Driving Behavior Differences among Early Licensed Teen, Novice Teen, and Experienced Drivers in Simulator and Real World Potential Hazards

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Abstract

Age and driving experience play a critical role in the vehicle control and eye movement behaviors of drivers subjected to hazardous environments. This study investigates whether significant differences exist in vehicle control and eye movement behaviors among drivers of different age and experience groups while driving in a simulator and through real world potential hazards. Three groups of drivers were studied: “novice teen,” “early licensed teen” and “experienced adult” drivers, consisting of five participants each and having driving experience of about 6 months, 2 years and 10 years, respectively. The subjects were asked to drive through four potentially hazardous scenarios in the simulator and in the real world, namely a left-turning truck ahead, a mid-block crosswalk, a hidden crosswalk, and curved stop ahead. Indicators measured for eye movement were eye gaze rotation for simulator and eye gaze direction for the real world. In the simulator drive, measured parameters for vehicle control analysis were speed, lateral and longitudinal acceleration, lane deviation and braking force. Those for the real world were speed, accelerator pedal angle and braking force. The results indicated that different driving conditions in the simulator did not have a major effect on the eye movement behavior of the participants. However, different eye movement behavior was evident, both in the simulator and the real world drive, between the “experienced” and “early licensed teen” driver group at the scenario “curved stop ahead”. Significant differences in the vehicle control behavior between these two groups were also observed under specific circumstances.

Keywords
Driving behavior, hazardous driving scenario, teen driver, experienced driver.

1. Introduction

Crash rates for the teen drivers is the highest among novice teens during the first six months and 1,000 miles after licensure and the amount of supervised practice driving has not been shown to alter this risk [1-3]. By analyzing police crash reports McKnight reported that failures of (a) visual scanning (ahead, to the sides, and to the rear), (b) attention maintenance (distribution of attention between the forward roadway and other locations inside and outside car), and (c) speed management, were responsible, respectively, for 43.6 percent, 23.0 percent and 20.8 percent of the crashes among drivers aged between 16 and 19 years [4]. Age and experience are often considered as the major contributing factors to the crash-related problems of novice teen drivers [5]. In terms of age-related factors, researchers have argued that young drivers’ overrepresentation in road accidents reflects the fact that they are teenagers and willing to take risks [5]. In terms of experience-related factors, research on skilled performance suggests that novice drivers’ performance is inferior in several ways to that of experienced drivers [1]. Maycock [6] demonstrated that driving experience has a profound effect on crash risk even when the effect of age is separated out. There is also a dramatic risk reduction taking place during the first few months after licensing [1, 7-8] that cannot be attributed to age differences or motivational changes, and must therefore be ascribed to some skill acquisition [9].

Driving skill or performance is concerned with limitations of performance on aspects of the driving task, such as the use of the steering wheel to track the road and the time taken to respond to traffic hazards [5]. It is expected that driving skill gradually improves with practice or training over time. Driving style or behavior, on the other hand, is more concerned with the decision-making aspects of driving. Driving style governs the manner in which people choose to drive or the driving habits they adopt that have developed over time—for instance, driving speed and how
close one drives to the car in front [5]. Thus it can be perceived that driving skill and driving style are closely related and may interact to affect a driver’s level of safety. For example, adopting a speedy driving style will necessitate faster reflex time, steering control, better hazard scanning and reaction time, etc., in order to drive without causing a crash or creating hazards on the road. So, it can be argued that the driving style and the driving skill are proportionally related to each other. Researchers have suggested that novice drivers are more likely than experienced drivers to adopt a riskier driving style (e.g., speeding, tailgating) and thus are more likely to find themselves in potentially risky situations [1, 10]. At the same time, novice drivers are less likely to deal with those situations effectively due to lower levels of driving skill [5]. The risky driving styles of young novice drivers may not always be deliberate but may stem, at least in part, from their inexperience or relatively low levels of driving skill [5]. For example, when confronted with a potentially hazardous situation (e.g., a pedestrian stepping off the curb to cross the road ahead), the young novice driver may fail to moderate driving speed because of poor hazard perception skills or because they do not know how to position their vehicle on the road to minimize the possibility of a crash [5]. As a result, tactical vehicle management skills, along with technical ones, are essential for confronting the potential hazards efficiently [11]. A study of the differences in tactical hazard anticipation vehicle management skills of young and experienced drivers indicates that the differences are pronounced in situations where hazards are difficult to detect [12]. Several studies of strategic scanning on the open road further indicate that young drivers: a) scan less broadly from side to side, especially when changing lanes [13]; b) have, on average, less widely spaced eye movements as measured along the horizontal axis [14]; and c) are less likely to make consecutive fixations on objects in the periphery [15]. Most of these skills develop and mature with added years of driving experience [16].

In light of these studies, the driving performance of young novice drivers is expected to vary considerably from the experienced driver especially in a driving environment where hazardous situations might appear. The objective of this study is to investigate whether significant differences exist in vehicle control and eye movement behaviors among three groups of drivers: “novice teen,” “early licensed teen” and “experienced,” having driving experience of about 6-12 months, 2 years and 10 or more years, respectively, while driving in a simulator and also in the real world through potential hazards. The study presented in this paper was conducted as a preliminary analysis of a National Science Foundation (Grant No. 1116378) supported driver’s hazard-perception study. Specifically, the objectives are to provide an initial understanding of the difference of eye movement and driving behavior among the three driver groups, as well as to explore the extent that the collected data from the two driving environments are similar or complementary in helping to understand driving behavior differences.

2. Methodology
In order to complete the study all the participants were required to drive in the real world, through four potentially hazardous scenarios, in an instrumented 2009 Chevy Impala. Participants also had to drive twice in a high fidelity driving simulator under the same simulated hazard scenarios with different resolution (800x600 pixels or 1440x1080 pixels), contrast levels (50% or 100%) and field of view (57° or 240° FOV) conditions imposed in different combinations. As eye gaze can be used as a proxy of visual attention of the observer [17], eye gaze output of the two systems, eye gaze rotation from FaceLab and eye gaze direction from the SmartEye system, were collected as the measures of eye movement analysis. However, during routine road observations, head rotations about the x-axis (horizontal) and y-axis (vertical) are most common as these represent natural head rotations that take place during normal observations [18]. For this reason, eye gaze of both left and right eyes with x-axis (horizontal) and y-axis (vertical) rotations (degree) /directions were used for this particular study. Few other studies also used these measures for analyzing the eye movement behavior of the drivers [18-22]. In case of the simulator drives, the measured parameters for vehicle control behavior analysis were vehicle speed (mph), braking force (N), accelerator pedal angle (degree), lane deviation (m), and lateral & longitudinal acceleration (m/s²). In the real world measures on speed (mph), accelerator pedal angle (degree), and braking force were collected. These kinematic measures were used in several studies as surrogate measures of safe driving performance [23].

2.1 Scenarios
The participants had to drive through four hazardous scenarios: behind a left-turning truck, past a blocked mid-block crosswalk, through a hidden crosswalk, and approaching a curved stop ahead. All four scenarios were adopted from Pradhan et al. [24] as examples of potentially hazardous driving maneuvers.

The objective of the “behind left-turning truck” scenario (Figure 1) was to investigate whether the drivers stop to check for oncoming traffic that is obscured by the truck during the left-hand turn. The truck was staged to enter traffic flow 200 m before the intersection. The moving truck obstructs the driver’s view of traffic coming from the
opposite direction, at the intersection, due to its width and height but depending on the driver’s car positioning on the road in relation to the truck, this could be mitigated.

The second scenario (Figure 2), “mid-block cross walk,” determines if drivers would predict the potential presence of pedestrians emerging from behind a parked truck obscuring the ingress of a mid-block crosswalk.

The third scenario, “hidden crosswalk” (Figure 3), determines if drivers would recognize that pedestrians could emerge from behind a line of bushes that obscured a sidewalk on the right. The driver’s potential hazard in the “hidden crosswalk” scenario is the chance that a sidewalk user could emerge from the right.

The last scenario, “curved stop ahead” (Figure 4), determines if drivers would pay attention to a “stop ahead” sign warning the drivers of an upcoming stop sign obscured by a curved road and roadside vegetation. The geometric features of this study are similar to Pradhan et al. [24] where the sign is at the beginning of a road curving to the right, and the stop sign is hidden by trees, but that the real-world location has vertical curvature.

These scenarios were modeled for the driving simulator using SimCreator (Version 2.36). Physical dimensions of the real world scenarios were collected and modeled in the virtual worlds to ensure that simulated scenarios adequately represent the real world in the simulator.

2.2 Participants
A total of 70 participants had completed the original study. Here we remind that the study presented in this paper was conducted as a preliminary analysis to provide an initial understanding of the difference of eye movement and driving control behavior among the three driver groups. So out of this 70 participants total 15 were selected randomly, consisting of 5 participants from each group, “novice teen” (3 male and 2 female), “early licensed teen” (2 male and 3 female) and “experienced” (5 male). Requirements for participation included having a valid Montana driver’s license and normal or corrected-to-normal vision. The mean age and driving experience for the “novice teen” group was 16.57 (SD=0.41) years and 0.89 (SD=0.11) years, for the “early licensed teen” group was 17.68 (SD=0.15) years and 2.06 (0.41) years, and for the “experienced” group was 40.2 (SD=8.49) years and 24.6 (SD=8.41) years. Parental consent and teen assent were obtained for all teen drivers. Consent was obtained for all adult drivers in accordance with university Institutional Review Board approval. Each participant was paid $100 for completing the study.
2.3 Equipment

Chevy Impala. The instrumented vehicle used in the study was a black Chevy Impala, 2009 model. The vehicle was equipped with Smart Eye Pro 5.9 - 5 Camera System to record driver behavior while driving on real roads, as well as external cameras that captured lane position, a panoramic view of the surrounding environment, and a rear-view video feed. Other sensors collected different environmental data, including GPS position, ambient light levels, steering heading, brake force, and vehicle speed.

Driving Simulator. Western Transportation Institute's (WTI) high-fidelity simulator was used for the study. This simulator consists of a 2009 Chevy Impala sedan mounted on a Moog 200E motion platform with six degrees of freedom. Simulation scenarios were projected forward in front of the driver by five projectors onto a curved screen (240 degree forward FOV) and behind the driver (60 degree FOV). Side-view mirrors with digital screens also portrayed the scenarios for a total of eight visual channels. Images were projected at two different resolutions, typical personal computer monitor resolution and projector resolution, for the two different drives of the study. Audio for the simulations was delivered through a Logitech Z-5500 505 Watt 5.1 surround sound system located both inside and outside the vehicle. A FaceLAB 5 eye tracking system was used to measure the eye movements of the participants while they were driving in the simulator.

2.4 Experimental Procedure

This study was conducted in two sessions (one for the driving simulator and the other for the actual driving scenario) on two different days. Experimental sessions, for each participant, were scheduled randomly in different days (preferably few days gap between two sessions) in order to reduce the effect of knowledge of the study scenarios faced during the former session of driving in the simulator or on road. Participants came to WTI during their scheduled appointment times for each session. Upon arrival, the participant’s valid licensure status was confirmed and vision testing was administered to confirm that they had the required visual acuity to participate in the study. After passing the vision testing, participants were directed toward their experimental session vehicle (Instrumented vehicle or Simulator). After a brief practice drive, participant were instructed to drive as they normally would and to drive straight through intersections unless told to turn; all turning instructions were given at least one block prior to the turn.

Participants drove a fixed route through Bozeman, Montana, during daylight hours avoiding heavily trafficked times and when it was not raining. Exterior video camera lenses, vehicle windows, and vehicle headlights were cleaned before every participant’s drive. The study route took approximately 36-45 minutes. In the driving simulator participants also drove a fixed route that appeared similar to the real world neighborhoods. The simulator driving route took approximately 7-10 minutes and participants performed it twice under two different simulator treatment combinations with a 10-minute break between Drive 1 and Drive 2.

2.5 Data Reduction

In order to collect the required data for the analysis from the recorded simulator and instrumented vehicle, a time window was extracted from the data set that started from the first moment the hazard situation was perceptible to the moment when the hazard had been passed. SAS (version 9.3) code was developed to crop the data for those particular time intervals for each drive.

3. Analysis and Results

After collecting all the required data from the selected participants, the data were then compiled and statistically analyzed. A two-factor repeated measures ANOVA model (2 levels of drive type X 3 levels of participant type) was used for the simulator-based analysis. A one-way ANOVA model was applied for all instrumented-vehicle-based analysis (participant type). All the ANOVA analyses were conducted at 5% (α=0.05) significance level. Kolmogorov-Smirnov test was performed to test the normality for each set of measured variables at 5% significance level. Violation of normality assumption was not observed for any data set. No major violation of homogeneity of variance assumption was observed. SAS software (version 9.3) was used for all the statistical analyses. The results of the analyses and the corresponding findings are given below.

3.1 Simulator-based Analysis

Gaze Rotation. No statistically significant effect of simulator drive type (different field of view, resolution, contrast) or participant group type was found for any response variables of left and right eye gaze rotation on any of the four driving scenarios. Simulator drive type-participation interaction was also not observed. However, significant group
effect, in terms of eye gaze rotation at y-axis (vertical), was found only for the “curve stop ahead” scenario (F (2, 12) = 4.22, p=0.04) in the second drive. Post-hoc test (Bonferroni) further confirmed significant difference in mean values of left eye vertical gaze rotation between “early licensed teen” and “experienced” group. This can also be inferred from the Figure 5 that depicts the mean values of left eye vertical gaze rotation of the participants at ‘curved stop ahead’ scenario while driving in the simulator.

**Velocity.** Apart from the “mid-block crosswalk” scenario, all the p-values for the other three scenarios were found to be greater than the preferred significance level (0.05). This indicates no significant main effect of the two factors for all those scenarios. Drive type and participant group interaction was not evident for any scenario. However, for the “mid-block crosswalk” both the simulator drive type (F (1, 12) = 8.26, p=0.01) and participant group (F (2,12) = 6.44, p=0.013) had significant main effects. It was observed that while driving in the simulator, on an average, the participants drove much faster in the second drive than the first one (Figure 6). This was expected as the participants became more familiar with the simulator from their experience of driving during the first drive. It was observed from the data that the “experienced” group drove (average 6.85 mph) relatively slower than the other two groups, whereas the “novice teen” group was faster (average 7.88 mph) while driving in the simulator.

**Brake Force.** For the variable brake, no significant participant group or drive type effect was found. However, on average the “novice teen” group applied relatively more brake force (average 7.3 N) than the other two groups and the “early licensed teen” group applied the least (average 6.16 N).

**Accelerator Pedal Angle (Throttle).** No significant simulator drive type effect was found on the observations from accelerator pedal angle applied by the participants. Participant group effect and participant drive type interaction was also not evident for any of the scenarios.

**Lane Deviation (Lane Offset).** Significant main effect of the simulator drive type was found only in the “left-turning truck” scenario (F (1, 12) =9.27, p=0.01). No group effect was observed for any other scenarios. However, from the distribution of the mean values, it was found that the mean lane offset for all drivers was greater in the first drive (-0.55 m, negative number indicates vehicle position was 0.55 m far on the left side from the center of the lane) than the second one (-0.26 m). This is also evident in the Figure 7, which represents the mean values of the observed lane offset from the center of the lane, yielded by the different participant groups during driving in the simulator. It can be inferred from the Figure 7 that the drivers were driving much closer to the center of the lane while driving the second time, indicating better control of the vehicle [23].

**Acceleration (Longitudinal, Lateral).** Participant group effect was found only in the “left-turning truck” scenario (F (2, 12) = 4.21, p=0.04). This is also apparent in the Figure 8 which shows the mean values of the longitudinal accelerations (negative sign indicates deceleration) applied by the different groups of participants at two driving sessions in the simulator. No simulator drive type or participant group - simulator drive type interaction effect was found. However, a Bonferroni t-test revealed that the mean longitudinal acceleration value (for both simulator
drives) differed significantly between the participant group “early licensed teen” (-0.053 m/s²) and “experienced” group (-0.21 m/s²), which indicates that in the “left-turning truck” scenario the experienced group reduced speed, on an average, much more than the “early licensed teen” group. For the “novice teen” group the mean longitudinal acceleration was -0.15 m/s², which is closer to the value observed for the “experienced” group. Thus, it can be inferred that the “novice teen” and “experienced” drivers were exhibiting more cautious behavior in the “left-turning truck” scenario than the “early licensed teen” group. For lateral acceleration, no significant main effect of drive type or participant group was found.

### 3.2 Instrumented Vehicle Analysis

For analysis, the focus was to investigate whether any significant participant group variability exists on the different response variables under the four hazard scenarios while driving in the real world.

#### Gaze Direction

No significant main effects were found for the left or right gaze direction except for the right gaze direction at x-axis (horizontal) for “curve stop ahead” scenario (F(2, 11) = 4.53, p=0.04). Figure 9 depicts the mean values of right eye horizontal gaze direction of the three participant groups. It is evident from the Figure 9 that the participant group “early licensed teen” significantly differ from the “experienced” and “novice teen” group in terms of the horizontal right gaze direction.

#### Velocity

For the variable velocity participant group effect was found only in the “mid-block cross walk” scenario (F(2, 11) = 4.16, p=0.04). From the Bonferroni t-test it was observed that the participant group “novice teen” drove significantly faster, on average 25.9 mph, in the “mid-block cross walk” scenario than the other two groups. “Early

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**Figure 7:** Mean values of lane offset at ‘Left Turning Truck’ simulator scenario

**Figure 8:** Mean values of longitudinal acceleration at ‘Left Turning Truck’ simulator scenario

**Figure 9:** Mean values of right eye horizontal gaze direction at ‘Curve Stop Ahead’ on-road scenario

**Figure 10:** Mean values of vehicle velocity at ‘Mid-block Crosswalk’ on-road scenario
licensed teen” drivers drove the slowest. This is apparent as well in the Figure 10, which shows the mean values of the vehicle speed of the participant groups while driving on road at the “mid-block cross walk” scenario.

**Brake force and Throttle.** No significant participant group effect was observed for these variables at any scenario.

4. **Discussion.**

It was expected that the different driving conditions (contrast, resolution and field of view) in the simulator might have an effect on the participant’s eye-gaze-related responses in terms of variable left and right eye gaze rotation [14,15]. However, the results of the analyses of these variables revealed no statistically significant effects of those different driving conditions. This implies that all the participants responded with similar eye movement patterns while driving under different resolution, contrast and field of view conditions in the simulator. Similarly, it was expected that participant’s eye movement would vary remarkably among different participant groups. But the results showed significant differences only for the “curved stop ahead” scenario during the second drive, for the variable left eye gaze rotation at y-axis (vertical), between participant groups “experienced” and “early licensed teen.”

In the real world driving, different eye movement patterns were also expected among the three participant groups. However, based on the analyses, statistically significant differences were found between the participant groups “experienced” and “early licensed teen” at the “curved stop ahead” scenario only for variable right eye horizontal gaze direction. As considerable difference was also found between participant groups, “experienced” and “early licensed teen”, while driving in the simulator under scenario “curved stop ahead”, these two groups might be considered as the potential source of variability for the eye-movement-related behavior.

As far as vehicle control behavior is concerned, it was found that different participant groups behaved differently in terms of variable velocity and braking, while driving in the simulator, only in the scenario “mid-block cross walk.” The participant group “experienced” applied more brake force than the “early licensed teen” group. This indicates that the “experienced” driver group was showing more cautious behavior than the other two groups [23]. In this regard “novice teen” drivers were showing better cautious behavior than the “early licensed” group. However, it was observed that, on an average, “novice teen” drivers drove faster than the other two groups in both the real world and the simulator in the “mid-block cross walk” scenario, whereas “experienced” group drivers were the slowest. This indicates that the participant “novice teen” group behaved in the same way while driving in the simulator and in the real world. Although the participant group “experienced” drove slower than the group “novice teen” in the real world in the “mid-block cross walk” scenario, they drove for a relatively longer duration at a speed over 25 mph than the “novice teen” group under the scenario “curved stop ahead,” which might indicate the confidence gained from driving experience among the “experienced” drivers. No statistically significant difference was found among the participant groups in terms of the variables brake force and throttle control while driving in the real world.

Further analyses also revealed that while driving in the simulator, the “experienced” participant group showed significantly different lateral acceleration and throttle control from the “early licensed teen” group in the “hidden crosswalk” scenario and for the variable longitudinal acceleration at “left-turning truck” scenario. This indicates that the experienced group may be exhibiting safer driving behavior than the early licensed teen drivers [23].

While several previous studies manifested significant differences between the “novice teen” and “experienced” drivers [5, 7, 8, and 11], in this study most of the differences observed were mainly between the “early licensed teen” and “experienced” driver group. This is in line with the finding from another recent study conducted by Klauer et al. [25]. The study concluded that at the beginning stage of driving, novice teen drivers are typically cautious as the experienced drivers. Over time, the more the teens grow in confidence through getting accustomed to driving, the more they get themselves engaged in secondary tasks and thereby exhibit different driving approach than their experienced counterpart [25].

5. **Conclusion**

It was expected from the results of the analyses that novice teen and young drivers would exhibit considerably different vehicle and eye movement behavior than their experienced counterparts [1, 12-16]. Although the analyses revealed some statistically significant differences among the three participant groups at some scenarios, it was not as much as assumed. This is probably due to the small sample size of participants (15 participants) used in the study. Overall, the present findings from the study suggest considerable behavioral differences among novice teen, early
licensed teen and the experience adult drivers, suggesting a need for further analysis with a greater number of observations. It is hoped that this would provide more contrasts in the driving behavior of the different participant groups within or between the driving platforms under different hazard scenarios.

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References


