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

Shan Bao, Linda Ng Boyle*

Department of Mechanical and Industrial Engineering, University of Iowa, 3131 Seamans Center, Iowa City, IA 52246, USA

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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

* Corresponding author. Tel.: +1 319 384 0554.
E-mail address: linda-boyle@uiowa.edu (L.N. Boyle).

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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 ($M = 21$, S.D. = 2.1), middle-aged drivers were between 35 and 55 years old ($M = 46$, S.D. = 4.8), and older drivers were between 65 and 80 years old ($M = 73$, 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.

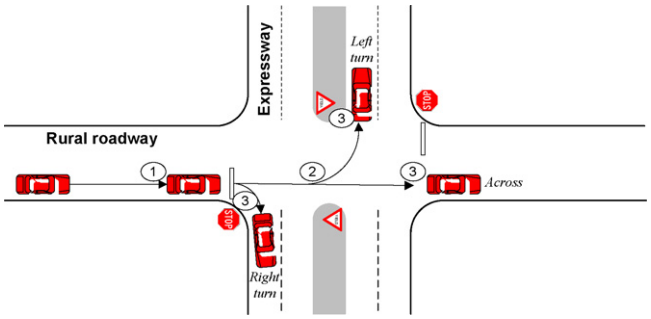

Fig. 1. Maneuvers evaluated at both intersections for (1) approach to intersection, (2) approach to median, and (3) exiting the intersection.

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