

Braking Behavior at Rural Expressway Intersections for Younger, Middle-Aged, and Older Drivers

Shan Bao
Department of Mechanical and Industrial Engineering
University of Iowa
3131 Seamans Center
Iowa City, IA 52242
sbao@engineering.uiowa.edu

Linda Ng Boyle
Department of Mechanical and Industrial Engineering
University of Iowa
3131 Seamans Center
Iowa City, IA 52242
linda-boyle@uiowa.edu

ABSTRACT

High speed expressway intersections can be problematic for drivers of all ages. The purpose of this study is to evaluate driver performance at a high crash rate rural expressway intersection for three age groups: older (65 to 80), younger (18 to 25), and middle-aged drivers (35 to 55). This study reports preliminary findings associated with 30 drivers (ten drivers in each age group) who participated in an instrumented vehicle study. Of particular interest was to understand how braking behavior may differ on the approach to an expressway intersection prior to executing one of three different maneuvers (e.g., going across the intersection, left turn, and right turn). The specific performance measures include mean deceleration, initial brake point, brake pedal differential time (difference in initial to maximum brake pedal depression), and whether or not the driver came to a complete stop. Overall, individual differences based on age were observed. Both younger and older drivers showed more dramatic changes in the braking profile when compared to middle-aged drivers. Middle-aged drivers had the highest number of complete stops prior to entering an intersection and less dramatic or longer brake pedal differential times when compared to the other two age groups. Younger drivers were the least likely to come to a complete stop. This can be a potential safety concern given the lack of time allocated to make appropriate decisions. Future analyses will compare these findings to a low crash rate intersection as well as investigate how physiological measures such as heart rate variability may differ for these same age groups.

Key words: age differences—expressway intersections—human factors—instrumented vehicle

INTRODUCTION

Studies show that age and roadway characteristics are significantly related to an increase crash likelihood (Chin and Quddus 2003; Kim et al. 2007). According to a recent U.S. study, intersection crashes account for over one-third of vehicle crashes and lead to approximately 9,000 fatalities every year (Alexander et al. 2006). Crashes at intersections without traffic controls were 1.7 times more likely to result in fatalities compared to crashes at intersections with traffic controls (Zhang et al. 2000). Rural expressway intersections are particularly problematic. These intersections consist of a high-speed, multi-lane, divided highway (major roadway) and a low-speed two-lane roadway (minor roadway) in a rural area (Hochstein et al. 2007). The typical rural expressway intersection is two-way stop-controlled (TWSC).

Older drivers (defined as 65 and older) have been shown to have a higher likelihood of crashes at intersections compared to other driver age groups (Keskinen, Ota, and Katila 1998; Guerriera, Manivannanb, and Nair 1999). The relative crash risk for older drivers is also much higher at uncontrolled or stop-controlled intersections when compared to signalized intersections (Preusser et al. 1998; Bayam, Liebowitz, and Agresti 2005) and if the intersection is located within a rural area (Garber and Srinivasan 1991). However, other studies also indicate that the crash rates at two-way stop-controlled intersections are also high for younger drivers (Retting, Weinstein, and Solomon 2003). Younger drivers tend to accelerate and decelerate at much quicker rates and, therefore, increase their potential for a crash (McGwin and Brown 1999; Neyens and Boyle 2007). Studies have shown that factors that influence safety at rural expressway intersections relate to roadway volumes (Maze, Hawkins, and Burchett 2004) and intersection designs (e.g., vertical/horizontal curves, skewed intersections) (Burchett and Maze 2006). However, few studies have fully examined the individual differences associated with the driver within these expressway intersections.

The objective of this study is to examine driver performances at a high-crash-rate rural expressway intersection as influenced by age-related differences. This objective is accomplished using data collected from an instrumented vehicle in an on-road study conducted in the state of Iowa. This paper focuses on one of the two intersections that were evaluated as part of the original study. More specifically, our hypothesis centers on differences that may exist in braking behavior among different driver age groups at the high crash rate intersection. The outcomes of this study will provide relevant design guidelines for future systems.

METHODS

Participants

A total of 30 drivers with equal proportions in three age groups were recruited through advertisements in the local newspaper. Younger driver were from 18 to 25 years old ($M=22$, $SD=2.1$, $n=10$); middle-aged drivers were from 35 to 55 years old ($M=46$, $SD=3.5$, $n=10$); and older drivers were from 65 to 80 years old ($M=73$, $SD=5.3$, $n=10$). All participants were active drivers with a valid U.S. driver's license, and had been screened to ensure safe driving records. They were compensated (U.S.) \$20 per hour for participation, and the study lasted approximately one hour.

Apparatus

A 2002 Ford Taurus instrumented sedan was used for this study. Two LP-850W weatherproof cameras and four MB-750 pinhole lens cameras were installed in the vehicle to capture foot movements, visual scanning behavior, steering position, and lane deviations. The four pinhole cameras were located inside

the car body, the two weatherproof cameras were located under the left and right mirrors, and all cameras were completely unobtrusive to the drivers. The video was captured with a sample frequency of 15Hz. A Garmin GPS-17N GPS receiver was installed on the back of the trunk so that the driver's position was known at all times. For the analyses, the driver's foot movement behavior is further examined.

Driving performance measures that were recorded include driving speed, braking force, throttle position, and GPS location. All data were automatically recorded by 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.

Procedure

Prior to starting, all participants were provided with a brief explanation of the main purpose of the study and an IRB consent form to sign. During the study, all participants were asked to perform three intersection maneuvers at a two-way stop-controlled (TWSC) intersection: drive across the intersection, turn left onto the expressway, and turn right onto the expressway. For this paper, the intersection examined was identified as having a high crash rate, as defined by the Iowa DOT, with approximately five crashes per year over the most recent four years of data (2002 to 2006). The TWSC intersection is composed of an expressway (major road) and rural (or minor) road. The expressway was a divided highway with two lanes of traffic on each side and speed limit of 65 mph (approximately 105km/h). The rural (or minor) road at the high-crash-rate intersection was a two-lane road with a speed limit of 35 mph (approximately 56 km/h). All participants were told to drive as they normally would, follow the instructions provided by the researcher who sat in the front passenger seat, and adhere to the posted speed limits whenever possible. Prior to beginning data collection on the study, all drivers had an opportunity to drive the car in order to become familiar with the controls. Immediately after the drive, all participants were asked to fill out three surveys that assessed their mental workload and perceived stress as it related to the completed drive. All experiments were conducted on dry roads and under normal weather conditions (i.e., no rain, sleet, or snow).

Independent and Dependent Variables

The focus of this study is to investigate the age differences in braking behavior as drivers slowed down for a stop sign at the high crash rate intersection. The independent variables for this analysis include age groups (younger, middle-aged, older) and gender (male, female). There were three dependent measures that relate to braking behavior and were used to describe how drivers respond prior to entering the intersection. To minimize learning effects, the braking behavior related to each continuous outcome was averaged across the three intersection maneuvers (left turn, right turn, and straight across). A binomial variable was also included in this analysis to investigate whether or not drivers came to a complete stop prior to entering the intersection.

Brake pedal differential time (in seconds). Measures the time from initial to maximum depression of the brake pedal (equation 1). Lower values represent a more sudden brake, and higher values indicate a more gradual braking profile.

$$\text{Brake pedal differential time} = \frac{\sum_{m=1}^3 (t_{f,mn} - t_{o,mn})}{3} \quad (1)$$

where

$t_{f,mn}$ = time at maximum brake pedal depression for driver n at maneuver m

$t_{o,mn}$ = time at initial brake pedal depression for driver n at maneuver m

Mean deceleration (in m/s^2): Describes the average deceleration from initial brake depression until the vehicle reaches its lowest speed during its approach to the stop sign prior to entering the TWSC intersection.

Initial brake point (in meters): Describes the distance or point at which the driver initially responds (by braking) to the stop sign prior to entering the intersection. This value is measured as the distance from the stop sign.

Complete stops (binary): Specifies whether or not a driver made a full stop (i.e., velocity >0) at the stop sign before execution of each maneuver. It was coded as a binary variable with '1' =complete stop and '0' =incomplete stop. There was a separate binary code for each drive maneuver. According to U.S. traffic regulations, drivers are required to make a full stop (i.e., velocity=0) at a stop sign. It was therefore of interest to observe whether drivers would comply and whether differences would exist between age groups.

RESULTS

The statistical software package, SAS 9.1, was used for the data analysis. A logistic regression model using the Proc GENMOD procedure was developed to predict the likelihood of an incomplete stop. The analyses on the continuous dependent variables were performed with the Proc ANOVA procedure. There were no significant differences in mean deceleration ($p>0.05$). All other dependent measures are discussed in this section.

Age was found to have a significant impact on the brake pedal differential time ($F(2, 24)=8.6, p=0.0015$). As observed in Figure 1, both older and middle-aged drivers took significantly more time to go from initial to maximum brake pedal depression when compared to younger drivers (Pairwise comparisons: $t(18)=2.86, p=0.01, \Delta=2.81$ sec, CI: 0.75,4.88 ; $t(18)=3.63, p=0.002, \Delta=3.52$ sec, CI: 1.48,5.55). The results suggest that younger drivers moved more quickly from initial to maximum brake pedal depression (mean=7.24 sec) than middle-aged (mean=10.8 sec) and older drivers (mean=10.1 sec).

There were significant age differences observed at the initial brake point ($F(2, 24)=10.45, p=0.0005$). Generally, middle-aged drivers braked on the approach to an intersection significantly earlier than younger drivers ($t(18)=3.53, p=0.002, \Delta=29.1$ sec, CI: 9.7388,38.42) or older drivers ($t(18)=3.7, p=0.002, \Delta=22.2$ sec, CI: 9.57,34.75). No differences in the initial brake points were observed between older and younger drivers.

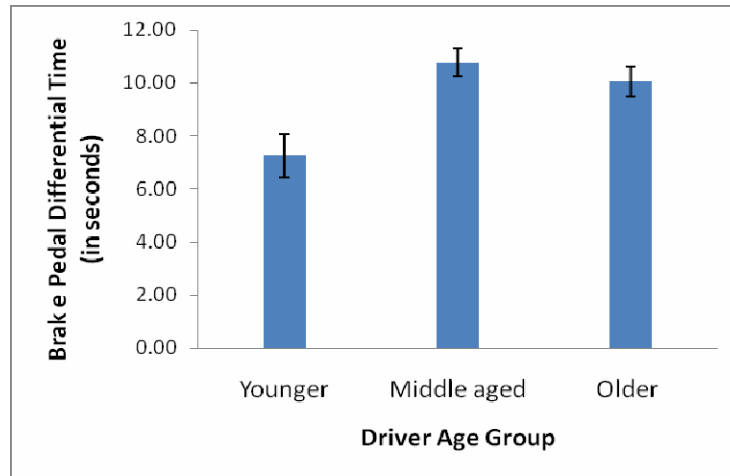


Figure 1. Mean difference in time between initial and maximum brake pedal depression (with standard error bars) for the three age groups

Figure 2 shows the average brake load sensor voltage readings from the instrumented vehicle over each consecutive five-meter interval for the three age groups. The brake load sensors are used to measure how much force is being applied to the brake pedal and the voltage reading from the sensor is an indicator of the pressure placed on the brake pedal with higher voltage values indicating higher brake pressure. For this vehicle, normal braking usually falls in the 2.8 to 3.3V range. As observed from Figure 2, the three driver age groups demonstrated very different brake profiles. Middle-aged drivers responded to the stop signs by braking significantly earlier and had a comparatively slower brake pressure profile than both older and younger drivers. Younger drivers depressed the brake much later and for a shorter distance thereby reaching maximum brake pressure in significantly less time, suggesting a more sudden and harder brake. Older and middle-aged drivers had similar brake profiles at the end of the braking event. However, older drivers do show a greater change from initial to maximum brake pedal pressure in a shorter distance when compared to the middle-aged drivers.

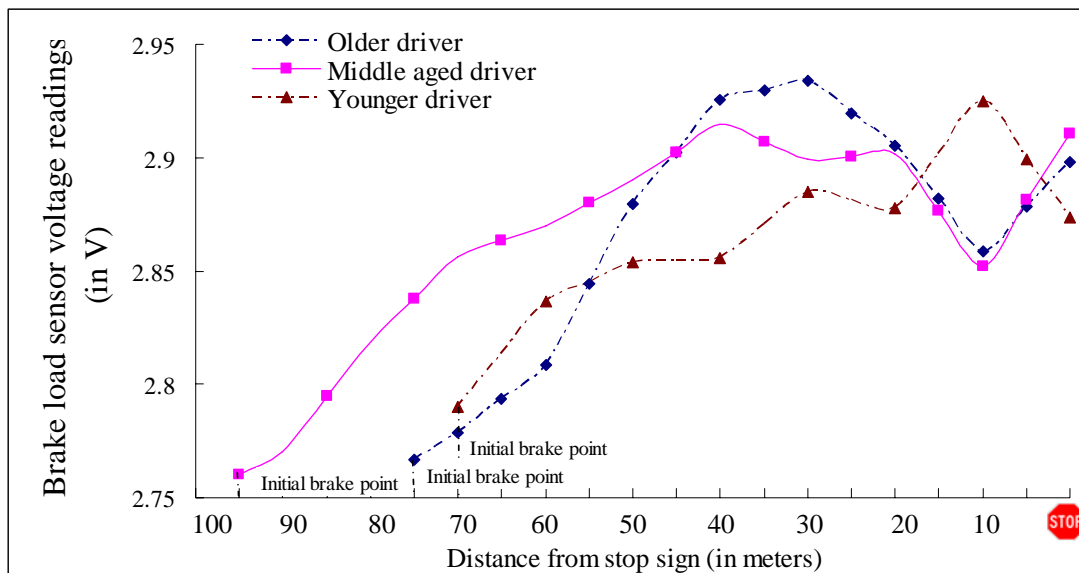


Figure 2. Profiles of brake load sensor voltage (in V) on the approach to the stop sign

Complete Stops

Both age ($\chi^2(2) = 8.37, p = 0.015$) and drive maneuver ($\chi^2(2) = 15.1, p = 0.0005$) had significant impacts on whether or not a driver came to a complete stop prior to entering the intersections. Younger drivers had a higher likelihood of not coming to a complete stop when compared to middle-aged drivers (Table 1). As observed in Figure 2, younger drivers did not maintain brake depression as forceful as the other two age groups further supporting the finding that younger drivers were less likely to come to a complete stop. The percentages of incomplete stops at the high-crash-rate intersection were 33% for young drivers, 20% for older drivers, and 7% for middle-age drivers. The possibility of an incomplete stop was higher for right turns than for other maneuvers with 3% being incomplete stops for going straight across, 17% for left-turn maneuvers, and 40% for right-turn maneuvers.

Table 1. Likelihood of an incomplete stop at a high crash rate expressway intersection

Effect	Contrast	Estimate	Std error	Odds ratio (95%CI)	p-value
Age	Older vs. middle-aged	1.40	0.90	4.05 (0.69, 24.05)	NS
	Younger vs. middle-aged	2.27	0.89	9.67 (1.69, 55.9)	0.010
	Younger vs. older	0.87	0.60	2.39 (0.64, 8.99)	NS
Drive Maneuver	Right turn vs. straight across	3.21	1.11	24.53 (2.8, 221.4)	0.004
	Right turn vs. left turn	1.37	0.66	3.94 (1.1, 14.5)	0.040
	Left turn vs. straight across	1.84	1.14	6.23 (0.66, 59.7)	NS

DISCUSSION

The objective of this study was to investigate how drivers in different age groups respond to stop signs at a high-crash-rate rural expressway intersection. This study used data gathered from an on-road experiment that was conducted in the state of Iowa. The high-crash-rate intersection was the focus of the analyses and paper because differences that may be observed in age would be more readily apparent if crashes were greatly influenced by that factor. Results of this study confirm the initial hypothesis that differences in age groups do exist. More specifically, middle-aged drivers have a steadier and more gradual brake profile when compared to the other two age groups and, therefore, respond much earlier when approaching a TWSC intersection. Although older drivers and middle-aged drivers transitioned from initial braking to maximum braking within a similar timeframe, older drivers appear to have much higher brake pressure values than middle-aged drivers. Other studies have also shown that intersections are problematic for older drivers (Preusser et al. 1998; Bayam, Liebowitz, and Agresti 2005), and this may be explained by the braking profiles observed among this age group.

Older drivers tend to be more cautious and usually compensate for driving difficulties by avoiding problematic situations (Stamatiadis, Taylor, and McKelvey 1991; Hakamies-Blomqvist 1994). Decreasing functional abilities of older drivers might provide one explanation why they respond to stop signs significantly slower and more sudden than middle-aged drivers. After the age of 65, most adults experience measurable functional impairment including a reduction in the visual field (Preusser et al. 1998). Driving requires continual and complex visual search and decision making to appropriately respond to abrupt changes and potential hazards that can arise. This can be particularly demanding at complicated roadways such as those observed in a two-way stop-controlled rural expressway intersection. Due to the high speed and density of non-stop traffic on major highways, drivers on minor roads at these intersections need to have enough time to perceive and appropriately judge the cross traffic. Younger drivers also showed greater brake pedal differential time when compared to middle-aged drivers. They

also appeared to brake more sudden and harder. Their ability to respond quickly to situations appears adequate, but their decision to wait before initiating a response can pose some additional risks, including a greater likelihood of rear-ends collisions. Younger drivers also have greater crash risks at intersections (Retting, Weinstein, and Solomon 2003) and education on appropriate decision making and the consequences of inappropriate decision making may be of value.

All drivers were less likely to come to a complete stop prior to executing a right turn when compared to the other two intersection maneuvers (i.e., going straight across and making left turns). This finding is expected given that there is only one direction of traffic that needs to be observed for potential conflicts prior to the maneuver. Most drivers have a greater comfort level merging into the same direction than judging gap acceptance for left-turn maneuvers and traversing across multiple traffic streams. However, the higher likelihood of incomplete stops at right-turn maneuvers may result in more right-angle collisions and requires further research.

In conclusion, both younger and older drivers appear to take greater risks when compared to middle-aged drivers as exhibited by their braking profiles prior to entering rural expressway intersections. It is important to note that these analyses were based on a subset of data. There will be a total of 60 drivers at study completion, and all drivers' braking profiles will be examined and compared with these existing results. The analyses will also include physiological measures (i.e., heart rate variability) and differences in visual scanning patterns. Thus, future analysis will examine all these outcomes across the high and low crash rate rural expressway intersections in enhancing our understanding of driver performance and mental workload.

ACKNOWLEDGMENTS

We would like to acknowledge the Iowa Department of Transportation (Tom Welch and Sandra Larson) for funds that made this project possible.

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