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Are Driving Simulators Effective Tools for Evaluating Novice Drivers' Hazard Anticipation, Speed Management, and Attention Maintenance Skills

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Abstract

Novice drivers (teen drivers with their solo license for six months or less) are at a greatly inflated risk of crashing. Post hoc analyses of police accident reports indicate that novice drivers fail to anticipate hazards, manage their speed, and maintain attention. These skills are much too broadly defined to be of much help in training. Recently, however, driving simulators have been used to identify those skills which differentiate the novice drivers from older, more experienced drivers in the areas of hazard anticipation and speed management. Below, we report an experiment on a driving simulator which compares novice and experienced drivers' performance in the third area believed to contribute especially heavily to crashes among novice drivers: attention to the forward roadway. The results indicate that novice drivers are much more willing to glance for long periods of time inside the vehicle than are experienced drivers. Interestingly, the results also indicate that both novice and experienced drivers spend equal amounts of time glancing at tasks external to the vehicle and in the periphery. Moreover, just as a program has been designed to train the scanning skills that clearly differentiate novice from experienced drivers, one might hope that a training program could be designed to improve the attention maintenance skills of novice drivers. We report on the initial piloting of just such a training program. Finally, we address a question that has long been debated in the literature: Do the results from driving simulators generalize to the real world? We argue that in the case of hazard anticipation, speed management, and attention maintenance the answer is yes.

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Keywords

Driving Simulation; Novice Drivers; Eye Movements; Attention Maintenance; Distraction; Hazard Anticipation; Speed Management

1. Introduction

The crash risk for younger, newly-licensed drivers (teen drivers with a solo license for six months or less) decreases radically over the first six months (McCartt, Shabanova, and Leaf, 2003; Mayhew, Simpson and Pak, 2003; Vlakveld and Twisk, 2005). It has been argued from police crash reports (McKnight and McKnight, 2003) and related crash statistics (Braitman, Kirley, McCartt and Chaudry, 2008) that the crashes were due largely to failures to scan the roadway ahead, failures to manage speed, and failures to maintain attention. Admittedly, experienced drivers who get into crashes also fail to scan the roadway, manage their speed and maintain attention. However, it is likely that newly-licensed drivers experience at least some of these failures more often than experienced drivers. Thus, it is important to discover which failures are particularly characteristic of newly-licensed drivers in order to determine why the crash rate is so much higher for newly-licensed drivers.

Recent work on a driving simulator points more precisely to the differences between novice and experienced drivers. First, in the area of scanning, it is known that novice drivers fail to anticipate hidden or latent hazards as well as do more experienced drivers (Pollatsek, Fisher, and Pradhan, 2006; Pradhan, Hammel, DeRamus, Pollatsek, Noyce and Fisher, 2005; Borowsky, Shinar and Oron-Gilad, 2007). For example, imagine that a truck is parked in front of a marked midblock crosswalk. Drivers approaching the truck should scan to the right for pedestrians who might be in the crosswalk and obscured by the truck. In fact, experienced drivers were almost six times as likely to look to the right for a potential pedestrian as novice drivers (Pradhan et al., 2005). This difference is consistent with findings on the open road (for a recent review see Shinar, 2008). Specifically, young drivers: a) scan less broadly from side to side, especially when changing lanes (Mourant & Rockwell, 1972); b) have, on average, less widely spaced eye movements as measured along the horizontal axis (Crundall & Underwood, 1998); and c) are less likely to make consecutive fixations on objects in the periphery (Underwood, Chapman, Brocklehurst, Underwood & Crundall, 2003).

Second, in the area of speed management, it is known that novice drivers are more likely to fail to respond appropriately to traffic signs and road geometries which require them to manage their speed. For example, in one study on a driving simulator, a scenario was included where the road curved to the right (Fisher, Laurie, Glaser, Connerney, Pollatsek, Duffy and Brock, 2002). A stop sign at the end of the one-tenth mile curve was obscured by bushes and the curved road. A ‘stop ahead’ sign appeared just before the curve. The novice drivers braked much harder on average just before the stop sign than did the experienced drivers indicating that they had failed to reduce their speed appropriately in response to either the ‘stop ahead’ sign or road geometry.

In summary, in at least two of the three areas where novice drivers are likely to crash, much more is now known about the exact set of behaviors which discriminate the novice from the experienced driver based on simulator studies of driver behavior. The question addressed here is whether the third area, attention maintenance, can be evaluated in driving simulators as well. There is reason specifically and in general to believe that such might not be the case. A quote from the well regarded book, *Traffic Safety*, indicates the problem:

> Enthusiasm for driving simulators ignores some of the most basic understanding about the nature of traffic crashes…. Simulators measure *driving performance*, what the driver *can do*. However, safety is determined primarily by *driver behavior* or what a driver *chooses to do*. It is exceedingly unlikely that a driving simulator can provide useful information on a driver's tendency to speed, drive while intoxicated, run red lights, pay attention to non-driving distractions, or not fasten a safety belt. Twenty-year-olds perform nearly all tasks on simulators better than the 50-year-olds, but it is the 50-year-olds who have sharply lower crash risks (Evans, 2004, pg. 188).

In general, one needs to take seriously the claim that driving simulators measure performance rather than behavior, as defined above. Thus, novice drivers may outperform experienced drivers in a simulator, but not on the open road. Interestingly, we saw that this was not true for two of the three critical areas in which novice drivers are especially likely to be involved in crashes: hazard anticipation and speed management. The question is whether this is true of the third area, attention maintenance.

Here it is less clear what the answer will be. With both hazard anticipation and speed management, knowledge and experience are a large component of what goes into making a driver skillful. Thus, in retrospect, it may not be surprising that novice drivers behaved in the simulator more poorly than did experienced drivers. However, with failures of attention maintenance, especially when that is defined as glances away from the forward roadway inside the vehicle, presumably novice drivers are as aware that they cannot see the road ahead as are experienced drivers. Although this does not appear to be the case in the field (e.g., Wikman, Nieminen and Summala., 1998), it may be the case in a driving simulator. In the field study, there was an instructor in the car. Novice drivers may have trusted the instructor to warn them of any potential problems (as is typically the case in driver's education programs). However, in the simulator there is no instructor. Thus, we may find that novice drivers perform as well as experienced drivers at limiting the duration of glances inside the vehicle, in which case driving simulators would not be a good way to assess attention maintenance skills. Therefore, in order to know whether a driving simulator can be used to differentiate novice and experienced drivers' willingness to maintain attention to the forward roadway one needs to run an experiment. We report such an experiment below.

The importance of maintaining attention to the forward roadway has long been recognized as a major contributor to automobile crashes among all drivers (Wang, Knipling, and Goodman, 1996). However, there is now a growing body of research indicating that this is a particular problem among novice drivers. The evidence that distraction poses a significant problem for novice drivers comes from many different sources, including police crash reports (Braitman et al., 2008; McKnight and McKnight, 2003; Wang, Knipling and Goodman, 1996), naturalistic studies (Klauer, Dingus, Neale, Sudweeks, and Ramsey, 2006), field experiments (Wikman, Nieminen and Summala, 1998; Lee, Olsen and Simons-Morton, 2006), simulator studies (Greenberg, Tijerina, Curry, Artz, Cathey, Grant, Kochhar, Kozak, and Blommer, 2003), and surveys of novice drivers (Olsen, Lerner, Perel and Simons-Morton, 2005). Furthermore, the magnitude of the problem will likely increase because of the growing popularity of in-vehicle tasks that require the driver to glance away from the forward roadway – most notably text messaging with cell phones (Lerner and Boyd, 2004; Strayer, Drews and Crouch, 2003) and in-vehicle music retrieval systems (Garay-Vega et al., in press). The problem may also increase because of recent changes in the environment, such as digital billboards that present information that may attract drivers' eyes away from the forward roadway for extended periods of time (Beijer, Smiley, and Eizenman, 2004; Smiley, Smahel, and Eizenman, 2004; Wallace, 2003).

In summary, the primary question we ask in the experiment described below is whether the critical factor discriminating the attention maintenance skills of the novice and experienced drivers on a driving simulator is the relative length of the glance durations to objects inside the vehicle. We know from field (Klauer et al., 2006) and simulator (Horrey and Wickens, 2006) studies that especially long glances inside the vehicle are more likely to lead to crashes. For example, in the simulator study reported by Horrey and Wickens (2007), glances 1.6 s or longer inside the vehicle, while constituting only a relatively small fraction of the total glances (22%), were responsible for the great majority of crashes (86%). We also know from field studies that novice drivers are much more likely to glance for extended periods of time inside the vehicle than are experienced drivers (Wikman, Nieminen & Summala, 1998). But as described above, we do not know whether this will be true in a driving simulator as well, something we need to know if we are going to use simulators to evaluate the different in-vehicle glance behaviors of novice and experienced drivers. (The one simulator study of driver distraction, Greenberg et al., 2003, used event detection, not eye movements as the dependent variable; we are interested in the possible underlying cause of the increased distraction, in particular the possibility that novice drivers are simply spending more time with their eyes away from the forward roadway.)

As indicated above, a distinctive feature of glances inside the vehicle is that it is clear to the drivers that they are not processing the roadway when their glance is such that little or none of the roadway is in their visual field. However, this is less clear for extended glances at objects to the side of the road such as billboards, highway signs, and other built and natural features of the environment. Drivers can see in the periphery of their forward vision enough of the roadway ahead to maintain their lane position (Summala, Nieminen and Punto, 1996), but only experience can tell them that this information is poor enough so that they are less likely to detect a vehicle that is stopping suddenly (Lamble, Laakso and Summala, 1999). Thus, if experience is a major determining factor in recognizing whether an extended glance away from the forward roadway is dangerous, one might almost expect a greater difference between novice and experienced drivers in extended glances at objects outside the vehicle than at objects inside the vehicle. Therefore, the second question of interest in the current study is whether differences between novice and experienced drivers are the same when the distraction is a stimulus inside the vehicle and when the distraction is coming from outside the vehicle.

2. Method

We asked newly-licensed and experienced drivers to perform various distracting tasks that were located either inside or outside the vehicle while navigating through a virtual world. (Tasks in which the stimulus to be attended to is inside the vehicle will be referred to as *in-vehicle tasks* and tasks in which the stimulus to be attended to is outside the vehicle will be referred to as *out-of-vehicle tasks*.) The participants' eyes were tracked throughout each drive.

2.1 Participants

There were two groups of participants: (a) the *newly licensed* drivers, who were between 16 and 18 years old and had a learner's permit or a driving license for less than six months; and (b) the *experienced* drivers who were 21 years old or older and had at least five years of driving experience in the United States. Each group of 12 participants had six men and six women. They were recruited from the student body of the University of Massachusetts at Amherst and the town of Amherst. The mean ages of the newly-licensed group and the experienced group were 16.8 and 23.9 years, respectively, with respective standard deviations of 0.6 and 3.8. Due to difficulties with eye tracker calibration for participants wearing eye-glasses, all participants either had normal vision or vision corrected to normal

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with contact lenses and were screened for (possibly corrected) 20/20 vision prior to the experiment using a visual acuity test.

2.2 Experimental Design

The virtual environment through which participants drove was a single visual database that included both city and rural sections. The city section (2.7 miles) contained city blocks with four lane city streets and multiple four way signalized intersections. The rural section (2.3 miles) contained an extended, slightly curved section of two-lane roadway. The environment was populated with pseudo randomly occurring traffic including parked vehicles.

There were a total of 23 distraction tasks during the experiment: 18 out-of-vehicle and 5 in-vehicle tasks. In each out-of-vehicle task, the participant was instructed to search for and indicate the presence or absence of a target letter in a 5×5 letter grid superimposed on a simulated 10 foot wide by 10 foot high display that was positioned 8 feet from the left or right hand edge of the street. Each display became visible exactly 350 feet before the driver encountered the sign (at the very beginning of a city block). At that point, the display subtended approximately 1.6 degrees of visual angle and its center was off to the side 5.1 degrees from the driver's point of view. If drivers were traveling at the posted speed limit (30 mph) the letters in the display would have been visible for 7.95 seconds. The target letters were P, E or X. Many of the distractors in a display had the same visual shape as the target letters (e.g., when P was the target, C, B, D, O, Q and R were the distractors; and so on) to reduce the salience of the target letter if it was present in a grid. A target letter was present in 6 grids; no target letter was present in the remaining 12. The letters were in Ariel font and were in black on a white background. The present and absent trials were intermixed throughout the experiment.

The five in-vehicle tasks consisted of two CD search tasks, two map search tasks, and a phone-dialing task. The CD search tasks required the driver to search for a target CD from 12 CDs in a CD case; in one case the target CD was present and in the other it was absent.

Similarly, the map search tasks required the driver to search for a target street name from a map that was provided; in one the target street name was present and in the other it was absent. The other in-vehicle task was a phone-dialing task, where the participant was instructed to dial a number that was provided in the vehicle on a sheet of paper using a cellular phone. The cell phone, the CD case and the piece of paper that had the phone number on it were all located next to the driver on the passenger seat. The participants were instructed to pick up the relevant item when asked to do so by experimenter.

2.3 Apparatus

2.3.1 Driving Simulator—The driving simulator setup consists of a fully equipped 1995 Saturn sedan placed in front of three screens subtending 135 degrees horizontally. The virtual environment was projected on each screen at a resolution of 1024 × 768 pixels and at a frequency of 60 Hz (see www.ecs.umass.edu/hpl for a more detailed description). The participant sat in the car and operated the controls, moving through the virtual world according to his or her inputs to the car. The audio was controlled by a separate system which consisted of two mid/high frequency speakers located on the left and right sides of the car and two sub-woofers located under the hood of the car. This system provides realistic road, wind and other vehicle noises with appropriate direction, intensity, and Doppler shift.

2.3.2 Eye Tracker—A portable lightweight eye tracker (Mobile Eye developed by Applied Science Laboratories) was used to collect the eye-movement data for each driver. It has a lightweight optical system consisting of an eye camera and a color scene camera mounted on a pair of safety goggles. The images from these two cameras are interleaved and recorded on a remote recording system, thus ensuring no loss of resolution. The interleaved video can then be transferred to a PC where the images are separated and processed. The eye movement data are converted to a crosshair, representing the driver's point of gaze, which is superimposed upon the scene video recorded during the drive. This provides a record of the driver's point of gaze on the driving scene while in the simulator. The remote recording system is battery powered and is capable of recording up to 90 minutes of eye and scene information at 60Hz in a single trial.

2.4 Procedure

After the initial screening and paperwork, the participants memorized the three target letters. The participant was then fitted with the head-mounted eye tracker which was calibrated within the simulator. After calibration, participants were given a practice drive to familiarize them with the driving simulator. The practice drive also included four examples of the out-of-vehicle distraction tasks. During the experimental drive, the participant followed a lead vehicle and was instructed to maintain a 3-second headway. The speed limit for the city streets was 30 mph and for the rural roads was 55 mph. As noted above, the grids for the out-of-vehicle tasks were timed to appear such that they would be visible to the participant for approximately 8.0 s when driving at 30 mph. The experimenter verbally indicated the onset of the in-vehicle tasks for each participant. This was timed so that the participant, when driving at the posted speed limit, would get approximately 14 seconds to complete the task before reaching an intersection. However, because the drivers sometimes drove more slowly during the in-vehicle tasks, the average time that each driver had to complete such tasks was 16.6 seconds.

3. Results

Given that glances away from the roadway of more than 2 seconds have been implicated as a major contributor to crashes, one wants a dependent variable that reflects the extent to which a single glance is away from the roadway for an extended period of time. By *glance* duration, we do not mean the duration of a single *fixation*. Instead, the duration of a glance is the period of time in which the eyes are pointing at a predefined area. For the in-car tasks, the duration of a glance inside the vehicle was set equal to the interval of time measured from when the eyes were first directed inside the vehicle to when the eyes returned to the forward roadway. Similarly, for the out-of-vehicle task, the duration of a glance was set equal to the period of time during which the eyes were fixating anywhere on the grid of letters.

One doesn't want to rely on just one measure because any particular measure may miss something; however, as will be seen below, an almost identical pattern emerged using a variety of different measures. For convenience, we will use the term *scenario* to refer to the interval between when the beginning of a particular distraction task was signaled until either (a) when the task was completed or (b) when the experimenter signaled the participant to complete it. One measure was the average *maximum duration* of a *glance* (i.e., the maximum time that the drivers spent continuously looking away from the forward roadway) during a scenario (our motivation for using such a measure comes, as discussed above, from the results of Klauer et al., 2006, and Horrey and Wickens, 2007). Three other measures were used to capture the distribution of glance durations: the probability during a scenario (a) that there is a glance over 2 s, (b) that there is a glance over 2.5 s, and (c) that there is a glance is over 3 s. Of course, these measures are not independent; however, we will typically report them all to indicate that our conclusions do not rest on a single, arbitrary measure. Finally we looked at the average total time drivers spent with their eyes off the road in each of the in-vehicle and out-of-vehicle scenarios. All five measures (average glance duration, total time with eyes off road, and the probability that the maximum glance in a scenario was longer than 2.0, 2.5 and 3.0 s) were averaged over the scenarios within a class of scenarios (in-vehicle or out-of-vehicle).

3.1 In-vehicle task behavior

Somewhat surprisingly, the absence of an instructor inside the driving simulator did not make novice drivers any more cautious than they were in the field when an instructor was present. In particular, there were large differences between the experienced and newly-licensed drivers in extended glances away from the forward roadway towards tasks inside the vehicle. The average maximum glance durations in a scenario were 1.63 s and 2.76 s for the experienced and newly-licensed drivers, respectively, $t(22)=3.57$, $p<.002$ (SE = .32 s). The pattern is similar for the other three related measures (see Figure 1). Experienced drivers had at least one glance inside the vehicle greater than 2 s in 20.0% of the scenarios, whereas newly licensed drivers had a glance greater than 2 s in 56.7% of the scenarios, $t(22) = 3.87$, $p < .001$ (SE = 9.5%). Similarly, for the 2.5 s and 3 s cutoffs, the respective values for the experienced and newly-licensed drivers were 10.0% vs. 45.0%, $t(22) = 3.72$, $p < .002$ (SE = 9.4%) and 6.7% vs. 33.3%, $t(22) = 3.17$, $p < .005$, (SE = 8.4%). Finally, although the total time that the experienced drivers spent with their eyes off the road for the in-vehicle tasks (5.80 s) was appreciably shorter than for newly-licensed drivers (7.36 s), this difference was not significant, $t(22)=1.49$, $p=0.075$ (SE = 1.05 s). Thus, the major difference between the groups was not so much the total time that their eyes were off the road but how they distributed it. Moreover, as illustrated by the 2 s data in Figure 2, the results for these three measures were also quite consistent across scenarios, $t(4) = 6.33$, 5.25, and 3.67, *p*s < .01, .01, and .05, for the percent greater than 2, 2.5, and 3 s data, respectively.

3.2 Out-of-vehicle task behavior

The pattern of data, however, was quite different for the out-of-vehicle tasks as there was little difference between the groups in how they scheduled their glances away from the forward roadway (see Figure 3). The average maximum glances in a scenario were 3.42 s for the experienced drivers and 3.75 s for the newly-licensed drivers, $t(22)=1.12$, $p >.20$ (SE = 0.29 s). The story is similar when one looks at the percent of scenarios in which the maximum glance was over 2 s, 2.5 s, and 3 s. The values for the experienced and newly-licensed drivers were, respectively: 2 s – 81.0% vs. 81.9%; 2.5 s – 65.3% vs. 71.3%; 3 s – 56.9% vs. 58.5%, all *t*s(22)<1 (SEs = 4.9%, 6.9%, 8.0%, respectively). There was also virtually no difference in the total time that the two groups of drivers spent with their eyes off the road in the out-of-vehicle tasks (experienced 4.29 s, newly-licensed 4.34 s), t(22)<1.

3.3 In-vehicle and out-of-vehicle behavior compared

An overall comparison of the driver performance on in-vehicle versus out-of-vehicle tasks was undertaken to determine the extent to which each of these potential distractions impacts driver performance. First, the average maximum glance durations in a scenario were much longer for the out-of-vehicle tasks than for the in-vehicle tasks (3.54 s, vs. 2.20 s), $t(22)=3.00$, $p<.001$; the differences in percentages over the 2s, 2.5s, and 3s cutoffs were all more than 40% greater for the out-of-vehicle tasks than the in-vehicle tasks, $t(22)$s > 6, *p*s < .001 (compare Figure 1 and Figure 3). Second, although the interaction between in-vehicle vs. out-of-vehicle and driver group was not significant for the maximum glance duration measure, $t(22)=1.56$, $p<.20$, it was clearly significant for the probability of exceeding the 2s, 2.5s, and 3s cutoffs, *t*s(22) = 3.10, 2.18, 2.14, *p*s < .01, .05, .05, respectively[1].

[1]We have reported the main effects of in-vehicle vs. out-of-vehicle task and the interaction of this with group as t-tests rather than F-tests in the usual analysis of variance format. However, they are logically equivalent to those tests and we prefer using the t-test format, as it makes the error variance of the test more comprehensible.

Another striking difference between the in-vehicle and out-of-vehicle distraction tasks was the relationship between the maximum duration of glances and both the total elapsed time of the whole scenario and the total time that the driver's eyes were off of the forward roadway. Specifically, the average total elapsed time of a scenario for the in-vehicle tasks (15.81 s and 17.56s for the experienced and newly-licensed drivers, respectively) was about double that for the out-of-vehicle tasks (7.82s and 8.26s for the respective groups). There was a different pattern, however, for the total time that drivers' eyes were off the forward roadway during a scenario. It was 5.84 s vs. 7.36 s for the in-vehicle tasks, and 4.29 s vs. 4.35 s for the out-of-vehicle tasks (for the experienced and newly-licensed drivers, respectively). Thus, the maximum glance durations in the in-vehicle tasks were only 10.3% and 15.7% of the total scenario duration for the experienced and newly-licensed drivers, respectively, but were 43.6% and 44.5% for the out-of-vehicle tasks, $t(11) = 13.98, 5.92$, ps $< .001$. Similarly, the maximum glance durations were only 27.9% and 37.5% of the total time looking away from the forward roadway in the in-vehicle tasks for the experienced and newly-licensed drivers, respectively, but were 79.6% and 84.4% for the out-of-vehicle tasks, $t(11) = 24.27, 12.72$, ps $< .001$. These data indicate that there was little apportionment of glances for either group in the out-of vehicle tasks; perhaps the difference between the maximum glance durations and total duration of the looks away from the forward roadway was due to an occasional second look at the sign to double-check the answer.

In contrast, for both groups, the maximum glance durations for the in-vehicle tasks were far less than the total looks off the road and seem to indicate an awareness on the part of the drivers that they couldn't look away too long; instead, the difference between the two groups appears to be a difference in judging "how long is too long?".

3.4 Speed

A final question that should be addressed is whether vehicle speed differences either between groups or between in-vehicle and out-of-vehicle tasks could have produced any of the differences we observed above. For example, if one group was going much slower than the other, longer looks inside the vehicle might appear as safe because less distance was being traveled during any one glance. However, we think that there is no significant confounding. First, although the experienced drivers had a slightly higher average speed than the novice drivers during the scenarios (30.2 mph vs. 28.4 mph), the difference was far from significant, $t(22) = 1.29$, $p > .20$ (SE = 1.40 mph). Thus, we think it is unlikely that experienced drivers spent less time looking inside the vehicle because they were going slightly under two miles per hour faster on average Second, average speeds were significantly higher in the out-of-vehicle scenarios (30.8 mph) than in the in-vehicle scenarios (27.9 mph), $t(22) = 2.97$, $p < .01$ (SE = 1.0 mph), which likely reflects the fact that the roadway was not completely hidden from view in the out-of-vehicle scenarios. However, it is hard to see how such a difference could have caused novice and experienced drivers to behave similarly in the out-of-vehicle tasks, but so very differently in the in-vehicle tasks. Moreover, there was virtually no interaction of driver group with in-vehicle vs. out-of-vehicle task on speed during a scenario, $|t| < .6$.

4. Discussion

A number of researchers have questioned the use of driving simulators as a tool for discovering how drivers actually behave on the roadway, as opposed to how well they can potentially perform (Evans, 2004). We noted that simulators do capture behavioral differences between novice and experienced drivers in the critical areas of hazard anticipation and speed management. We wondered whether driving simulators would be able to capture as well the differences between the way novice and experienced drivers maintain attention to the forward roadway.

4.1 In-Vehicle Distractions

First, consider distractions inside the vehicle. Field studies (e.g., Wikman et al., 1998) indicate that older teen drivers are more likely to glance continuously at an in-vehicle task for long periods of time than experienced drivers – at least when an instructor is in the car. We noted that in the simulator – where an instructor is not present – novice drivers might be less willing to glance away from the forward roadway because of the obvious threat it presents. However, this was not the case. Our experiment clearly indicates that newly-licensed drivers are more willing to glance for long periods of time inside the simulator than are experienced drivers. Specifically, the newly-licensed drivers looked for two seconds or longer during more than twice as many in-vehicle tasks as did older drivers and the difference between the percentage of scenarios in which younger and older drivers had glances in the vehicle at least two seconds long did not change greatly from one task to another even though the absolute percentages of these long glances varied substantially among the in-vehicle tasks. As the total time older drivers spent looking away from the roadway was not significantly less than for the younger drivers, it seems likely that there is something that the older drivers have learned about scheduling their in-vehicle glances.

Just as it was important to determine whether one can develop a training program that can remediate the large differences in hazard perception skills that separate novice and experienced drivers (the answer is “yes”, e.g., Pollatsek, Narayanaan, Pradhan, and Fisher, 2006), so too is it important to determine whether one can develop a training program that can remediate the large differences in attention maintenance skills that were reported above. In this regard, we have recently developed a PC-based attention maintenance training program (FOCAL, FOrward Concentration and Attention Learning) that can teach this scheduling to inexperienced drivers. In the training, drivers are shown a video of the forward roadway. They are asked to mouse over oncoming traffic, pedestrians and bicyclists as they appear in the video. In addition, they are asked to perform an in-vehicle task that can take anywhere between 10 and 15 seconds to complete. The in-vehicle task is presented on the same screen as the video. The video disappears when the in-vehicle task is displayed, and conversely. We can easily measure how long the in-vehicle task display is visible on the screen. We first train participants to schedule looks at the in-vehicle task that are no longer than three seconds and then train them to schedule looks that are no longer than two seconds. FOCAL has now been evaluated using a PC-based attention maintenance assessment program (AMAP) before and after training (Pradhan, Masserang, Divekar, Reagan, Thomas, Blomberg, Pollatsek, and Fisher, 2009). The results are striking (Blomberg, Thomas, Reagan, Fisher, Pollatsek, Pradhan, Romoser, Divekar, and Zafian, in review). For example, before training some 65% of the teen drivers looked away from the forward roadway for more than two seconds. After training, only 8% did such. Of course, it still needs to be determined whether this training generalizes to a driving simulator and ultimately to the open road. Those evaluations are now underway.

The extent to which long in-vehicle glances create problems for newly-licensed drivers depends in part on where the in-vehicle task is located and what the measure is of driving performance. Two studies are relevant here. First, for elementary driving skills such as lane keeping, novice drivers are much more likely to have difficulties while performing an in-vehicle task than experienced drivers, differences which are particularly marked at eccentricities of 23° down from the focus of expansion (speedometer level; Summala, Nieminen, and Punto, 1996). Second, for more difficult perceptual skills such as identifying the onset of a brake light, both novice and experienced drivers have much more difficulty doing such while attending to an in-vehicle task than while attending to the forward roadway at all eccentricities down from the forward roadway (Summala, Lamble, and Laakso, 1998).

Finally, there is a relation we think is worth pointing out between the actual values obtained in the simulator and the actual values obtained on the open road. We mentioned earlier that the Wikman et al. (1998) on-road study of in-vehicle distraction done in Finland found that glance durations of at least 2.5s occurred 46% of the time for inexperienced drivers but only 13% of the time for experienced drivers. These agree remarkably well with our in-vehicle data (45.0% vs. 10.0%). For glance durations of at least 3s, the analogous values were 29% vs. 0% for Wikman et al. (1998) and 33.3% vs. 6.7% for the present study. There are some differences in scoring, so the relation should not be taken too seriously. Nevertheless, the agreement between simulator and on road is not confined to attention maintenance. For example, the on-road data in Pradhan, Pollatsek, Knodler and Fisher (2009) on the effects of training on glances at potentially hazardous areas agreed quite closely with those observed in the simulator by Pollatsek, Narayanaan, Pradhan, and Fisher (2006). Perhaps the absolute agreement is a largely a function of the knowledge that the participants have in all such studies that they are part of an experiment. Certainly, there is no a priori argument one could make that one would find anything but an ordinal agreement in the simulator and field.

4.2 Out-of-Vehicle Distractions

The pattern of behavior in the out-of-vehicle tasks was very different from that observed in the in-vehicle tasks. The results were not as we had expected. We had predicted that novice drivers would perform worse than more experienced drivers in the out-of-vehicle tasks because experienced drivers would realize that being able to see the forward roadway in the periphery of their vision was not a guarantee that they could see vehicles slowing suddenly ahead, whereas novice drivers would not have the requisite experience. However, not only did novice and experienced drivers have a similar distribution of glance durations outside the vehicle, but that distribution was markedly different from the distribution obtained inside the vehicle.

The first and most obvious question arises as to the reason for the very different pattern of behavior in the two types of tasks: relatively short glances in the in-vehicle tasks, many more long glances in the out-of-vehicle tasks for both groups of drivers. Perhaps the question can be somewhat crudely rephrased by asking whether the groups are equally good or equally bad in their looking behavior in the out-of-vehicle tasks. That is, the “equally good” hypothesis would posit that for the out-of-vehicle tasks, unlike the in-vehicle tasks, there is little or no cost of an extended glance looking away from the roadway in front of the vehicle. In contrast, the “equally bad” hypothesis would posit that even experienced drivers haven’t learned to limit the durations of their glances off to the side of the vehicle. This is plausible because there is an illusion of how much visual information can be processed: people are generally unaware of the limitations of how much visual information they can perceive in the periphery when they are neither looking at something directly nor attending to it as long as the information is in the field of view (the examples in the study of inattention blindness are compelling and legion, e.g., Simons and Chabris, 1999). Needless to say, drivers in the in-vehicle tasks would not have such an illusion; they know that they are not processing information about the roadway. Although there is some evidence indicating that experienced drivers are somewhat better at processing events in the periphery than novice drivers (Summala, Nieminen, and Punto, 1996), this is limited to lane keeping and does not include critical information on braking of the lead vehicle (Summala, Lamble, and Laakso, 1998). The evidence below indicates that drawing the fixation point away from a region (and likely covert attention as well) has a markedly detrimental effect on performance for all drivers.

We think that the more likely answer is that both groups “equally bad” in the out-of-vehicle tasks, especially at large eccentricities. First, there are the results from the Klauer et al. (2006) study that show that drivers are 3.7 times more likely to be in a crash when they glance for an extended period of time at something outside the vehicle and away from the forward roadway. Second, it has been shown that a simulated cell-phone task (an auditory task that takes attention but does not require or cause the driver's eyes to leave the roadway) produces significant decrements in the driver's ability to react to stimuli such as sudden braking (Muttart, Fisher, Knodler, and Pollatsek, 2007) or traffic signals (Strayer & Johnston, 2001). The cognitive distraction in our case is the search task itself (not a cell phone task, but it is not clear that the search task is any less demanding cognitively than a cell phone task). Third, there is the abundant data indicating that perception of areas not fixated or attended to is severely compromised (Henderson and Hollingworth, 1999; see also Hollingworth & Henderson, 2002; Mack & Rock, 1998). Finally, the evidence in the studies reported by Summala et al. (1996, 1998) and Lamble et al. (1998) on the effect of in-vehicle glance durations on lane keeping and brake light detection indicate that performance on both measures is harmed at extreme eccentricities and brake light detection is harmed at all eccentricities, both when fixations are down and to the side. The decrements increase dramatically as the eccentricity of the information increases. (We realize that acuity drops off much quicker in the vertical direction than the horizontal direction.) Thus, we think it is likely that our out-of-vehicle tasks (which not only engage attention but also draw the eyes and visual attention away from in front of the vehicle) would generally have quite significant detrimental effects on processing the roadway in front of the vehicle for glances that are far off to the side. As a result, a training program for all drivers may be needed that makes them aware of how long out-of-vehicle glances can safely be and that their processing of the road ahead is compromised during these glances in some tasks (e.g., brake light detection) even though it may not be seriously compromised in others (e.g., lane keeping), a point consistent with much earlier work by Leibowitz and Owen (1977) on nighttime driving skills.

The second question which arises concerns generalization. Specifically, just as there are limitations with generalizing from the in-vehicle results on the driving simulator to the field, there are limitations on generalizing from the out-of-vehicle results on the driving simulator to the field. A billboard or external display which required overlong glances in the driving simulator might not require overlong glances in the real world. Since we did not test particular billboards, our only claim is that billboards in the field that require reading times much longer than 2 s present potential problems, especially when they are located far into the periphery.

The third question we need to address is why the experienced drivers did not differ from the novice drivers in their pattern of out-of-vehicle glance durations. The answer is implicit in what we wrote above. In particular, we expected experienced drivers to keep their glances durations relatively short when looking at objects outside the vehicle. On the basis of our results, we would speculate that the fact that they did not do so is a function both of the illusion that information in the periphery is much greater than is actually the case and of their successful experience of driving while glancing to the side. The experience is a successful one because information in the periphery is sufficient to keep within the lane markers and because it is only infrequently that vehicles stop suddenly. Thus, in essence experienced drivers have little exposure to the difficulties that their strategies ultimately entail. Given that experienced drivers glanced for long durations to the side, it is hardly surprising that the novice drivers and experienced drivers had similar patterns of glance durations.

4.3 Summary

In summary, driving simulators appear to be useful in differentiating the behaviors of novice and experienced drivers in all three areas in which there are known differences on the open road: hazard anticipation, speed management and attention maintenance. In this article, we focused on attention maintenance because no simulator studies had specifically compared the glance durations of novice and experienced drivers in such tasks. In-vehicle tasks are clearly much more distracting for newly-licensed drivers than they are for experienced drivers, both in the simulator (our study) and on the open road (Wikman et al., 1998). Surprisingly, while out-of-vehicle tasks are even more likely to receive long glances, they are equally likely to receive such for both newly-licensed and experienced drivers. Training programs may potentially address the risky behaviors of the novice drivers, both with in-vehicle (Blomberg et al., under review) and out-of-vehicle tasks. It remains to be seen whether some education is needed for experienced drivers when the task is external to the vehicle. But it is clear that both novice and experienced drivers are at a greatly elevated risk of crashing when they stare as long as they do at an object off to the side of the vehicle (Klauer et al., 2006).

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References

Beijer D, Smiley A, Eizenman M. Observed driver glance behavior at roadside advertising signs. Transportation Research Record 2004;1899:96–103.

Blomberg, R.; Thomas, D.; Reagan, I.; Fisher, DF.; Pollatsek, A.; Pradhan, A.; Romoser, M.; Divekar, G.; Zafian, T.; Pradhan, Anuj. NHTSA technical report. Washington, D.C: Attention maintenance training among newly-licensed drivers: FOCAL (FOcussed Concentration and Attention Learning). (in review)

Borowsky, A.; Shinar, D.; Oron-Gilad, T. Age, Skill and Hazard Perception in Driving. Proceedings of the 4th International Driving Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design; July 9–12; Iowa City: Public Policy Center, University of Iowa; 2007.

Braitman KA, Kirley BB, McCartt AT, Chaudry NK. Crashes of novice teenage drivers: Characteristics and contributing factors. Journal of Safety Research 2008;39:47–54. [PubMed: 18325416]

Crundall DE, Underwood G. Effects of experience and processing demands on visual information acquisition in drivers. Ergonomics 1998;41:448–458.

Evans, L. Traffic Safety. Bloomfield, MI: Science Serving Society; 2004.

Fisher DL, Laurie NE, Glaser R, Connerney K, Pollatsek A, Duffy SA, Brock J. The use of an advanced driving simulator to evaluate the effects of training and experience on drivers' behavior in risky traffic scenarios. Human Factors 2002;44:287–302. [PubMed: 12452274]

Garay-Vega L, Pradhan AK, Weinberg G, Schmidt-Nielsen B, Harsham B, Shen Y, Divekar G, Romoser M, Knodler M, Fisher DL. Evaluation of different voice and touch interfaces to in-vehicle music retrieval systems. Accident Analysis & Prevention. (In press).

Greenberg J, Tijerina L, Curry R, Artz B, Cathey L, Grant P, Kochhar D, Kozak K, Blommer M. Driver distraction: evaluation with an event detection paradigm. Transportation Research Record 2003;1843:1–9.

Henderson JM, Hollingworth A. The role of fixation position in detecting scene changes across saccades. Psychological Science 1999;5:438–443.

Hollingworth A, Henderson JM. Accurate visual memory for previously attended objects in natural scenes. Journal of Experimental Psychology: Human Perception and Performance 2002;28:113–136.

Horrey, WJ.; Wickens, CD. Transportation Research Record, 2018. Transportation Research Board of the National Academies; Washington, D.C: 2007. In-Vehicle Glance Duration Distributions, Tails, and Model of Crash Risk; p. 22-28.

Klauer, SG.; Dingus, TA.; Neale, VL.; Sudweeks, JD.; Ramsey, DJ. The Impact of Driver Inattention On Near-Crash/Crash Risk: An Analysis Using the 100-Car Naturalistic Driving Study Data. Washington, D.C: National Highway Traffic Safety Administration; 2006.

Lamble D, Laakso M, Summala H. Detection thresholds in car following situations and peripheral vision: Implications for positioning of visually demanding in-car displays. Ergonomics 1999;42:807–815.

Lee SE, Olsen ECB, Simons-Morton B. Eyeglance Behavior of Novice Teen and Experienced Adult Drivers. Transportation Research Record 2006;1980:57–64.

Leibowitz HW, Owens DA. Nighttime accidents and selective visual degradation. Science 1977;197:422–423. [PubMed: 17783227]

Lerner, N.; Boyd, S. Report Jointly Funded Under National Highway Safety Administration (Contract DTNH22-99-D-07005, Task Order Number 7) and National Institute of Child Health and Human Development (Contract GS-23F-8144H). Westat, Rockville: MD: 2004. Task Report: *On-Road Study of Willingness to Engage in Distracting Tasks*.

Mack, A.; Rock, I. Inattentional Blindness. Cambridge, MA: MIT Press; 1998.

Mayhew DR, Simpson HM, Pak A. Changes in collision rates among novice drivers during the first months of driving. Accident Analysis and Prevention 2003;35:683–691. [PubMed: 12850069]

McCartt AT, Shabanova VI, Leaf WA. Driving experience, crashes and traffic citations of teenage beginning drivers. Accident Analysis and Prevention 2003;35:311–320. [PubMed: 12643948]

McKnight JA, McKnight SA. Young novice drivers: Careless or clueless. Accident Analysis and Prevention 2003;35:921–925. [PubMed: 12971927]

Mourant RR, Rockwell TH. Strategies of visual search by novice and experienced drivers. Human Factors 1972;14:325–335. [PubMed: 5054829]

Muttart J, Fisher DL, Knodler M, Pollatsek A. Driving Simulator Evaluation of Driver Performance during Hands-Free Cell Phone Operation in a Work Zone: Driving without a Clue. Transportation Research Record 2007;2018:9–14.

Olsen ECB, Lerner N, Perel M, Simons-Morton BG. In-car electronic device use among teens. TRB Annual Meeting CD-ROM. 2005

Pollatsek A, Fisher DL, Pradhan AK. Identifying and Remediating Failures of Selective Attention in Younger Drivers. Current Directions in Psychological Science 2006;15:255–259.

Pollatsek A, Narayanaan V, Pradhan A, Fisher DL. The use of eye movements to evaluate a PC-based risk awareness and perception training (RAPT) program on an advanced driving simulator. Human Factors 2006;48:447–464. [PubMed: 17063961]

Pradhan AK, Pollatsek A, Knodler M, Fisher DL. Can younger drivers be trained to scan for information which will reduce their risk in roadway traffic scenarios that are hard to identify as hazardous? Ergonomics 2009;62:657–673. [PubMed: 19296315]

Pradhan AK, Hammel KR, DeRamus R, Pollatsek A, Noyce DA, Fisher DL. The Use of Eye Movements to Evaluate the Effects of Driver Age on Risk Perception in an Advanced Driving Simulator. Human Factors 2005;47:840–852. [PubMed: 16553070]

Pradhan, A.; Masserang, K.; Divekar, G.; Reagan, I.; Thomas, FD.; Blomberg, R.; Pollatsek, A.; Fisher, DL. Attention Maintenance in Novice Drivers - Assessment and Training. Proceedings of Driving Assessment 2009; Big Sky, Montana. Iowa City: Public Policy Center, University of Iowa; Jun. 2009

Simons DJ, Chabris CC. Gorillas in our midst: Sustained inattentional blindness for dynamic events. Perception 1999;28:1059–1074. [PubMed: 10694957]

Shinar D. Looks Are (Almost) Everything: Where Drivers Look to Get Information. Human Factors 2008;50:380–384. [PubMed: 18689042]

Strayer DL, Johnston WA. Driven to distraction: Dual-task studies of simulated driving and conversing on a cellular phone. Psychological Science 2001;12:462–466. [PubMed: 11760132]

Smiley A, Smahel T, Eizenman M. Impact of video advertising on driver fixation patterns. Transportation Research Record 2004;1899:76–83.

Strayer DL, Drews FA, Crouch DJ. A Comparison of the Cell Phone Driver and the Drunk Driver. Human Factors 2003;48:381–391. [PubMed: 16884056]

Summala H, Nieminen T, Punto M. Maintaining lane position with peripheral vision during in-vehicle tasks. Human Factors 1996;38:442–451.

Summala H, Lamble D, Laakso M. Driving experience and perception of the lead car's braking when looking at in-car targets. Accident Analysis and Prevention 1998;30:401–407. [PubMed: 9666236]

Underwood G, Chapman P, Brocklehurst N, Underwood J, Crundall D. Visual attention while driving: sequences of eye fixations made by experienced and novice drivers. Ergonomics 2003;46:629–646. [PubMed: 12745692]

Vlakveld, WP.; Twisk, DAM. Young, novice motorists, their crash rates, and measures to reduce them: A literature study Leidschendam. the Netherlands: SWOV; 2005.

Wallace, B. Transport Research Series (Transport Research Planning Group). Edinburgh: Scottish Executive Social Research; 2003. External-to-vehicle driver distraction.

Wang, JS.; Knipling, RR.; Goodman, MJ. The role of driver inattention in crashes: New statistics from the 1995 crashworthiness data system. 40th Annual Proceedings of the Association for the Advancement of Automotive Medicine; Vancouver, British Columbia. 1996.

Wikman A, Nieminen T, Summala H. Driving experience and time-sharing during in-car tasks on roads of different width. Ergonomics 1998;41(3):358–372.

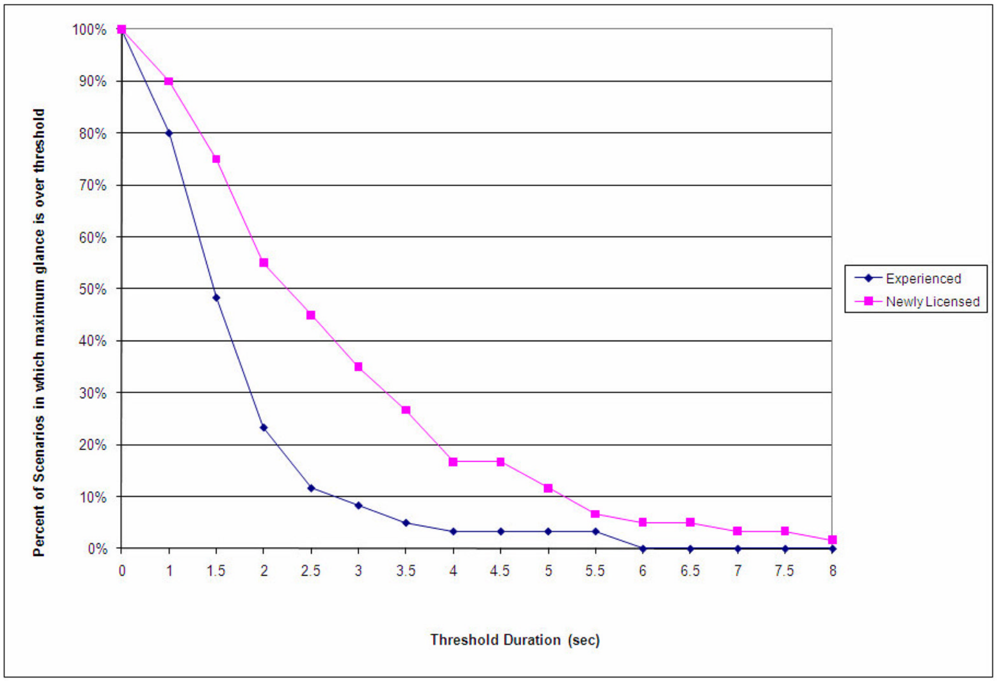

Figure 1.
Percent of In-Vehicle Scenarios in which the Maximum Glance is over Various Duration Thresholds for the Experienced and Newly-Licensed Drivers

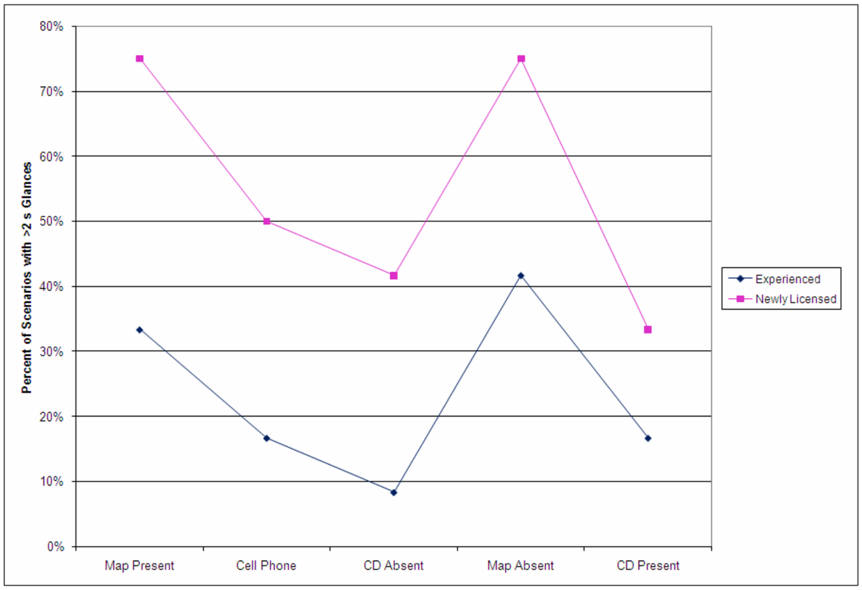

Figure 2.
Comparison of the Percent of Scenarios in which the Maximum Glance is over Two seconds for the five In-Vehicle Scenarios

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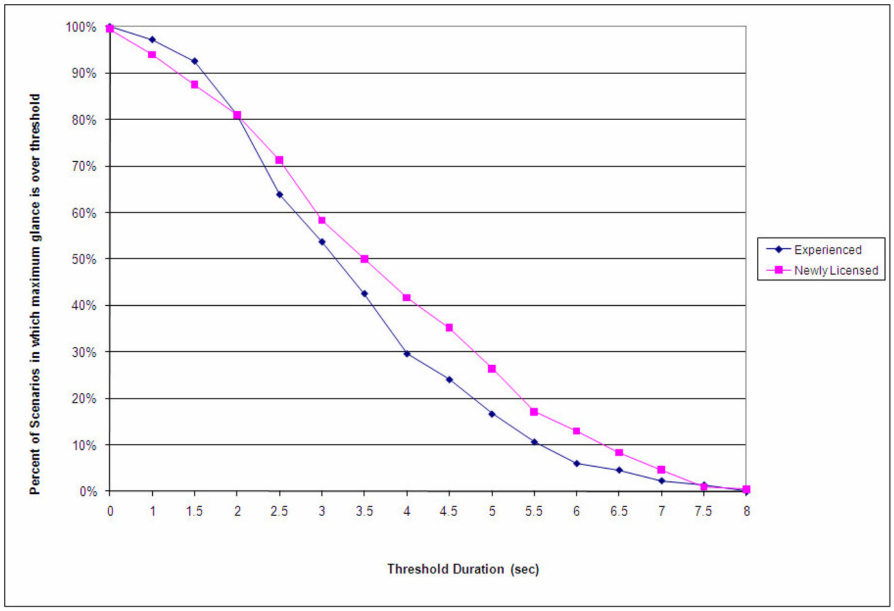

Figure 3.
Percent of Out-of-Vehicle Scenarios in which the Maximum Glance is over Various Duration Thresholds for the Experienced and Newly-Licensed Drivers