dependent variables

Visual scanning was classified into seven possible viewing regions relative to a straight ahead position while executing an intersection maneuver (Fig. 2): (1) far left hand side (head movements greater than 45° to the left), (2) close left hand side (head movement less than or equal to 45° to the left), (3) far right hand side (head movement greater than 45° to the right), (4) close right hand side (head movement less than or equal to 45° to the right), (5) opposing direction, (straight ahead without head movements), (6) rearview mirror and (7) other (e.g., speedometers). These scanning areas were then used for examining the proportion and randomness of visual scanning as described further in the next two subsections.

2.4.1. Proportion of visual scanning

The proportion of visual scanning towards the left (regions 1 and 2 in Fig. 2) or right (regions 3 and 4) within the three locations was calculated in 3-m intervals: (1) on the approach to the

![Fig. 1. Maneuvers evaluated at both intersections for (1) approach to intersection, (2) approach to median, and (3) exiting the intersection.](image-url)
intersection, (2) on the approach to the median, and (3) upon exiting the intersection (see Fig. 1). The data was collected from 24 m before the stop-sign (the point at which most drivers began checking their right or left side for traffic) to 6 m after the intersection (the point at which most drivers stopped checking their right or left side for traffic). The separation of the three locations was defined by drivers’ foot movement. For example, approach to the intersection (Location 1 in Fig. 1) started at 24 m from the stop-sign and ended when the driver started depressing the accelerator pedal to begin entrance into the intersection.

Checking the rearview mirror has been used as an indicator of driver’s visual attention towards the environment (Brookhuis et al., 1991; Pastor et al., 2006) and has been used to study intersection maneuvers (Harbluk et al., 2006). Thus, the proportion of time driver’s glanced toward the rearview mirror (regions 6) during each drive maneuver was also collected.

### 2.4.2. Randomness of visual scanning

Entropy rate has been introduced as a good indicator of scan randomness in aviation (Ioth et al., 1990; Tole et al., 1983). Tole et al. (1983) showed that for less difficult tasks, a higher scan randomness or a greater entropy rate was observed. This measure is also useful in the driving domain because it can provide insights on how attentive drivers are to their surroundings. As discussed in the introduction, visual scan patterns tend to differ among different age groups. More specifically, older drivers were found to have more centered (i.e., less random) scan patterns and focused on their central visual field with significantly longer mean fixation durations (Maltz and Shinar, 1999). Thus, entropy rate can provide insights into the scan randomness across the visual field based on age-related differences. A higher entropy rate represents greater randomness or higher scanning to multiple areas with shorter average fixation duration. A lower entropy rate indicates more focused scanning in only a few areas with longer average fixation duration.

Entropy rate is defined as

\[
\text{Entropy rate} = \frac{1}{D} \sum_{i=1}^{D} E / E_{\text{max}}
\]

where \( E \) is the information entropy (Shannon, 1948) of a discrete random variable \( x_i \), that denotes the fixation location \( x \) at scan \( i \) and defined as

\[
E = - \sum_{i=1}^{D} P_{x_i} \log_2 P_{x_i}
\]

The variable \( P_{x_i} \) defines the probability of occurrence of \( x_i \) and \( D \) is the number of variables in the visual scanning sequence and has been defined as \( M \times (M-1)^{N-1} \) with \( M \) being the visual scanning area, and \( N \) is the sequence length of interests. For example, \( N = 1 \) indicates that each individual scan is of interest, and \( N = 2 \) indicates that two consecutive scans are being examined, and so forth. In this study, each individual scan rather than a series of scans are of interest Therefore, the visual scanning area, \( M \), is equal to \( D \).

The maximum entropy, \( E_{\text{max}} \), is achieved when each \( x_i \) has an equal probability of occurring, or at \( P_{x_i} = 1/D \). Therefore, \( E_{\text{max}} = \log_2 D \). The average fixation duration in the visual scanning sequence is denoted as \( T_{x_i} \).

The number of visual scanning areas (i.e., variable \( x_i \)) in a consecutive sequence, \( D \), is based on all 7 regions, shown in Fig. 2. The shortest fixation of a visual scan area is defined as 0.133 s (2 frames in the video). The entropy rate calculation measures the visual scanning randomness with higher values representing greater randomness. Based on the entropy rate calculation, the minimum entropy rate will be zero when there is minimum randomness as defined by repeated samples fixated in only one area. Conversely, if the driver checks all seven areas with equal probability, the entropy rate would be at a maximum value of 7.52 (1/0.133).

#### 2.5. Experimental design

This was a mixed design with two between-subject variables (gender [male, female] and age [younger, middle-aged and older]) and two within-subject variables (intersection and drive maneuver). That is, all drivers traversed the same two intersections (high crash area, low crash area) and performed three drive maneuvers at each intersection.

Analysis of variance (ANOVAs) techniques in SAS 9.1 using PROC MIXED were used to analyze the proportion of time checking the rearview mirror, proportion of visual scanning towards the left and right, and entropy rate. Pair-wise comparisons using the Tukey test was conducted post hoc. Traffic conditions may also have an influence on the visual scanning behavior. For that reason, the model included traffic volumes as a covariate. The distance to the stop-signs (at an interval of 3 m) was also included in the model as a covariate to identify differences in drivers’ visual scanning behavior along their drive locations.

### 3. Results

Age-related differences are examined based on each stage of an executed maneuver to distinguish differences that may exist on the approach to the intersection, to the median, and upon exiting the intersection. The goal is to identify the stages that appear to be the most problematic for specific age groups. All results are reported at a significance level of 0.05. If the effect was significant, the exact \( p \)-value is provided.

The proportion of time drivers spent checking each scanning area is shown in Table 1. Similar scanning patterns were observed at both high crash and low crash intersections with the majority of visual scanning occurring in the far right, far left, and straight ahead.

With respect to rearview mirror checking, a significant interaction between age and drive maneuver was observed (\( F(4,108) = 2.6, p < 0.05 \)). As shown in Fig. 3, middle-aged drivers checked their rearview mirror with significantly higher proportion of time than older and younger drivers during all three maneuvers. This difference was more pronounced for the straight across maneuver. Differences between older and younger drivers were also observed at straight across and left turning maneuvers with younger drivers checking the rearview mirror at a higher proportion.
Scan patterns are expected to differ when drivers approach an intersection when compared to exiting the intersection. Therefore, the proportion scanning toward the left and right were further segmented into three locations and discussed further with respect to age-related differences and intersection type.

3.1. Approach to the intersection

3.1.1. The proportion of time scanning to the left

The proportion of visual scanning to the left side differed significantly by age \((F(2,108) = 53.07, p < 0.0001)\), and distance to stop-sign \((F(1,12786) = 120.41, p < 0.0001)\). Pair-wise comparisons showed that middle-aged and younger drivers had significantly higher proportions of visual scanning to the left \((\text{elder vs. middle-aged, } t(54) = -2.84, p = 0.0063, \Delta = -11.52, CI: -19.64, -3.39; \text{older vs. younger, } t(54) = -2.36, p = 0.02, \Delta = -9.57, CI: -17.69, -1.44)\). No difference was observed between younger and middle-aged drivers.

In general, drivers had a significantly higher proportion of time visually scanning to the left before executing a right turn when compared to the straight across and left turn maneuvers \((\text{straight across vs. right turning, } t(108) = -9.08, p < 0.0001, \Delta = -14.35, CI: -17.48, -11.21; \text{left turning vs. right turning, } t(108) = -8.76, p < 0.0001, \Delta = -13.71, CI: -16.81, -10.61)\). The proportion of visual scanning to the left was found to be significantly higher as drivers got closer to the stop-signs when compared to distances further away. Traffic volumes from the left were also found to have a significant impact \((F(1,2786) = 3.89, p = 0.04)\) with higher traffic volumes leading to a higher proportion of visual scanning to the left.

There was an interaction between drive maneuver and intersection \((F(2,108) = 5.67, p = 0.0046)\). As shown in Table 2, drivers spent a significantly greater proportion of time visually scanning to the left before executing a right turn maneuver at the high crash intersection than at the low crash intersection. Similar proportions were observed at both intersections before going straight across and executing a left turn.

3.1.2. The proportion of time scanning to the right

Drivers were found to have a significantly smaller proportion of time visually scanning to the right at the high crash intersection than at the low crash intersection \((t(54) = 4.97, p = 0.03, \Delta = -2.54, CI: -4.82, -0.26)\). A significant three-way interaction, drive maneuver by age by intersection type was also found to have impact on proportion of time scanning to the right \((F(4,108) = 2.48, p < 0.05)\). At the high crash intersection, drivers in the three age groups spent similar proportion of time scanning to the right before executing a left turn maneuver \((t(54) = 17.69, p < 0.0001)\).

3.1.3. Visual scanning randomness

A significant interaction between drive maneuver and age was observed for entropy rate \((F(4,108) = 8.72, p < 0.001)\). Middle-aged drivers had significantly higher entropy rate than both older and younger drivers before two turning maneuvers \((t(54) = -2.34, p = 0.02, CI: -9.57, -0.74)\) and younger drivers \((t(54) = 2.98, p = 0.004, CI: -6.59, -2.15)\). No difference was observed between middle-aged drivers and younger drivers. All drivers scanned the left significantly more while preparing for left turns than for going straight across \((t(54) = 6.73, p < 0.0001, \Delta = -7.47, CI: -9.69, -5.24)\). With respect to the distance to the stop-sign, drivers scanned the left side less frequently when they were closer to the median.

3.2. Approach to the median

On the approach to the median, going straight across and making left turns were included in the analysis but right turn was not since it is not a maneuver executed in this area.

3.2.1. The proportion of time scanning to the left

Age \((F(2,154) = 4.92, p = 0.01)\), drive maneuver \((F(1,54) = 45.23, p < 0.0001)\), and distance to the stop-sign \((F(1,1840) = 7.29, p = 0.007)\) were all found to have a significant impact on the proportion of visual scanning towards the left in the median area. Pair-wise comparisons showed that older drivers performed significantly less visual scanning toward the left than middle-aged drivers \((t(54) = -2.34, p = 0.023, \Delta = -5.16, CI: -9.57, -0.74)\) and younger drivers \((t(54) = -2.98, p = 0.004, CI: -6.59, -2.15)\). No difference was observed between middle-aged drivers and younger drivers. All drivers scanned the left significantly more while preparing for left turns than for going straight across \((t(54) = -6.73, p < 0.0001, \Delta = -7.47, CI: -9.69, -5.24)\). With respect to the distance to the stop-sign, drivers scanned the left side less frequently when they were closer to the median.

3.2.2. The proportion of time scanning to the right

Drivers had a higher proportion of visual scans toward the right side during straight across maneuvers than when executing a left turn \((t(54) = 2.02, p < 0.05, \Delta = 3.61, CI: 0.03, 7.19)\). Drivers also had

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**Table 1**

Proportion of time driver checked each scanning area.

<table>
<thead>
<tr>
<th>Intersection</th>
<th>Scanning area</th>
<th>Drive maneuver</th>
<th>Left</th>
<th>Straight</th>
<th>Right</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>High crash</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1: Far left</td>
<td>21.3</td>
<td>20.0</td>
<td>40.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2: Close left</td>
<td>6.5</td>
<td>3.6</td>
<td>6.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3: Far right</td>
<td>24.1</td>
<td>23.7</td>
<td>0.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4: Close right</td>
<td>5.6</td>
<td>8.5</td>
<td>10.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5: Straight ahead</td>
<td>37.8</td>
<td>37.6</td>
<td>33.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6: Rear mirror</td>
<td>1.6</td>
<td>1.6</td>
<td>0.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7: Others</td>
<td>2.7</td>
<td>5.0</td>
<td>8.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Low crash</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1: Far left</td>
<td>17.5</td>
<td>21.4</td>
<td>30.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2: Close left</td>
<td>7.2</td>
<td>4.6</td>
<td>4.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3: Far right</td>
<td>22.8</td>
<td>19.4</td>
<td>1.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4: Close right</td>
<td>5.9</td>
<td>5.9</td>
<td>8.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5: Straight ahead</td>
<td>43.1</td>
<td>46.1</td>
<td>52.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6: Rear mirror</td>
<td>1.5</td>
<td>1.1</td>
<td>0.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7: Others</td>
<td>2.0</td>
<td>1.5</td>
<td>2.7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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**Fig. 3.** Mean proportion of time checking rearview mirror (with standard error bar) by age groups during each drive maneuver.
significantly higher proportion of time visually scanning the right at the high crash intersection (t(54) = 3.8, p = 0.0004, Δ = 6.84, CI: 3.23, 10.45). At the same time, higher traffic volumes from the right led to a higher proportion of time visually scanning the right while approaching the median (t(1,1840) = 9.53, p = 0.002). No age differences were found.

### 3.3. Visual scanning randomness

The specific drive maneuver executed (F(1,54) = 4.45, p < 0.05) also had an impact on the entropy rate with higher entropy rate observed while turning left than going straight across (t(54) = 3.1, p < 0.05, Δ = 0.2, CI: 0.07, 0.34).

### 3.3.3. Visual scanning randomness

#### 3.3.3.1. The proportion of time scanning to the left

The proportion of time drivers visually scanned their left side while leaving the intersection differed significantly by age (F(2,54) = 6.23, p = 0.0037), drive maneuver (F(2,108) = 75.92, p < 0.0001), and distance to the stop-sign (F(1,629) = 82.96, p < 0.0001). Older drivers spent less time visually scanning to the left than both younger and middle-aged drivers (pairwise comparison: older vs. younger, t(54) = -2.79, p = 0.0073, Δ = -9.19, CI: -15.79, -2.59; older vs. middle-aged, t(54) = 3.27, p = 0.002, Δ = -10.75, CI: -17.35, -4.15). With respect to the drive maneuvers, drivers visually scanned the left side significantly less when completing a straight across maneuver than a right (t(108) = -12.01, p = 0.0001, Δ = -34.19, CI: -39.84, -28.55) or left turn (t(108) = -8.42, p < 0.0001, Δ = -23.99, CI: -29.65, -18.34). The proportion of time drivers visually scanned the left side imme-

![Fig. 4](image-url)  
**Fig. 4.** Entropy rates for visual scanning (with standard error bar).

#### 3.3.3.2. The proportion of time scanning the right

Age (F(2,54) = 6.57, p = 0.0028), drive maneuver (F(2,108) = 7.07, p = 0.0013), and the distance to the stop-sign (F(1,629) = 52.66, p < 0.0001) were all found to have a significant effect on the proportion of time drivers’ visually scanned the right while leaving the intersections. Middle-aged drivers had a significantly higher proportion of time scanning the right than both younger and older drivers (pair-wise comparison: older vs. middle-aged, t(54) = -2.34, p = 0.02, Δ = -8.36, CI: -15.53, -1.19; younger vs. middle-aged, t(54) = -3.57, p = 0.0008, Δ = -12.76, CI: -19.93, -5.59). No differences were found between younger and older drivers. Drivers also visually scanned the right side significantly more after completing a straight across maneuver than a right (t(108) = 3.22, p = 0.0017, Δ = 9.76, CI: 3.76, 15.76) or left turn maneuver (t(108) = 3.29, p = 0.0013, Δ = 9.99, CI: 3.98, 15.99).

#### 3.3.3.3. Visual scanning randomness

There was an interaction effect observed between drive maneuver and age for the entropy rate (F(4,108) = 10.29, p < 0.05). Middle-aged drivers had significantly higher entropy rate of visual scanning after left turning than both older and younger drivers (t(108) = 4.74, p < 0.0001, Δ = 0.8, CI: 0.47, 1.14; t(108) = 2.19, p = 0.03, Δ = 0.4, CI: 0.04, 0.71). No other differences were observed here.

### 4. Discussion

The objective of this study was to examine age-related differences in visual scanning behavior at median-divided highway intersections. Driving safely through intersections depends on the drivers’ ability to visually detect and monitor traffic signs and conflicts. Selective attention directs gaze towards objects of interests and concerns in the environment (Chun and Wolfe, 2000). Therefore, differences in visual selection may reflect different driver strategies. In this study, differences were assessed using the proportion of time drivers looked at different locations and an entropy rate indicating the randomness associated with their scanning patterns. The results confirm the hypothesis that differences do exist for the three age groups examined in terms of where they look and for how long.

Older drivers scanned significantly less toward the left and right during intersection negotiations when compared to middle-aged and younger drivers. The older drivers also focused more on one traffic stream before executing a right or left turn and this was shown also by the lower proportion of time looking toward the
turning direction when compared to the other age groups. Studies show that older drivers are more likely to be involved in left turn and angle collisions (HSIS, 1999). In the crash analysis conducted by Garber and Srinivasan (1991), there were significantly higher numbers of crashes involving a right or left turn maneuver for older drivers when compared to younger drivers. By examining the maneuvers based on the stages of events, greater insights can now be provided for where older drivers may have greater difficulty attending to traffic. Although one would expect that all drivers should spend more time looking for oncoming traffic, a certain portion should also be dedicated to the turning direction to ensure the avoidance of pedestrians or bicyclists. All drivers actually spent more time looking at the oncoming traffic. However, because older drivers had significantly fewer glances toward the turning direction, they may have a greater likelihood of a critical incident.

The definition of entropy rate used in this paper has previously been used to assess the randomness of pilots attending to all instruments during flight task (Iloth et al., 1990). In this study, it provides a way to quantify how drivers of different age groups monitor potential conflicts from multiple locations in the environment. Both older and younger drivers were less likely to scan all areas as indicated by their lower entropy rate than middle-aged drivers during the approaches to and leaving the intersection. That is, they tend to spend more time checking within certain areas before they entered the intersections.

Younger drivers were also less likely to visually sample their right side while performing right turns. All drivers were found to check fewer areas before turning right than turning left or going straight across. Summala et al. (1996) also observed that drivers were less likely to check their right hand side before executing a right turn maneuver when compared to left turn maneuvers. This study is consistent with their findings and further demonstrates the differences in visual scanning between age groups. This is of concern since failure to look both ways appropriately may increase the likelihood of collisions into unobserved objects or unanticipated pedestrians located on the right hand side. Both younger and older drivers are more likely to be considered as the at-fault driver for crashes at intersections (Cooper, 1990; Hakamies-Blomqvist, 1994; Keskinen et al., 1998). The results of this study may therefore provide some insights into why these age groups are more likely to be at-fault.

Significantly less visual scanning toward oncoming expressway traffic was observed at the high crash intersection. In a study by Harbluk et al. (2006), drivers were observed to have significantly reduced inspection glances during intersection negotiations when performing a difficult secondary task when compared to driving alone. Consistent with their study, drivers’ visual scanning toward strategic areas tends to be less during demanding situations. In our study, the high crash intersection consisted of more complicated geometric features with horizontal curves on the expressway. This can also decrease the ability of detecting traffic from the minor roads and increase the likelihood of crashes in this area.

As discussed earlier, checking the rearview mirror is indicative of the driver’s ability to attend to environmental situations as well as oncoming traffic. This study found that middle-aged drivers had significantly more rearview mirror checking than both younger and older drivers, especially at straight crossing maneuver. This provides further evidence that middle-age drivers have a greater awareness of their surrounding environment.

This study also showed that there were greater scanning patterns toward the side that had higher traffic volumes prior to the approach to the median. This was the case for all drive maneuvers. Although this may not seem surprising, it was interesting to observe drivers traversing through the median at these intersections. The median allowed drivers to proceed in more of a stepwise pattern, with greater scanning to one direction prior to the median and greater scanning to the other direction after the median. Of interest for future studies is to examine whether the proportion of scanning patterns would differ if there was no median.

Crundall and Underwood (1998) showed that experienced drivers had a greater spread in horizontal searching than novice drivers during more demanding environments. This study also showed that drivers of varying ages have different search strategies and this was influenced by traffic volumes and types of intersections. More specifically, middle-aged drivers were more likely to search for conflicts across a wider range than the other two age groups, particularly during more demanding situations. These differences are helpful in understanding the age-related differences in crash likelihood and can provide some insights into traffic and road improvements. Greater detail on visual behavior may be obtained using an eye tracker which can then enhance the findings of this study by providing insights into specific placement of traffic controlled devices, and on understanding the focus of driver’s attention related to oncoming vehicles.

There were no gender differences observed even though data was collected equally between male and female drivers. However, the number of subjects may have limited the ability to discern any differences. There are studies that demonstrate that gender differences do exist with respect to crash likelihood (Hill and Boyle, 2006), but these differences have not been focused on visual scanning in the driving domain. Thus, there may be other factors related to gender differences in addition to visual scanning patterns that need to be examined.

This present study was conducted in rural areas and the results may not reflect the age differences in urban or suburban areas because of the differences in traffic volumes and speeds. Another thing worth noting is that entropy rate is a fairly new concept in driving and there are limitations to the interpretation of results. For example, this study found middle-aged drivers generally had a higher scanning randomness (i.e., a greater entropy rate value) than older drivers. However, the result of this study does not suggest a linear relationship between higher scanning randomness and better performance. There is more likely a threshold or limit that needs further investigation. This study does demonstrate the application of entropy rate and the benefits of segmenting the drive maneuvers into different stages to help explain age differences in visual scanning patterns.

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References


