AN EYE SCANNING APPROACH OF EXPLORING THE EXPERIENCE LEVEL AT WHICH NOVICE DRIVERS EXHIBIT HAZARD PERCEPTION SKILL AS GOOD AS THEIR EXPERIENCED COUNTERPARTS

by

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ABSTRACT

Hazard perception is a key skill needed to drive a vehicle safely. Literature has shown that this skill improves with experience. Little is known regarding the time window in which novice young drivers start exhibiting essential hazard perception skills as efficiently as their experienced counterparts do. This research was an attempt to address this unknown through the use of a semi-naturalistic driving study employing eye tracking technologies and by examining the roadway eye scanning pattern of young and highly experienced drivers with respect to eight indicators: percentage of gaze duration, mean gaze duration, percentage of time taken to make the first gaze at the study region of interest, gaze rate, gaze heading, gaze pitch, head heading and head pitch. A total of 90 participants completed the study. Participants were split into six groups (15 each) on the basis of their driving experience, ranging from novice young drivers with less than 1 year of driving experience, to highly experienced drivers with more than 10 years of experience and asked to drive through two predetermined potentially hazardous scenarios. An observation time window, beginning at the first moment the potential hazard came into view through the moment it had passed, was extracted from the recorded eye-movement videos. Based on the time window, necessary data were collected and analyzed. The results of the study indicated that novice drives do not differ significantly with other young drives, but their visual search strategy remains inflexible even after two years of experience. However, with growing experience, young drivers learn to look farther ahead and scan more widely along their horizontal field of view. The study thus adopted Equivalence Testing procedure to quantify the transition time window from novice to experienced drivers. Each of the novice drivers' groups was compared against the highly experienced drivers. Based on the overall results and careful observation of descriptive statistics, the study concluded that after five years of driving experience young drivers' visual search pattern can be considered comparable to their experienced counterparts.

CHAPTER 1 – INTRODUCTION

Roadway hazards can be defined as any aspect of road environment or road condition that has the potential to pose crash risk to the driver. Thus, the ability to scan and perceive potentially dangerous roadway conditions is considered as an important part of driving competency. Drivers who perceive and react to the potential hazards quickly are less likely to be involved in traffic crashes. It is evident in the existing literature that such important skill develops as the drivers grow with experiences. As they become more experienced, their repertoire of driving behaviors and schemata get enriched in their long-term memory. As a result, they become more effective at selecting the cues, perceiving their meanings and quick in identifying current and potential future situations (Hickford, 2010).

In the United States, the minimum age to obtain a restricted driver's license varies from 14 years, three months in South Dakota to as high as 17 in New Jersey, the average being 16 years. Hence, by the time the novice drivers are between the ages of 18-20, they are more likely to have more than two years of driving experience. Yet, numerous studies reported that these drivers are over-involved in crashes. Younger drivers of this age group have a fatality rate per 100 million vehicle miles that is almost five times higher than the safest group of drivers, aging between 50 and 54 years (Insurance Institute for Highway Safety 2004a). There are many reasons reported for the increased fatality rate, including speed and alcohol (Mayhew et al., 1986). However, over half of the crashes do not involve high speed or alcohol, they are rather due to failure to scan and perceive the roadway hazards which were out of the driver’s control (McKnight and McKnight 2003).

Hazard perception related studies have been carried out since the mid-1960s. Researchers have investigated which situations drivers consider hazardous, how various hazardous situations are judged to be, or how fast drivers react to different kinds of hazardous situations (Sagberg, 2009). However, most of these studies employed the young novice drivers having less than or at most one year of driving experience and compared their hazard perception skill with experienced adult drivers. Based on the findings, several suggestions had been made; training programs were developed to improve the hazard perception skills of novice drivers and thereby to reduce their high crash likelihood. Though young drivers with more than one year of experiences are also over involved in traffic crashes, very little is known about their hazard perception ability. Are they better than the novice drivers? Do they demonstrate hazard perception skill comparable to the experienced drivers? If not, then they might require hazard perception training like the novice drivers to compensate for their inexperience. Several researchers suggested that training of hazard perception skills should take place only after the drivers have gained enough experience manipulating the vehicle so that they could place the emphasis more on the high cognitive functions such as hazard perception (Deery, 1996; Elsner and Hommel, 2001). McKnight and Peck (2003) noted that the ability to cope with the attention requirements of everyday traffic situations, when confronting the vehicle control demands, requires advanced skill that cannot be achieved until more basic skills are mastered. Surprisingly, this group of young experienced drivers are the least targeted for additional training like hazard perception. They are particularly a critical group to consider for such training (Pradhan et al., 2009). This young drivers have already learned the basic vehicle navigation skills enough and hence will be able to focus on the additional behaviors that needed to reduce their crash rates without compromising handling of the car.

Research Objective

The main objective of this research is twofold: first to investigate the hazard perception differences of young drivers; and second, to explore the experience level at which novice drivers exhibit hazard perception skill as well as their experienced counterparts through the use of an on-road driving study employing eye-tracking technologies. 16 to 21 years old young drivers will split into five groups (Group 1 to Group 5) based on their experience, ranging from 1 to 5 years, respectively. Then the eye-scanning pattern of these drivers' will be compared against the eye-scanning pattern of highly (over 10 years) experienced drivers (Group 6) while driving in real world potential hazards. Young drivers with 1, 2, 3, 4, and 5 years of experiences will be referred as novice, limited experienced, intermediate, moderately experienced and experienced young, respectively. Upon completion of the study, researchers will have greater understanding of the hazard perception behaviors of young drivers. Thus, it might be possible to establish a driving experience standard for young drivers, for which they could be considered experienced enough to have efficient hazard perception abilities on par with experienced drivers.

General Hypothesis Statements

The following hypotheses are posited in accordance to the study objectives:

1) Significant trend or association will be observed between the measured indicators and driving experience.
2) Inexperienced drivers will differ significantly with experienced drivers in regard to the measured indicators.
3) There will be significant within-group variability between each of the young drivers' groups and the highly experienced drivers' group.
4) Young drivers' group with higher experience will be found equivalent to the highly experienced group in terms of the measured indicators.

CHAPTER 2 - LITERATURE REVIEW

Novice Drivers

Young-novice drivers are the riskiest group in road traffic crashes. They are consistently over-represented in crash statistics, especially within the first few months after licensure (McCartt et al., 2003; Mayhew et al., 2003). Stradling and Meadows (2001) proposed three phases of driving that novice drivers normally go through before becoming a competent driver. They referred the first phase as the technical mastery phase, during which the novice driver learns the basic vehicle handling skills. The second phase is the road reading phase in which the novice driver learns to anticipate and interpret the other road users' actions/reactions that might eventually develop into a hazardous situation. Gaining mastery of road reading phase is of great importance in terms of avoiding potential accidents and becoming a safe driver. The last phase is the expressive phase, at which the driver adopts a particular driving style that essentially reflects his/her attitudes and personality traits. Gregersen (1996) argued that since the skills related to handling the car develops gradually and traffic-related schema is lacking, driving takes place as a highly rule-based task in the first-few months for the novice driver. Hence, this period is very critical for the young drivers since at this phase there is the absence of higher-order safety skills, such as hazard or risk perception. At a first glance, it seem the higher crash likelihood of the young novice drivers can be explained by inexperience in predicting how the traffic situations will develop.

Novice Drivers and the
Effect of Age and Experience

As the novice drivers become more experienced, their driving skill level increases and become less likely to be involved in a crash as shown by their decreased number of crashes (Mayhew et al., 2003). Maycock et al. (1991) found that crash rates fell 6% from 17 years old drivers to 18 years old, but the rate reduced to 30% after the first year of driving at any age suggesting experience as the dominant factor. Another study conducted on newly licensed drivers in the USA, reported a significant decrease in crashes within the 12 months of driving and this decrease was also observed when the same analysis was repeated by taking “exposure to the road” as the independent variable (McCartt et al., 2003). Considering that the analysis covered 12 months, the authors concluded that experience was more predictive of young/novice driver crash involvement as compared to age effect. However, this observation differs somewhat from the earlier finding by Pelz and Schuman (1971) who reported that even when controlling the experience in terms of years and miles, 18 to 19 year olds still have the highest crash rate, suggesting the importance of driving age. Mayhew et al. (2003) also found that older novice drivers had lower accident rates than younger ones. They examined the effect of age on crash rates by separating age and experience as confounding factors, and investigated crash rates for novices who had similar experience but different ages. Crash rates of young novice drivers (16 – 19 years) were found to be two times higher than that of advanced novices (20 years and older), a 45% difference despite 24 months of exposure, demonstrating a vivid example of the age effect. Similar findings were also reported by Lewis-Evans, (2010). They controlled for experience by using participants of different ages with similar levels of experience, for example, drivers who had been fully licensed for the same amount of time, yet were different in age. The results of their study demonstrated that, in the time period between receiving learners licenses to graduating with restricted licenses, drivers aged 15.5 to 16.5 years had 7.4 times higher crash rate compared to all other groups (except those aged 18.5 - 19.5 years). Those who gained their restricted license, aged 16.5 to 17.5, had a higher crash rate than those aged 17.5 to 18.5 and 19.5 to 20.5 years, highlighting the significant role age plays in traffic crashes.

Warren and Simpson (1979, cited in COMSIS, 1995) compared the accident frequencies of 30-years-old experienced and inexperienced drivers and found that crash risk of 30-years-old inexperienced drivers was 38% higher than the experienced group. However, in another study by Warren and Simpson (1979, cited in COMSIS, 1995), that compared 20 years-old drivers, the crash risk of inexperienced drivers was found to be only 8 % more than 20 years-old experienced drivers, pointing out to the fact that younger in age is associated with more crashes. Similarly 18-20 years-old inexperienced drivers were found to be more accident-involved as compared to 21-30 and 31-50 years-old inexperienced drivers (Laapoti, Keskinen, Hattaka, & Katilla, 2001). These findings suggest that whilst experience can explain a considerable amount of the effect of age on crash involvement, there are also age related factors that play vital role on the crash rates of novice drivers. Therefore, it can be concluded that age and driving experience have an interactive effect in the accident proneness of young and novice drivers, and the riskiest group seems to be the combination of inexperience and youth.

Hazard Perception

Any feature of a road environment or combination of road conditions that expose the driver to the possibility of a crash can be deemed as a hazard. Benda (1983) argued that safe driving requires perceiving of hazards in the environment and combining them into a coherent evaluation of the traffic situation's hazardousness. Numerous studies have attempted to define hazard perception in the literature. Some of these include the ability to identify potentially dangerous traffic situations as they arise (Mills, 1998), refer to the identification of hazards. Others attempt to quantify the risk level associated with a particular hazard (Deery, 1996). Horswill (2004) referred to hazard perception as the ability to scan the road and to perceive potentially dangerous situations in time and to predict the way in which traffic situations will develop. Isler et al. (2009) noted that hazard perception skills involve having a continuous and always changing complex representation of current traffic situations. Fitzgerald and Harrison (1999) view hazard perception as embedded within the broader context of driver's behavior, and as such is a skill with cognitive and behavioral aspects that include cognitive workload, automation, and attention. Many studies have suggested that the hazard perception is an important part of driving competency, possibly explaining part of the difference in crash risk between novice and experienced drivers (Horswill, 2004; Pradhan & Pollatsek, 2006).

Hazard Perception and Situation Awareness

Situation awareness can be defined as the process of making decisions that are bounded or limited based on the previous experiences. If a driver makes decisions that are bounded or limited according to previous experience, then the process of such decision making is known as Situation Awareness (SA). SA refers to the ability of an operator to filter the necessary information from a data-rich environment, such as driving. It has been defined as the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future (Endsley, 1995). As per Endsley's model of SA to the driving environment, the driver firstly perceives his or her surroundings, the road geometry, other vehicles and road users, relative distances, speeds and accelerations. The driver then has to comprehend what he or she has perceived, by forming "a holistic picture of the environment, comprehending the significance of those objects and events". Finally, the driver takes this understanding, and projects into the near future, in order to take the most appropriate action. By accurately predicting what will happen next, the skilled driver gets in a position to avoid potential hazards.

In terms of hazard perception and hazard avoidance, this SA model is likely to work differently for novice and experienced drivers (Shinar, 2007). For example, to develop the three levels of SA for any given situation, a novice driver must, in a limited time period, be able to select the cues that are indicative of a hazard, integrate them into holistic patterns, comprehend their implications, project how the situation may evolve into a potential crash, and select the appropriate action from his or her repertoire of driving behaviors (Hickford, 2010). As they become more experienced, drivers develop a greater repertoire of driving behaviors and schemata in the long term memory, and so become more effective at selecting the cues, perceiving their meanings and quickly identifying the current and potential future situations (Hickford, 2010). Using scripts developed through past experience, such a driver is likely to control the vehicle very effectively, as the complete situation is quickly assessed using partial information, which triggers pre-established behavior sequences. Driving then becomes so largely automated that an experienced driver will have spare mental capacity to deal with unexpected and previously un-encountered hazards (Hickford, 2010).

Hazard Perception and Crash Involvement

As part of the complex decision-making processes involved in driving, hazard perception is likely to be highly correlated with traffic crashes (Horswill, 2004). Drivers who perceive and react to potential hazards quickly are likely to be involved in fewer crashes (Pelz, 1974). Therefore, the time taken to respond to the presence of a road hazard decreases with increasing age and experience (until around the age of 55) (McKenna, 1997). Quimby et al. (1986) found that slower detection of hazards, while participating in a simulated driving, is associated with higher crash rates independent of age and mileage. The crash rate was found to double between the 5th and the 95th percentiles of hazard perception scores. Based on an analysis of 2000 crashes involving young, novice drivers in the US, McKnight & McKnight (2003) concluded that not perceiving and recognizing hazards in time had played a role in approximately 44% of those crashes. In the remaining crashes, the young novice drivers were mainly distracted (23%) or they drove too fast under the circumstances (21%). Hence, they concluded that the overwhelming majority of non-fatal crashes resulted from a failure to employ safe operating practices and to recognize the dangers rather than due to thrill-seeking or other forms of deliberate risk-taking actions.

Hazard Perception and Driving Experience

While it is likely that young drivers' attitudes to risk-taking, over-confidence and underestimation of skills play a role in their relatively high crash liability, it has been shown that when attitudes are accounted for, there is still a deficit in hazard perception skills (Gregersen, 1996).This relationship between hazard perception and age/experience might account (at least partly) for the over-involvement of young drivers in traffic crashes. Wallis and Horswill (2007) discovered that novice drivers did not assess the dangers differently from the way experienced drivers did, yet they were slower in perceiving hazards and failed to recognize potential hazards more often than their experienced counterparts. Gregerson (1996) has estimated that up to 70% of the novice drivers' errors can be attributable to the drivers' inexperience. Awareness of hazards protects against collision involvement in the early stages of driving (Wells, 2008), yet inexperienced drivers are less able to identify and respond to them (McKenna, 1994; Pollatsek , 2006; Quimby, 1981). Lee et al. (2008) also reported significantly better hazard perception behavior of adult drivers compared to the newly licensed teens on a test-track. However, a few studies did not find any difference in hazard perception between experienced and inexperienced drivers (e.g. Sagberg & Bjørnskau, 2006).Though there was no apparent reasons reported for such insignificant difference, perhaps the test situations, under which the participants were subjected to, were either too complex or too simple.

Hazard Perception- a Skill
That Improves Over Time

Young drivers have a high crash liability relative to those with just a few years of driving experience. Rolls and Ingham (1992) reported that 20% of the 17–20 year old drivers have at least an ‘own fault’ crash each year, whereas this figure is only 4.5 % for the 31–40-year-old drivers. This suggests that the drivers might be learning the skill and techniques of avoiding the collisions and conflicts with the other road users as they grow with experience. Thus, like any skill, it is reasonable to assume that the driver’s ability to detect hazards improves with growing experience. Novice drivers learn the basic vehicle handling skills and traffic laws relatively quickly. Indeed, the crash rate for young novice drivers has been found to decrease by 40%, from 123 crashes per 10,000 to a rate of 73 crashes, during the first seven months of licensure. But the remaining crashes, around 60 per 10,000, involve the novices holding licenses for between 7 and 20 months (Mayhew, 2003). Another study indicated a similar decline in crash rates as the number of miles driven increases; the rate of crashes fell from 2.3 per 10,000 miles driven during the first month, to 1.1 crashes during the second month, with a steady decline again until the sixth month (McCartt, 2003). Olsen et al. (2006) reported that 6 months of driving experience for teen drivers did not result in significant improvements on hazard perception related to road intersections, but after six months the novices had learned the need to survey the roadway and were able to do so. However, Pradhan et al. (2011) reported that while driving through hazard scenarios and engaged in secondary tasks the novice drivers showed an improvement in hazard perception, and a small but insignificant decrease in task suspension after 12 months of driving experience. One possible explanation of such improvement is that with the growing experience, drivers encounter diverse hazardous situations and adopt the appropriate response mechanism through evaluating the perceived response from the roadway environment. Thus, this continuous process of learning enables the drivers to improve their repertoire of knowledge regarding environmental constraints and consequently assists them to predict only those typical hazards which might appear in any given traffic situation.

On-Road Test Based Hazard Perception Studies

Since the inception of research in this field, many methods have been adopted in order to measure driver's hazard perception. During the 1970s, hazard perception was usually measured by observing drivers, particularly where they looked, or by assessing verbalized thoughts while driving. Later, greater use was made of driving simulators, video fragments and photographs (Hickford, 2010). The ability to carry out tests in the real driving environment has considerable merits for many areas of driving research. However, it has been suggested that there are certain difficulties associated with on-road testing of hazard perception, including lack of control over the frequency and complexity of the hazards presented, difficulties in determining the precise time that a hazard is detected, as well as the ethical implications of presenting a driver with real hazards during a test (McKenna, 1997). Despite these apparent difficulties, most of the on-road studies of hazard perception involved detection of eye movements. A few studies compared eye movements of drivers of varying experience on different road types (Falkmer, 2005; Underwood, 2002b). A few other studies aimed to discern the effects of experience on eye movements under varying levels of cognitive load (Crundall, 1998;

Patten, 2006). Recarte and Nunes (2000) examined the different eye movement and fixation durations in normal traffic conditions for a small number of drivers who had been asked to complete a number of different mental tasks. Bellet et al. (2009) aimed to determine the driver's mental representations of the road scene during a left turn maneuver. Chapman et al. (2002) studied the effect of training intervention on novice drivers, examining drivers' eye movements both on-road testing, and while watching videos of hazardous situations.

Visual Search and Eye Movement

While driving, it is essential to identify the salient static and moving objects or traffic conflicts in order to better navigate, and select driving routes at the strategic level, plus, better direct the vehicle with respect to others and avoid potential hazards at a tactical stage. In his review of 50 years of safety research, Lee (2008) concluded that drivers crash into each other because they ‘‘fail to look at the right thing at the right time’’. Failure of visual search was found as a prominent feature in surveys of police reports of crashes (Lestina, 1994), and in-car observations of the precursors to crashes and near-misses in the Virginia Tech Transportation Institute (VTTI) group's100-car naturalistic driving study (Klauer, 2006). Failing to scan the roadway is a common cause of the driver colliding with another vehicle or having to brake or swerve suddenly to avoid a crash (Geoffrey, 2010). Thus, the capability of performing the visual search for traffic conflicts while following the traffic control devices could be considered as a measure of driving safety. Less experienced or newly qualified drivers are observed to be prone to inefficient visual search related driving mistakes that include not searching far enough ahead, or lack of attention, or failing to avoid distraction. These factors were found to be associated with 39% of the crashes had by the very youngest drivers in the 15-19-year-old age group. On the other hand, 18% of the crashes were associated with the failure to comply with the road rules (right-of-way crashes), which is considered as the second most influential factor.

Drivers' Visual Search Mechanism

Human eye movements provide strong evidence about the location of meaningful content in an image or scene (Mackworth and Morandi, 1967; Just and Carpenter, 1976; Henderson and Hollingworth, 1998). Thus, drivers' visual search behavior can be detected by measuring their eye movements (Brown and Groeger, 1988). Analyses of eye movement data take into consideration the anatomy and physiology of the human visual system, as the measurements of the movements relate to what the foveal vision is directed toward (Falkmer, 2005). Foveal vision provides the driver with high resolution information, which supports capabilities such as recognition (Samuelsson, 1996). Peripheral vision supports capabilities such as the driver's orientation, but without the driver being fully conscious of this process (Leibowitz, 1986). When driving, the driver uses his/her foveal vision to detect directional cues, whereas the peripheral system is used to maintain lateral control of the vehicle (Rockwell, 1972). Peripheral vision also provides the driver with a wide range of visual information from which the foveal sampling of features takes place (Lansdown, 1996).

However, basic eye movement is comprised of two components: fixations and saccadic movements. Fixations are defined as eye movements which stabilize the retina over a stationary object of interest while saccades are defined as the rapid eye movements occurring between fixations, used to reposition the fovea to a new location in the visual environment (Duchowski, 2003). A fixation is the duration of time for which an individual is visually collecting and interpreting whatever information is available within the foveal range of the eye (Ellis, 2009). A saccade typically lasts for 20 to 35 milliseconds when no visual processing occurs in the brain, i.e. the fast motion cannot be perceived and no information obtained (Dong & Lee, 2008). Since fixations only cover a finite space filled with information, saccadic movements trace the area of desired information so fixations can collect all the information necessary for the brain to interpret the overall image.

In order to regard a gaze event as a fixation, a cognitive act of perception, it should last at least a pre-defined number of milliseconds. In the existing literature, there is no clear definition of a fixation in terms of exact duration. Some researchers suggested that a fixation might typically range from one to three degrees of visual angle for 80 -150 ms (Carpenter, 1988; Vickers, 2007). Thörnell (2010), on the other hand, argues that during a fixation the eye position stabilizes within dispersion of typically ~2° and over a duration lasting from 66 to 416 milliseconds. Thus, in the eye-tracking literature there is much debate about a standard minimum fixation duration (Munnet al. 2008), and this duration seems to be highly linked to the specific task of the eye-tracked person. In reading the minimum fixation duration will typically be as short as 60 milliseconds, whereas for other tasks this is generally between 150 and 400 milliseconds (Oben & Brône, 2012). Irwin (1992) found the theoretical minimum duration for a single fixation to be 150 milliseconds, whereas Inhoff and Radach (1998) advised the lower threshold value for a fixation should be at least 100 milliseconds. Manor and Gordon (2003) also asserted that 100 milliseconds as a minimum fixation duration can be justified.

Eye Movement Differences between Novice and Experienced Drivers

Though the role of peripheral vision with respect to detecting sudden movements while driving was widely recognized, Mourant & Rockwell (1970) first shed some light on its role with respect to vehicle control. They recorded eye movements of novice drivers while driving on an Interstate highway and observed that only 1% of the eye fixations of the eight drivers using peripheral vision to monitor lane position fell directly on road markings. In a later study, Mourant & Rockwell (1972) also observed marked differences in the eye scanning behavior of novice and experienced drivers. Firstly, the novice drivers were found to frequently fixate their eyes on road edge markings, and target the moving lane markers for tracking eye movements, which indicates their lack of peripheral vision for monitoring a vehicle’s lane position. Secondly, the younger drivers made much smaller eye fixations along the horizontal axis of the scene compared to the experienced, indicating they are more vulnerable state in terms of detecting potential and immediate hazards in multiple driving environments. The third significant result was that the novice drivers scarcely did any mirror sampling, which is absolutely imperative to maintain situational awareness. Fisher and Pollatsek (2006) reported on a series of experiments where novice and experienced drivers' eye movements were recorded as they drove a route with scenarios that could develop into real hazards. They examined the visual scanning of drivers experiencing the scenarios, and found that novice drivers looked at the risky areas less frequently than experienced drivers. They argued that novice drivers do not recognize a risky situation when they see one. Also, Lee et al. (2008) studied the visual behavior of novice and experienced drivers as they drove through three hazard perception scenarios on a test track. They found that novice drivers observed and demonstrated overt recognition of hazards less frequently than experienced drivers. Underwood (2007), Crundall and Underwood (1998) observed that novice drivers' visual scanning did not show sensitivity to road complexity. Crundall and Underwood (1998) reported that, on busier roads, horizontal variances of fixation positions were larger and fixation durations were shorter for experienced drivers than novices. On rural roads, however, experienced drivers showed smaller variances of fixation positions and longer fixation durations than novices did although the difference in both measures between the two groups was not significant. These results suggest that the effects of driving experience on eye movements may change with the complexity of driving conditions, and that the inflexible strategies of novices may not be able to meet changing demands whereas experienced drivers increased the frequency of scanning based on situational demands. They suggested this might be due to novice drivers having underdeveloped situational awareness skills. They found a reduction in the attention resources available to novice drivers, for perception of information in the periphery of the visual field, compared to more experienced drivers. It appears that a significant factor underlying these differences is that inexperienced drivers have a lower demand of foveal attention resources (Chen, 2012). Carter and Laya (1998) reported that experienced drivers, as compared to novice drivers, had longer fixation durations while the standard deviation of fixations did not differ between the two groups. These results, considered together, suggest an important relationship between eye movement patterns and driving performance.

<u>Measuring Eye Movement</u>

Driver's eye movement patterns can be measured through field observation (Robinson et al., 1972), with an instrumented vehicle with camera recording (Bao & Boyle, 2009), or in controlled experiments with "eye tracker" (Underwood et al., 2003). Each method has limitations and advantages. Data collection in the field is of relatively low-cost. However, the data reduction and interpretation can be very time consuming and the outcome is less controlled. On the other hand, eye trackers can provide more objective and accurate measures of drivers' eye movements by extrapolating and graphically representing where a person is looking (Bao, 2009). Eye-tracking, thus, allows researchers to identify how users scan a display, locate areas that are frequently looked at versus areas that are often neglected, and detect instances when the user is confused by an object on-screen. Such knowledge would be very difficult to gain through other measurement tools such as observations and surveys (Cooke, 2005). Eye-tracking, thus, provides insight into the cognitive processing behind human behavior that is not available through observation and think-aloud practices (Cooke, 2005). In the driving domain, researchers typically use eye tracker to analyze eye movements in terms of fixation or gaze durations, saccadic velocities, saccadic amplitudes, and various transition-based parameters between fixations and regions of interest (Salvucci et al., 2000). Numerous studies employed eye tracker to record eye movements and fixations of novice drivers and experienced drivers while participants in both groups drove in real traffic (Mourant & Rockwell, 1972; Crundall & Underwood, 1998; Underwood, Chapman, Brocklehurst, et al., 2003; Falkmer & Gregersen, 2005). Several driving simulator based studies also used eye tracker to record eye movements of novice and experienced drivers (Miltenburg & Kuiken, 1990; Garay-Vega & Fisher, 2005; Pradhan et al., 2005; Konstantopoulos, Chapman, & Crundall, 2010). Eye tracking equipment has even been used in a case where two groups of participants watched video clips taken from the driver's perspective (Chapman & Underwood, 1998; Underwood, & Chapman, 2002; Underwood, Crundall, & Chapman, 2002; Chapman et al., 2004; Borowsky, Shinar, & Oron-Gilad, 2010) and also the static traffic scenes (photographs) (Huestegge et al., 2010).

Eye Tracking Analysis

Eye tracking systems measure the eye movement and project the calculated fixation/gaze onto the record of the test person’s field of view, which is also called the “stimulus”. In eye tracking analysis the stimulus usually is a picture, a sequence of pictures, a movie or the scene video. Thus, eye tracking analysis is based on the combined interpretation of eye movement data and the stimulus data. A widely-used approach to visualize this combination of data is attention mapping. As described above fixations are indicators for visual attention to certain areas of the stimulus. Thus, in order to map a person's attention, the gaze's dwell time have to be graphically represented for every point of the stimulus (Lohmeyer et al., 2013). Another popular form of representation contains highlighting regions of many or long fixations by warm colors and marking regions that are less considered by cold color. In doing so, the stimulus (e.g. a picture) is overlaid by a "heat map" representing the areas of high visual attention by flame red hot spots. In addition to heat maps (warm/cold) visual attention can also be represented by luminance maps (light/dark) and contrast maps (sharp/blur) (Lohmeyer et al., 2013). Although attention maps provide a quick and very intuitive representation of eye tracking data, they usually do not fulfill the high level of accuracy and unambiguity as required for drawing valid research conclusions (Lohmeyer et al., 2013). Nowadays, most scientific eye tracking studies are conducted by the application of "areas of interest" (AOIs) (Lohmeyer et al., 2013). AOIs are relevant areas on the stimulus that are usually defined before starting the experiment. The definition of AOIs is closely connected to the research question and the corresponding research design. There are three basic AOI events (Holmqvist et al., 2011): (1) the AOI hit, i.e. there is at least one fixation inside the AOI, (2) the AOI dwell or gaze, i.e. there are two or more sequenced fixations inside the same AOI for a certain period of time and (3) the AOI transition, i.e. there are two or more sequenced fixations across different AOIs in a certain order. Corresponding to the different AOI events presented above, several AOI-based representation forms (e.g. transition matrices or Markov models) support the quantitative analysis of gained eye tracking data (Lohmeyer et al., 2013). Based upon the raw fixation data a number of eye-tracking measures can be derived. The importance of AOIs in research is fortified by

Jacob and Karn (2003). In a comparative study, they revealed that the data collected within 24 reviewed eye tracking experiments was analyzed regarding the following six metrics: (1) overall number of fixations, (2) overall gaze % (proportion of time) on each AOI, (3) overall fixation duration mean, (4) number of fixations on each AOI, (5) gaze duration mean on each AOI and (6) overall fixation rate (fixations/s).

Summary

Driving is a highly visual and complicated task that involve a variety of interactive information processing and decision making procedures that depend on continuous visual input. Safe driving requires accurate and persistent attention to the dynamic environment for detecting critical information, especially in driving situations where potential roadway hazards needed to be anticipated for safe maneuvers. Several studies suggested that novice young drivers' inadequate scanning behavior is probably due to their incomplete mental model of roadway environments. As a result, they cannot spot or recognize crucial cues which might hint potential road hazards. Hazard perception related studies have been carried out since the mid-1960s, and the concept has been defined and measured in different ways. Researchers have investigated which situations drivers consider hazardous, how various hazardous situations are judged to be so, or how quickly drivers react to different kinds of hazardous situations (Sagberg, 2009). These variables have been investigated by a variety of methodological approaches, including questionnaires, still pictures, film, video, driving simulator, and driving in real traffic (Sagberg, 2009). However, existing literature regarding eye tracking suggests that eye tracking measures provide more objective and accurate eye movement behavior of the drivers which would be very difficult to gain through other measurement tools such as observations and surveys.

Research Motivation

In light of the existing literature, it can be concluded that hazard perception skill, or the ability to anticipate traffic situations, is an important aspect of safe driving behavior. It was evident from the literature that such an important skill develops in the drivers as they grow with driving experience. Studies indicated that hazard perception skill differs significantly between the novice and experienced drivers, in both real world and driving simulator, while driving through potentially hazardous situations. Even after being trained and having one year of driving experience, young drivers still have poorer hazard perception skill than their experienced counterparts (Underwwod, 2007). However, most of these studies employed young novice drivers having less than or at most one year of driving experience and explored their hazard perception ability, when compared with experienced adult drivers, with respect to proficiency, speed, and identification of hazards that are not clearly visible to a driver until the last moment (McDonald et al., 2015).

Very little is known about the hazard perception ability of young drivers having more than one year of experience, especially in terms of their eye scanning behavior. Do they differ significantly with their less experienced peers or highly experienced counterparts? If they differ significantly, then after how many years of driving experience do young drivers begin to exhibit essential hazard perception skills comparable to the highly experienced drivers? The existing hazard perception related literature lacks in providing enough knowledge regarding the above questions. Thus, the researcher was motivated to conduct a real-world driving study employing eye-tracking technologies to address these issues and provide some insights about the hazard perception differences of young drivers with varying experience level. If it can be explored at what experience level young drivers acquire visual searching skill comparable to the experienced drivers, then this would open the possibility for crash reduction through more frequent training for the young drivers till that driving experience level.

CHAPTER 3 – METHODS

The methodology was developed with an aim to partially utilize the data already generated by a recent NSF-funded study (Grant No. 1116378) focused on the hazard perception of teen drivers at Western Transpiration Institute (WTI), Bozeman. The main objective of the NSF-Study was to understand how hazard perception in the virtual world translates to the real world; thus, the study was conducted in both real (on-road) and simulated traffic setup. Though driving simulator provides an excellent means of experimental control and offers greater ability to draw cause-effect conclusions, the extent to which simulator results translate to on-road performance still remains a question (SAFERSIM, 2015). Besides, the behavioral response of the drivers may also be influenced by the drivers' lack of confidence in the authenticity of the simulation at a fundamental level (Caird & Horrey, 2011). Hence, it was decided to conduct the current study in a real traffic setup. The methodology of the current study was, therefore, developed based on the methodology of the "on-road" portion of the NSF study and extensive review of the existing literature on hazard perception.

Equipment

Data collection was conducted using a 2009 Chevy Impala with safety equipment including antilock brakes, driver and passenger airbags, and an emergency passenger-side brake. The vehicle is instrumented with a SmartEye eye-tracking system, eight video channels, and equipped with devices capable of collecting streaming vehicle, GPS, and radar data as the driver operates the vehicle (Figure 1).

Figure 1: Instrumented Impala with three scene cameras mounted on the top

The dash-mounted SmartEye eye tracking system (Figure 2) is consisted of five infrared cameras monitoring the driver's face and eyes, three cameras mounted on the top of the car to record the scenes along the routes (Figure 3), and a specialty computer for real-time data acquisition and post-test information processing. The face monitoring units emit infrared beams to the driver's face and eyes to capture the positions of major face components (ear, nose, eyes, etc.) and the gaze directions. With this particular camera setup eye movement output can be recorded approximately 150 degrees in the driver's forward field of view. The system uses a proprietary algorithm to determine the locations of the driver's fixations. The three scene cameras record the forward view at 30 frames per second. During post processing stage, images recorded by the three scene cameras are stitched together to create a panoramic scene, and the driver's eye fixation locations are superimposed onto the stitched images by matching up the synchronized time stamps of the images and text records.

Figure 2: SmartEye 5 Camera System

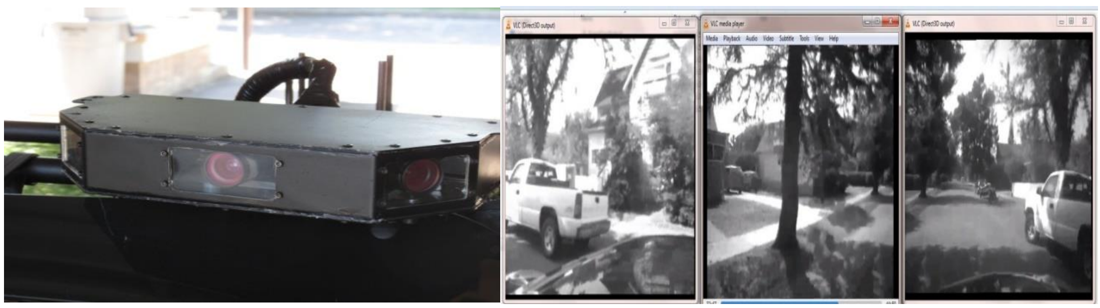


Figure 3: 3 Camera Scene Recorder System

Figure 4: OPTEC 5000 (P) Vision Tester

An OPTEC 5000 (P) vision tester was used to test the required visual acuity (20/40 vision) of the participants.

Driving Scenarios

In order to complete the study, participants were required to drive in the real world, under two potentially hazardous scenarios: 1) through a hidden crosswalk (Figure 5) and 2) approaching a curved stop ahead (Figure 6).

Figure 5: Hidden crosswalk on-road scenario

Figure 6: Curved stop ahead on-road scenario: left - "Stop Ahead" warning sign and right- "Stop Sign" obscured by roadside vegetation

These scenarios were adopted by the aforementioned NSF study from Pradhan et al. (2005) as examples of roadway conditions that require greater attention by the driver for potential hazards. The first scenario was meant to measure a driver's ability to recognize that pedestrians might emerge from behind a line of bushes and a house that obscured a sidewalk on the right. The second scenario determined whether drivers would pay attention to a “stop ahead” sign warning of an upcoming stop sign obscured by a curved road and roadside vegetation. The geometric features of this scenario were similar to Pradhan et al. (2005) where the sign was at the beginning of a road curving to the right, hidden by trees.

Participants

A total of 90 participants took part in the study. The required participant sample size of the study was estimated by utilizing highly experienced participants’ data (33 in particular) collected by the referenced NSF study. Highly experienced drivers are expected to exhibit better group consistency in terms of the measured variables than the teen driver groups. The percentages of the fixation and gaze duration on the region of interest of the study at each driving scenario were extracted from the video outputs of the SmartEye system (see “Data Collection” section). For the fixation duration, the minimum difference to detect between means (for statistical analysis purpose) was set to 100 milliseconds. Several studies advised using such duration as threshold value for fixation (Inhoff & Radach, 1998; Manor & Gordon, 2003). On the other hand, 60 milliseconds was used as a threshold value for gaze measure. Such duration was reported as the shortest time to view an item and transmit that information to the brain (Oben & Brône, 2012). Then the standard deviations for each measure were estimated from the collected data and used to determine the necessary number of participants to achieve sufficient test power (1-β) which is 0.90 at alpha equal to 0.05. The sample size estimation was conducted using SAS 9.4 “proc glmpower” function. The summary of the all the sample size estimations are provided in Table 1.

The “estimated sample size” values (Table 1) indicated that the ideal sample size for this study would be 150 participants. However, employing such a large sample could be very difficult due to time, budget and other constraints. Hence, a total sample size of 90 (15 participants for each group) was considered to be more realistic. Moreover, this number is quite comparable to many other driving simulator/on-road studies, which generally contain 10-60 participants.

Table 1: Summary of sample size estimation results

Variable	Study Scenario	Estimated Standard Deviation (seconds)	Min. Difference to Detect	Nominal Power (1-β)	Sample Size		Actual Power
					Estimated	Determined	
Fixation	1	0.083	0.1	0.90	90	90	0.931
	2	0.064			60		0.998
Gaze	1	0.051	0.06	0.90	90		0.895
	2	0.042			90		0.98

As the objective of the study was to observe the differences in eye movement as a function of driving experience, the recruitment/inclusion (for the NSF study data) criteria for novice and young participants were: the participants had to 1) be between 16-21 years old at the time of participation, 2) have valid driver’s license, 3) obtain the license at the age of 15-17 years, 4) have normal or corrected-to-normal vision (20/40 which is MT driver’s licensure requirement), 5)and 6) not have previously participated in any driving hazard perception related studies. For the highly experienced group, the main selection criteria was to have at least 10 years of driving experience and be between 30 to 55 years of age (as specified in the referenced NSF study) at the time of participation in addition to criteria number 2-5 stated above for the novice and young groups. Participants were recruited/selected mainly based on the age limit and driving experience level. Participants' gender was not of concern as a selection criteria. Although numerous studies suggesting the effect of gender on driving style adaption, risk perception and crash involvement of young (16-20 years old) drivers can be found in the existing literature (e.g., Kirkham & Landauer, 1985; Laapotti, 2003; Mayhew et al., 2003; McKenna et al., 1991), no clear evidence of gender having significant effect on hazard perception behavior was found. Scrimgeour et al. (2011) conducted a study to examine gender differences in a hazard perception task independent of motion judgments. Their results showed that there was no gender difference, with males and females rating all scenes comparably. Similar result was reported by the Institute for Road Safety Research in its 2014 annual fact sheet (SWOV, 2014). This is why gender was not considered while recruiting or selecting (from NSF study) participants. As a result there was no balanced sample for gender across the participants' groups.

A total of 72 participants took part in the on-road portion of the NSF study. As per the selection/recruitment criteria stated above, data of 50 participants (Group1=12, Group 2=15, Group 3=8 and Group 6=15) were collected from the NSF study. Thus, 40 more participants (Group1= 3, Group 3=7, Group 4=15 and Group 5 =15) were required to be recruited for the proposed study. Initially a total of 45 participants were recruited. However, four of them did not show up on their scheduled day and three participants' data were not recorded properly. Hence, two more participants were recruited in order to conform to the desired sample size. The demographic information (gender, mean age, driving experience) of the participants who completed the study were given in Table 2.

Table 2. Participant Demographic Information

Participant Group	Gender		Age (in years)		Driving experience (in years)		Driving Experience (in miles/annum)
	Male	Female	Mean	Std. Dev	Mean	Std. Dev	
1	9	6	16.97	0.69	0.89	0.26	4273.3
2	8	7	16.99	0.38	1.49	0.24	6033.3
3	11	4	18.54	1.89	2.44	0.25	5367
4	13	2	19.48	0.81	3.58	0.28	6133.3
5	12	3	20.28	1.15	4.63	0.31	8233
6	8	7	38.02	7.70	22.31	7.92	19933.3

Participants recruited for the current study, were compensated at $12.5 per hour. Consent was obtained for all the drivers in accordance with the university's Institutional Review Board (IRB) approval. All who participated in the NSF study were recruited from the Gallatin Valley classified ads in the newspaper, Craigslist advertisements and high school posters. The majority of the participants in the current study were recruited from the university community; the rest were found from the ads in Craigslist and different Bozeman Community Facebook pages.

Experimental Procedure

The experimental protocol, utilized in the current research, was adopted from the referenced NSF study. The objective was to ensure consistency of the data collection process across the two studies. All the participants recruited for this particular research, thus, went through the same experimental procedure as the participants of the NSF study did. The data of the current study were collected from September to October 2014 and from May to June 2015, the NSF data were collected from July to October 2013.

The participants were asked to come to the Driving Simulator Lab at WTI during their scheduled appointment time and the experiment was conducted within one session. Upon arrival, the participant's valid licensure status was first confirmed. Then a vision test was administered using an OPTEC 5000 (P) vision tester to confirm that he/she had the required visual acuity (20/40 vision). Once the participant had passed the vision test, he/she was asked to read the consent form carefully and sign. After completing all the formalities, he/she was briefed about the experimental procedure and directed toward the instrumented vehicle. The eye-scanning system in the vehicle was then calibrated to ensure the mean gaze accuracy was within 2-3°. Finally, the participant was asked to drive through a test route to get comfortable operating the vehicle. Once the participant was ready for the actual drive, he/she was asked to drive through the study routes consisting of real, pre-selected 'on-road' locations in Bozeman, Montana. Participants were instructed to drive as they normally would and to drive straight through intersections unless being told to turn by the accompanied researcher; all turning instructions were given at least one block prior to the turn. All driving sessions were conducted in clear weather during daylight hours avoiding heavy traffic periods. The study route took approximately 20-25 minutes to drive.

Independent Variable

As per the research objective of the study, the only independent variable was the driving experience consisted of six levels: less than 1 year, 1-2, 2-3, 3-4, 4-5 and over 10 years. Measuring driving experience in terms of time elapsed since licensure is a more frequent surrogate measure of experience in driving-behavior related studies (Mccartt et al., 2003). It is quite evident in the existing literature that such measure of experience plays a vital role in crash rate reduction (Mayhew, 2003, Mccartt, 2003) and hazard perception improvement (Gregersen & Bjurulf, 1996, Olsen et al., 2006; Pradhan et al., 2011). McCartt et al. (2003) reported a significant decrease in crashes within the 12 months of driving and observed similar result when the same analysis was repeated by taking "exposure to the road" as the independent variable. Unlike youth-related factors, however, making mistakes while learning skilled behavior like hazard perception occurs at any age. Therefore, it would be expected to find higher crash rates for people who are just learning to drive, regardless of age, when compared with drivers who have more years of experience (Eby, 1995). Cooper et al. (1995) examined crash likelihood of drivers in British Columbia, Canada as a function of driver age and number of years of driving experience. They reported that, between the ages of 15 and 55, those drivers with one year of experience tended to have higher crash rates than same age drivers with two or three years of experience when at-fault crashes were considered.

However, most of the hazard perception studies were conducted to assess the difference between the novice (especially teenage drivers having around 1 year of experience) and experienced drivers. No such study was found that focused on how the hazard perception of the young drivers (having 2+ years of experience) differ from the novice or much experienced drivers. Hence, the major focus of the study was to investigate how hazard perception differs among the drivers having one to five years of post-licensure driving experience.

There is another way of measuring drivers' experience, which is how many miles driven or travelled per annum. With longer distances travelled, it is quite likely that drivers will experience a broader range of traffic scenarios and thereby such experience may help them to improve their hazard perception ability (Isler et al., 2009). However, this measure of driving experience is mostly self-reported and not precise. Besides, most of the reported higher mileage per annum, are mainly based on the approximate miles driven in highways rather than in city areas. Since the driving scenarios utilized in the current study were in city area, both the inexperienced and experienced drivers were assumed to have similar exposure while driving in such roads. Consequently, driving experience in terms of cumulative number of miles driven both before and after licensure were not controlled in this study.

Dependent Variables

Dependent variables were the same for both scenarios and were selected to reflect the eye scanning pattern difference among the driver groups. These variables were selected based on extensive literature review of eye tracking metrics used in driving and other domains. The eye tracking metrics, considered for the analysis, were all subsets of one basic eye movement "Fixation"- utilized widely for eye tracking studies. Several metrics were measured and calculated as per the area of interest described in the driving scenario section. These are the percentage of fixation and gaze duration (in seconds), the fixations and gaze rate (number/second), mean fixation and gaze duration (in seconds), and the time to first gaze (expressed in percentage of the time the participant took to make first gaze on the study AOI).

Fixation / Gaze (also termed as “dwell”) Percentage per AOI refers to the proportion of time the eyes dwell on a specific AOI for the specific period of interest at each scenario. However, since the frequency of fixations and duration of fixations are not differentiated, the existing literature suggests caution in using this parameter. More frequent, short-duration focus on the AOI may result in the same gaze percentage as found from less-frequent, longer duration focus, whereas, in reality, these are two different metrics requiring separate analyses. Hence, the variable Fixation/Gaze Rate per AOI was also selected as a dependent variable. This metric indicates how often participants glance at specific areas. Although the importance and interpretation are difficult to decipher using Fixation/Gaze Percentage per AOI, this metric can indicate which AOIs are attended to for larger percentages of the time. According to Fitts et al. (2005), frequency indicates the importance of the element whereas duration indicates the difficulty of interpreting the information. In this regard, the Mean Fixation/Gaze duration per AOI, describing the average length of gazes within an AOI, becomes handy. Longer gazes may indicate that the objects were difficult to interpret while shorter gazes can indicate efficiency of the glance.

In addition to the above dependent variables, measures of head and gaze rotation, namely Head Heading, Head Pitch, Gaze Heading and Gaze Pitch, were further analyzed to assess the scanning pattern of the driver while driving through the scenarios. Head Heading refers to the left/right-rotation of the head, also known as “no”-rotation. Head Pitch, on the other hand, refers to the up/down-rotation of the head and is also known as “yes”-rotation. Gaze heading is the left/right angle of the gaze vector, whereas, gaze pitch represents the up/down angle. Numerous studies on the dynamics of head and eye gaze revealed that humans’ attention is very much linked to the rotation or movement of head and eye (Doshi et al., 2012). Land et al. (1996) reported that the positioning of the head plays a considerable role in determining the range of the field from which the next fixation will occur. Thus, the measures of head rotation, along with the gaze measures, were additionally selected to differentiate the visual search behavior of the novice and young experienced drivers. Few other studies (e.g., Hafizah et al., 2012; Son & Oh, 2012; Son et al., 2012; Shechtman et al., 2007; Pradhan et al., 2005; Recarte & Nunes, 2000) also used these measures for analyzing the eye movement behavior of the drivers. However, apart from the above mentioned dependent variables, no additional driving performance measures were collected.

Data Collection

The SmartEye system provides two types of output: video based real time eye tracking measures recorded by the scene recorders, and text output of eye tracking measures, e.g., gaze origin, gaze direction, saccade, fixation, eye closure, head position, pupil diameter, quality measures, etc. at a sampling frequency 60 Hz. Data quality checking of each collected data set was administered upon completion of the data collection. The text output of the SmartEye system contains 172 variables with more than

30,000 data points under each variable. Codes were developed in SAS to check each data point against the range of its expected values. No major issues regarding the quality of the collected data sets were observed.

Once the quality of the collected data was ensured, then video outputs from the three scene recorder cameras were stitched together (Figure 7) using Panorama Builder Software, which also superimposes the recorded eye movements on the video. Stitched videos were then uploaded in the 2-D eye-tracking software named Multiple-Analysis of Psychophysical and Performance Signals (MAPPS™, Version 3.1). This software allows the user to reduce the eye tracking data, recorded by SmartEye system. The analysis software, thus, provides an interface in which the gaze vectors determined by the eye tracker can be related to areas or objects in the scene camera view of the forward field of driving. Analysts can indicate regions of interest (ROIs) in the scene camera views and the analysis software then assigns gaze vectors to the ROIs.

Figure 7: Stitched Video

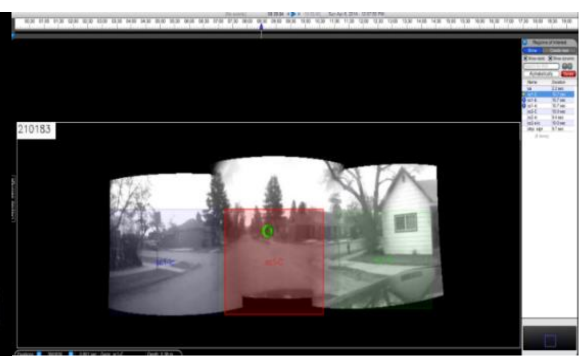


Figure 8: MAPPS Computer Interface

In order to collect the required data from the recorded eye movements, a study time window was extracted for both scenarios from the data set. The time window begins at a specific landmark (a house with extended porch at Scenario 1 and an electric pole at Scenario 2) at which the hazard situation is first perceptible and ends at the moment when the participant has made a complete stop at Scenario 1, and at Scenario 2 the time window ends at the moment the "stop-ahead" sign has been passed. As soon as the participant reached the specific landmarks at each scenarios, the recorded eye movement video in MAPPS software was paused and the required ROIs were created. Based on the time window for the first scenarios, the forward view of the driver was divided into three dynamic regions of interests (ROI): center, right and left corner (as shown in Figure 8). For the second scenario, only one dynamic AOI was defined on the "Stop Ahead" sign for the extracted study time window. Eye fixation and gaze duration data on the defined ROIs were then exported from the video using MAPPS. This software uses three parameters in the determination of a fixation: a fixation radius, fixation duration, and a time out. The determination begins with a single-gaze vector intersection. Any subsequent intersection within a specified radius will be considered part of a fixation if the minimum fixation duration criterion is met. The radius parameter used in this study was 2 degrees and the minimum duration was 300 ms; eye points over 60 milliseconds were recorded as gaze. The 2-degree selection was based on the estimated accuracy of the eye tracking system, as recommended by Recarte and Nunes (2000). Thus, the accuracy of the outputs from MAPPS software mainly depends on the accuracy of the data recorded by the eye tracking system.

The head and gaze rotation data were extracted from the text output by using the first and last frame number of the study time window (extracted for the video data) for each participant. Finally, after collecting all the text data for the study time windows at both scenarios, data loss percentage was calculated. There are generally two main reasons of data loss: first, the participant is not looking at within the range of the cameras recording the eye movements; second, the participant is looking at within the range but the eye-tracker is failing to detect it due to some reasons (e.g. internal system failure, too much light either on the camera or on the face of the participant etc.). The eye-tracker aims to perform three separate identifications per frame to perform eye tracking: pupil, corneal reflection, and head position. An inability to perform any of these identifications accurately can lead to the eye-tracker returning null values for that frame, leading to periods of data loss ranging from a single sample to periods of several seconds. Necessary codes were developed in SAS to figure out the percentage of the null values recorded during the study time windows. The data loss percentages at Scenario 1 was found 12.2% and was 9.58 % at Scenario 2.

Statistical Analysis

Descriptive statistics like mean, standard deviation, inter-quartile range were estimated and presented for each dependent variable at each scenario in order to provide an initial understanding of the eye scanning pattern differences among the driver groups and their group homogeneity.

Then Spearman’s correlation was run to determine any association between the independent variable and each of the dependent measures for both scenarios. Though Pearson correlation is the most widely used method to measure association between two variables, however, when the variables are not normally distributed or the relationship between the variables is not linear, it may lead undesirable or misleading conclusions (Hauke & Kossowski, 2011). In contrast, Spearman's correlation does not require the assumption that the relationship between the variables is linear, nor does it require the variables to be measured on interval scales. It is, thus, not a measure of linear relationship between two variables. Rather, it assesses how well an arbitrary monotonic function can describe the relationship between two variables without making any assumptions about the frequency distribution of the variables (Hauke & Kossowski, 2011).

The Kolmogorov-Smirnov Test of normality and Levene's Test of homogeneity of variance were conducted for each data set. Parametric one-way ANOVA was performed for each of the data sets that conformed to the ANOVA assumptions. For the non-conforming data sets, non-parametric Kruskal–Wallis Test was administered to determine any significant effect of driving experience on each measured dependent variable. In case any significant effect observed, Bonferroni multiple comparison tests (for parametric ANOVA) or Wilcoxon-Mann-Whitney tests (non-parametric) were further performed to determine which groups were significantly different than each other.

The Siegel-Tukey Test was then performed. It is a non-parametric test for equality in variability. In other words, this test is used to determine if one of the two groups of data tends to have more widely dispersed or spread out values than the other. For this particular study the purpose of the test was to investigate the equality in variability between each test group (Group 1-5) and the reference group (highly experienced drivers, Group 6). The test was conducted to address, partially, the second objective of the current study which was: to find out which, if any, of the young driver group had within-group variability similar to that of the experienced group.

The inferential statistics only provide the information whether there is any significant difference among groups of data. It does not provide evidence to conclude whether two groups can be considered equivalent if the null hypothesis is failed to be rejected. Therefore, equivalence testing procedure was utilized to assess if the observations from the two groups were similar enough in terms of the measured dependent variables. This test can help to assess which group of young drivers' hazard perception behavior was equivalent (if any) to the highly experienced group. In this regard, the Schuirman's Two-Sample Equivalence Test was administered between each of the young driver group and their experienced counterparts. The threshold values (represented as δ in Table 3) of the equivalence tests for the dependent variables pertaining to the fixation/gaze duration measures, were set to the values used earlier in sampling analysis (100 milliseconds for fixation duration and 60 milliseconds for gaze duration). For the other dependent variables, no such threshold value was found in the existing literature. Hence, overall standard deviation of each data set was fixed as the threshold value for the corresponding variable in the equivalence test.

All tests of inferential statistics were conducted at five percent significance level. SAS software (version 9.4) was used for all the statistical analyses. A summary of statistical testing approaches is listed below in Table 3.

Table 3: Statistical Approach

Objective	Test	General Hypotheses
Is there any trend or association between the driving experience and each of the measured dependent variables?	Spearman's Correlation	**H_0:** There is no monotonic correlation **H_a:** There is monotonic correlation
Does the driving experience have an effect on the drivers' group in terms of the measured variables?	One-way ANOVA	**H_0:** $\mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5 = \mu_6$ **H_a:** not all μ_i (i=1,2,3,4,5,6) are equal Where μ_i= mean of group i (i=1,2,3,4,5 6)
	Kruskal–Wallis	**H_0:** There is no difference between the groups **H_a:** There is a difference between the groups
Does the dispersion (within-group variability) of the response data of each young driver group vary significantly compared to the highly experienced group?	Siegel-Tukey	Two-sided: **H_0** : $\sigma_i = \sigma_6$ **H_1**: $\sigma 1 \neq \sigma_6$ Where σ_i represent the scale parameter of the test groups (i=1, 2, 3, 4, 5) and σ_6 is for the reference Group 6.
Which driver group, if any, is equivalent to the highly experienced driver group?	Two-Sample Equivalence	**H_0:** $\lvert\mu_i - \mu_6\rvert > \delta$ **H_1:** $\lvert\mu_i - \mu_6\rvert \leq \delta$ Where δ= interval of tolerable difference μ_i= mean of test group i (i=1,2,3,4,5) and μ_6 is mean of reference Group 6.

CHAPTER 4 – RESULTS

Scenario 1

Figure 9 and 10 show the percentage of total fixation and gaze duration across the three defined ROIs at Scenario 1. It is evident from the figures that while driving through the scenario, participants were paying attention mostly in the central region of their forward field of view. It was observed from the gaze data that while 87 % of Group 1 and 93 % of Group 2 drivers looked at the left corner, only 40% and 53% of them looked on the right corner (the study ROI). In contrast, considerably more drivers from the other young groups (80% of Group 3, 87% of Group 4, 67% of Group 5) and highly experienced group (67%) looked at the right corner. However, 16 participants (3 each from Group 1 & 2, 4 from Group 3, 2 each from Group 4, 5 and 6), had fixation on the

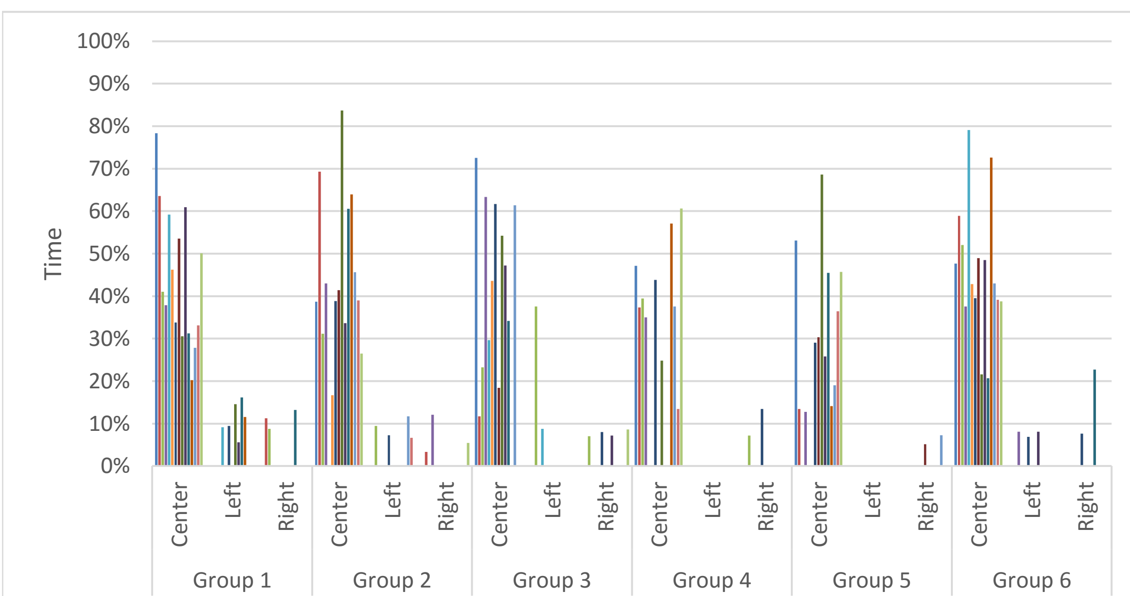


Figure 9: Percentage of fixation duration across the three ROIs

study ROI. Thus, due to lack of fixation data, statistical analyses of eye movement behavior were performed based on the gaze data only.

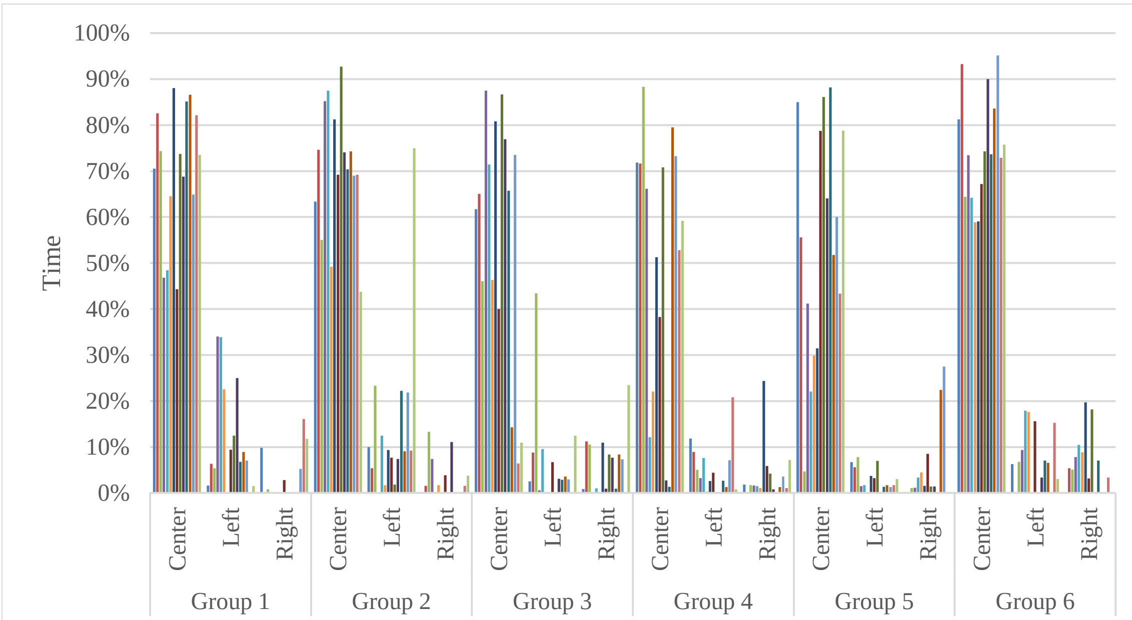


Figure 10: Percentage of gaze duration across the three ROIs

Descriptive Statistics

Gaze Measures

Figure 11 presents the boxplot diagrams of the distribution of (a) percentage of the gaze duration, (b) mean gaze duration, (c) gaze rate, (d) percentage of time to first gaze. The summary statistics of each of these measures are given in Table 4, 5, 6 and 7 respectively. It was observed from the data sets that the highly experienced drives (Group 6) had the highest mean score of the percentage of gaze and mean gaze duration measure. This indicates that participants of Group 6 spent relatively more time in viewing the ROI than any other group, and Group 4 spent the least. Group 3 looked at the ROI more frequently than other groups, as suggested by their higher gaze rate. However, on an average Group 5 took the lowest time to make the first gaze on the study ROI. In this regard, it can be noted that the time taken to make the first gaze reduced gradually from Group 2 to Group 5, indicating a negative association between the time to make first gaze and the level of driving experience across the groups.

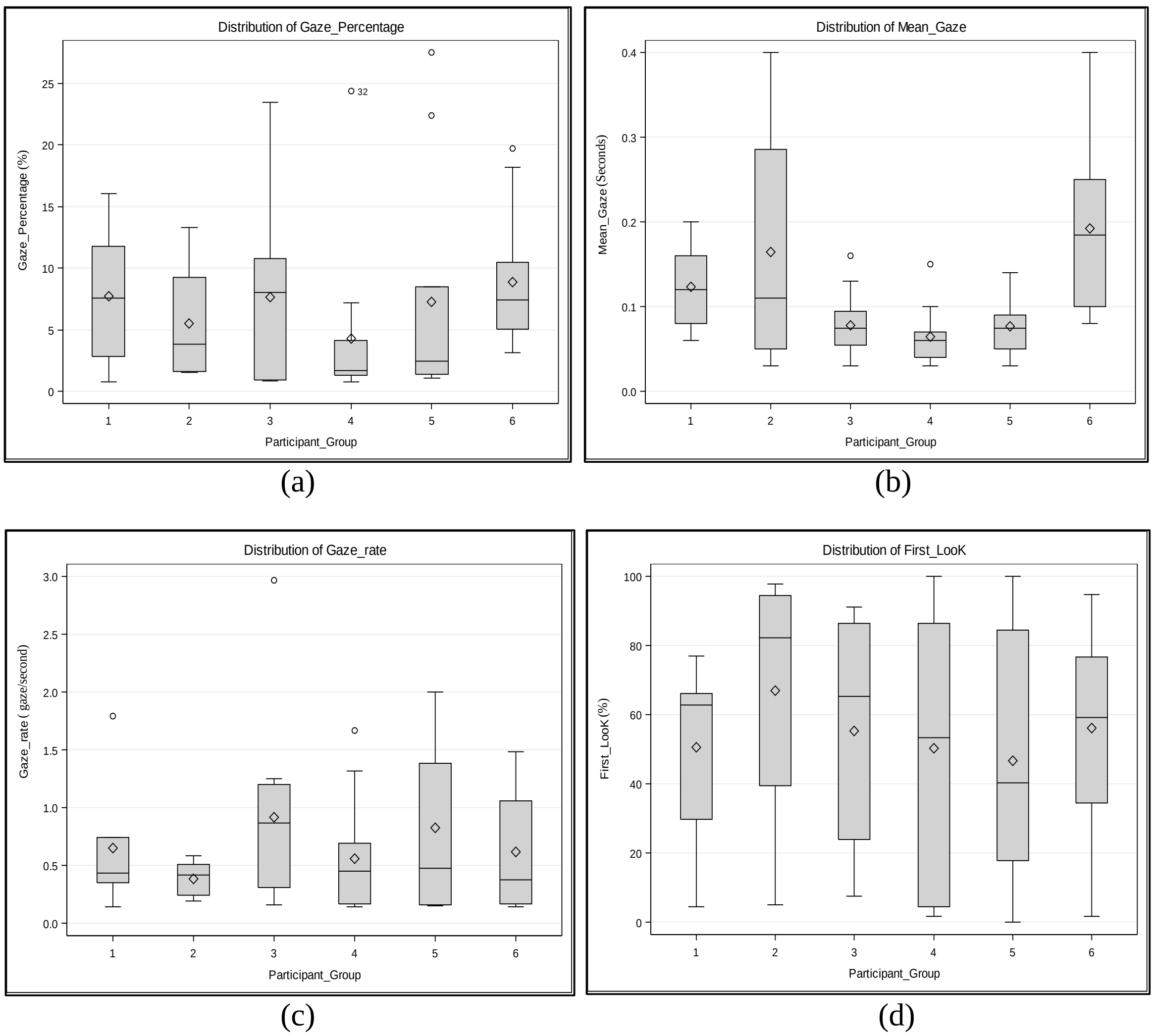


Figure 11: Boxplot diagram of the distribution of (a) percentage of the gaze duration, (b)

Table 4: Descriptive statistics of percentage of gaze duration

Group	Mean	Standard Deviation	Range	Inter Quartile Range
Group 1	7.8%	5.8%	15.3%	8.9%
Group 2	5.5%	4.6%	11.8%	7.6%
Group 3	7.6%	6.5%	22.6%	9.8%
Group 4	4.3%	6.4%	23.6%	2.9%
Group 5	7.3%	9.7%	26.4%	7.1%
Group 6	8.9%	5.78%	16.5%	5.4%

Table 5: Descriptive statistics of mean gaze duration (seconds)

Group	Mean	Standard Deviation	Range	Inter Quartile Range
Group 1	0.12	0.06	0.14	0.09
Group 2	0.17	0.14	0.37	0.23
Group 3	0.078	0.04	0.14	0.04
Group 4	0.064	0.031	0.11	0.03
Group 5	0.077	0.032	0.10	0.041
Group 6	0.19	0.1	0.32	0.15

Table 6: Descriptive statistics of gaze rate (number of gazes/second)

Group	Mean	Standard Deviation	Range	Inter Quartile Range
Group 1	0.64	0.59	1.65	0.38
Group 2	0.38	0.15	0.39	0.26
Group 3	0.91	0.77	2.81	0.88
Group 4	0.56	0.48	1.53	0.52
Group 5	0.82	0.76	1.85	1.22
Group 6	0.61	0.49	1.34	0.89

Table 7: Descriptive statistics of percentage of time to make first gaze

Group	Mean	Standard Deviation	Range	Inter Quartile Range
Group 1	50.53%	27.61%	72.49%	36.39%
Group 2	66.88%	35.68%	92.61%	54.90%
Group 3	55.24%	33.26%	83.56%	62.67%
Group 4	50.10%	40.29%	96.33%	81.94%
Group 5	46.61%	35.26%	97.83%	66.58%
Group 6	56.12%	29.49%	92.84%	42.19%

Rotation Measures

Figure 12 illustrates the distribution of the mean (a) gaze heading, (b) gaze pitch, (c) head heading, (d) head pitch (in radian). Summary statistics are given in Table 8, 9, 10 and 11 respectively. While extracting data in MAPPS software, it was found that mean gaze heading typically ranges from -1.3 (left most corner of their horizontal field of view) to 1.3 (right most corner). Thus the data indicates that most of the Group 1 and 2

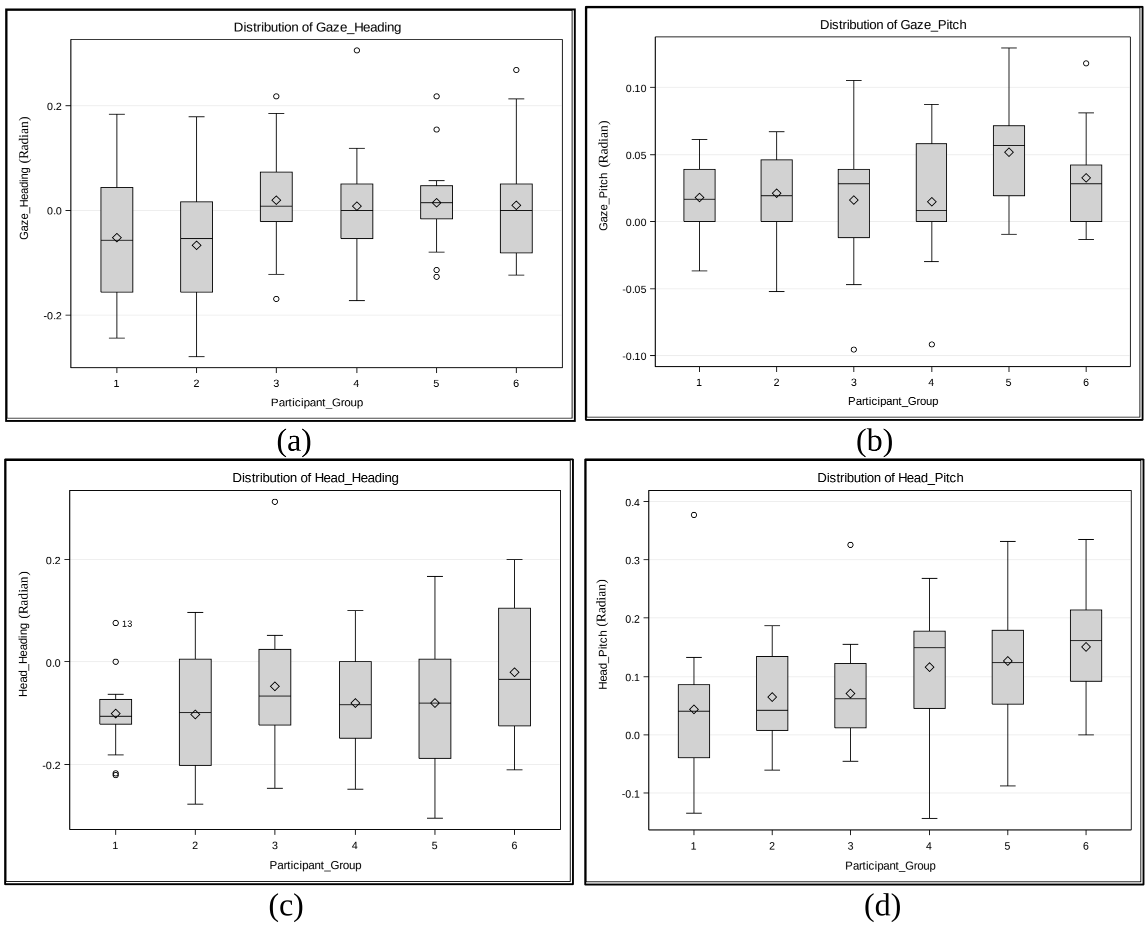


Figure 12: Boxplot diagram of the distribution of mean (a) gaze heading, (b) gaze pitch, (c) head heading, (d) head pitch

participants had their gaze directed toward the left side of the horizontal field of view. As the experience level increased, participants of the other young drivers' groups tended to have their gaze directed either closer to the center or to the right side of the horizontal field of view. Similar pattern was noticed among the drivers' groups in terms of head

Table 8: Descriptive statistics of percentage of gaze heading

Group	Mean	Standard Deviation	Range	Inter Quartile Range
Group 1	-0.052	0.132	0.427	0.200
Group 2	-0.067	0.126	0.458	0.171
Group 3	0.019	0.103	0.386	0.095
Group 4	0.008	0.109	0.478	0.103
Group 5	0.014	0.089	0.343	0.064
Group 6	0.009	0.117	0.391	0.131

Table 9: Descriptive statistics of percentage of gaze pitch

Group	Mean	Standard Deviation	Range	Inter Quartile Range
Group 1	0.018	0.029	0.098	0.039
Group 2	0.021	0.032	0.119	0.046
Group 3	0.016	0.050	0.200	0.051
Group 4	0.015	0.045	0.179	0.058
Group 5	0.052	0.039	0.139	0.052
Group 6	0.033	0.035	0.131	0.042

Table 10: Descriptive statistics of percentage of head heading

Group	Mean	Standard Deviation	Range	Inter Quartile Range
Group 1	-0.101	0.075	0.296	0.048
Group 2	-0.102	0.121	0.374	0.207
Group 3	-0.047	0.132	0.560	0.147
Group 4	-0.080	0.105	0.349	0.149
Group 5	-0.080	0.137	0.472	0.195
Group 6	-0.020	0.131	0.410	0.230

Table 11: Descriptive statistics of percentage of head pitch

Group	Mean	Standard Deviation	Range	Inter Quartile Range
Group 1	0.044	0.118	0.511	0.124
Group 2	0.065	0.072	0.249	0.127
Group 3	0.071	0.091	0.371	0.111
Group 4	0.116	0.105	0.412	0.133
Group 5	0.127	0.110	0.421	0.128
Group 6	0.152	0.093	0.335	0.122

heading measure. In the vertical field of view participants were generally rotating their head and gaze vertically upward from the center. The mean score of head pitch per group was observed to be increasing with the driving experience level, suggesting that the drivers with more experience looked relatively far ahead compared to their less experienced peers.

However, as indicated in the above boxplots, most of the data sets had outliers. An outlier is an observation point that is distant from other observations. Thus, outliers might affect the statistical analysis, especially the parametric type. For the purposes of all analyses, outliers were defined as those data points which fall more than 3 times the interquartile range above the third quartile or below the first quartile. These data points are known as “extreme outliers” and can have dramatic influence on statistical analyses (Durkee, 2010). Outliers were analyzed for each scenario of each dependent variable. Using the above definition no “extreme outlier” was found for any of the data sets.

Trend Analysis

Spearman’s correlation was run to determine trend/association between any of the dependent variables and the driving experience. The results are given in Table 12. Significant association was found only for head pitch measure. The correlation coefficient ($r_s = 1$) suggested very strong positive association between mean head pitch and driving experience. Apart from this, the values of the correlation coefficient for gaze

Table 12: Trend analysis results

Variable Type	**Dependent Variable**	**Coefficient (r_s)**	**p-value**	**Remarks**
Gaze Measures	Percentage of Gaze Duration	0.14	0.79	Insignificant
	Mean Gaze Duration	-0.03	0.95	Insignificant
	Gaze Rate	0.09	0.87	Insignificant
	Time to First Gaze	-0.20	0.7	Insignificant
Rotation Measures	Gaze Heading	0.54	0.26	Insignificant
	Gaze Pitch	0.43	0.4	Insignificant
	Head Heading	-0.09	0.87	Insignificant
	Head Pitch	1	<0.001	**Significant**

heading (r_s = 0.54) and gaze pitch (r_s = 0.43) indicate moderate positive association between these measures and driving experience level, though statistically insignificant. This is, perhaps, due to the small data set (6 pairs) being used to perform the analysis.

However, such results of the trend analysis might have been confounded by participants' age and driving experience in terms of mileage driven per annum. Because experienced drivers are often older and drive more than novice drivers, these "natural" confounds are common limitations to studies of novice drivers. Ignoring confounding when assessing the association between an exposure and an outcome variable can lead to an overestimate or underestimate of the true association between exposure and outcome and can even change the direction of the observed effect. Thus, partial Spearman's correlation was further administered in an attempt to assess the effect of each confounding factor on the dependent measures. The results are given in Table 13. Partial correlation analysis revealed that only the drivers' age had statistically significant but weak positive association (r_s = 0.22) with the dependent measure head heading while controlling the driving experience in both years and miles. No association was observed between the factor driving experience in miles per annum and any of the dependent measures when factor age and experience in years were controlled. Thus, the partial correlation analyses ruled out the potential significant effect of confounding factors on the results of the primary trend analyses.

Table 13: Partial Trend Analysis results

Factor	Control	Dependent Variable	Coefficient (r_s)	p-value	Remarks
Age	Driving Experience in years and miles	Percentage of Gaze Duration	0.054	0.69	Insignificant
		Mean Gaze Duration	0.083	0.53	Insignificant
		Gaze Rate	-0.017	0.89	Insignificant
		Time to First Gaze	-0.014	0.917	Insignificant
		Gaze Heading	-0.18	0.10	Insignificant
		Gaze Pitch	-0.063	0.56	Insignificant
		Head Heading	**0.22**	**0.04**	**Significant**
		Head Pitch	0.086	0.28	Insignificant
Driving Experience in miles	Age and Driving Experience in years	Percentage of Gaze Duration	0.001	0.994	Insignificant
		Mean Gaze Duration	0.23	0.08	Insignificant
		Gaze Rate	-0.18	0.17	Insignificant
		Time to First Gaze	0.15	0.25	Insignificant
		Gaze Heading	-0.08	0.42	Insignificant
		Gaze Pitch	0.19	0.082	Insignificant
		Head Heading	-0.18	0.093	Insignificant
		Head Pitch	-0.007	0.94	Insignificant

ANOVA Analysis

Kolmogorov-Smirnov and Levene Tests were performed to test the normality and homogeneity of variance of the each data set at five percent significance level. Violation of ANOVA assumptions were observed for all of the gaze measures. Necessary transformations were performed. None of the transformations resulted in data that met the ANOVA assumption of normality. Thus, nonparametric one-way ANOVA Kruskal-Wallis Test was administered for all gaze measures. On the other hand, all the rotation measures had met the normality assumption. Furthermore, no major violation of homogeneity assumption was observed. Hence, one-way ANOVA was administered for all rotation measures. The results of all ANOVA analyses are given in Table 14.

Table 14: ANOVA analysis results

Variable Type	Dependent Variable	Test Type	Test Statistics	P - value	Remarks
Gaze Measures	Percentage of Gaze Duration	Kruskal-Wallis	$\chi^2_{(5, n=59)} = 6.13$	0.29	Insignificant
	Mean Gaze Duration		$\chi^2_{(5, n=59)} = 18.7$	0.002	**Significant**
	Gaze Rate		$\chi^2_{(5, n=59)} = 2.8$	0.72	Insignificant
	Time to First Gaze		$\chi^2_{(5, n=59)} = 2.1$	0.83	Insignificant
Rotation Measures	Gaze Heading	One-Way Kruskal-Wallis	F (5, 84) = 1.66 $\chi2(5, n=90) = 6.83$	0.15 0.23	Insignificant
	Gaze Pitch		F (5, 84) = 2.04 $\chi2(5, n=90) = 8.54$	0.08 0.13	Insignificant
	Head Heading		F (5, 84) = 1.09 $\chi2(5, n=90) = 4.36$	0.37 0.49	Insignificant
	Head Pitch		F (5, 84) = 3 $\chi2(5, n=90) = 17.9$	0.030 0.031	**Significant**

Based on the Kruskal-Wallis test results, significant main effect of driving experience was found only on mean gaze duration. Post hoc comparisons, using the Wilcoxon-Mann-Whitney test, indicated that the mean gaze duration of Group 3, 4 and 5 were significantly different than the highly experienced drivers (Group 6) at five percent significance level. Group 4 was also found to be significantly different than Group 1. All other comparisons were not significant. Significant results of the Wilcoxon-Mann-Whitney tests and the corresponding effect sizes are given in the Table 15. The value of the effect size for each comparison indicated high practical significance.

Table 15: Significant results of Wilcoxon-Mann-Whitney test for mean gaze duration

Group	Z Score	p-value	Effect size *r*
Group 1 vs Group 4	2.425	0.015	0.44
Group 3 vs Group 6	3.108	0.002	0.57
Group 4 vs Group 6	3.578	0.0004	0.65
Group 5 vs Group 6	-3.032	0.002	0.55

For the rotation measures, one-way ANOVA analysis revealed significant effect of driving experience only on head pitch at five percent significance level. Post hoc comparisons using the Bonferroni correction indicated that the mean score for the Group 1 ($M = 0.044$, $SD = 0.12$) was significantly different than the highly experienced group ($M = 0.152$, $SD = 0.093$). Further, Cohen's effect size value ($d = 1.01$) suggested a high practical significance.

Since the data sets of rotation measures had mild outliers, non-parametric Kruskal-Wallis test was administered to verify one-way ANOVA results. Significant main effect of driving experience was found only on head pitch measure, verifying previous parametric test results. Wilcoxon-Mann-Whitney test further indicated that the mean head pitch of Group 1 was significantly different than Group 6 ($Z = -2.47$, $p=0.02$).

Siegel-Tukey Test

Two sided Siegel-Tukey test was performed to determine which one of the five young driver groups tended to have more widely dispersed or spread out data than the highly experienced group (Group 6). Each young drivers' group was tested against the experienced group with respect to each of the dependent variable. Significant results were observed for mean gaze duration, gaze rate and head heading measures. Other comparisons were insignificant at five percent significance level. Significant results of the Siegel-Tukey tests for the mean gaze duration measure are given in Table 16. The results revealed that the data spread or dispersion within Group 3, 4 and 5 were significantly different than the highly experienced driver group.

Table 16: Siegel-Tukey test results for mean gaze duration

Group	Z value	p value
Group 3 vs Group 6	-2.38	0.0175
Group 4 vs Group 6	-2.71	0.0067
Group 5 vs Group 6	-2.69	0.0153

For the gaze rate, Siegel-Tukey test results indicated that only the Group 5 tended to have significantly spread out data than the highly experienced group (z=-2.32, p=0.021). However, in terms of head heading measure, the test result revealed that the within group variability was significantly different than the highly experienced group (z=-2.34, p=0.02).

Equivalence Analysis

Schuirman's TOST (Two One Sided Test) for equivalence analysis was performed to determine which young drivers' group could be considered to be equivalent to the highly experienced group in terms of the measured indicators. Existing literature recommended the threshold value to be set as 100 milliseconds for glance duration (Inhoff and Radach, 1998, Manor and Gordon, 2003). For the percentage of gaze duration measure, the threshold value was then set to 1.5 %, since 1.5% of the average study time window (6.8 seconds) was ~ 100 milliseconds. As recommended, 100 millisecond was also set as threshold for mean gaze duration. Rest of the thresholds were set to the overall standard deviation of each data set. The threshold values utilized to perform equivalence test are given in Table 17.

Table 17: Thresholds for Equivalence Analysis

Variable Type	Dependent Variable	Threshold
Gaze Measures	Percentage of Gaze Duration	1.5%
	Mean Gaze Duration	100 milliseconds
	Gaze Rate	0.19/second
	Time to First Gaze	7.1%
Rotation Measures	Gaze Heading	0.04 radian
	Gaze Pitch	0.014 radian
	Head Heading	0.074 radian
	Head Pitch	0.042 radian

Each one of the five young drivers' groups was tested against the experienced group with respect to all dependent variables. Based on the results at 5% significance level, none of the young drivers' groups was found to be equivalent to the experienced group in terms any of the measured indicators.

Scenario 2

Figure 13 shows the percentage of fixation duration on the defined ROI at Scenario 2. Only 9 participants had fixations on the study ROI. Thus, there were not enough fixation data to perform statistical analysis further. 24 participants, 20% of Group 1, 33% of Group 2, 27% of Group 3, 40% of Group 4, 27% of Group 5, and 13% of Group 6, were found to have gazes (Figure 14). Overall 29 participants (few made only fixation but not any gaze and vice versa) had looked at the ROI while driving through. Though not sufficient enough to make compelling argument, gaze data were still analyzed to have some general understandings about the drivers' eye scanning pattern at Scenario 2.

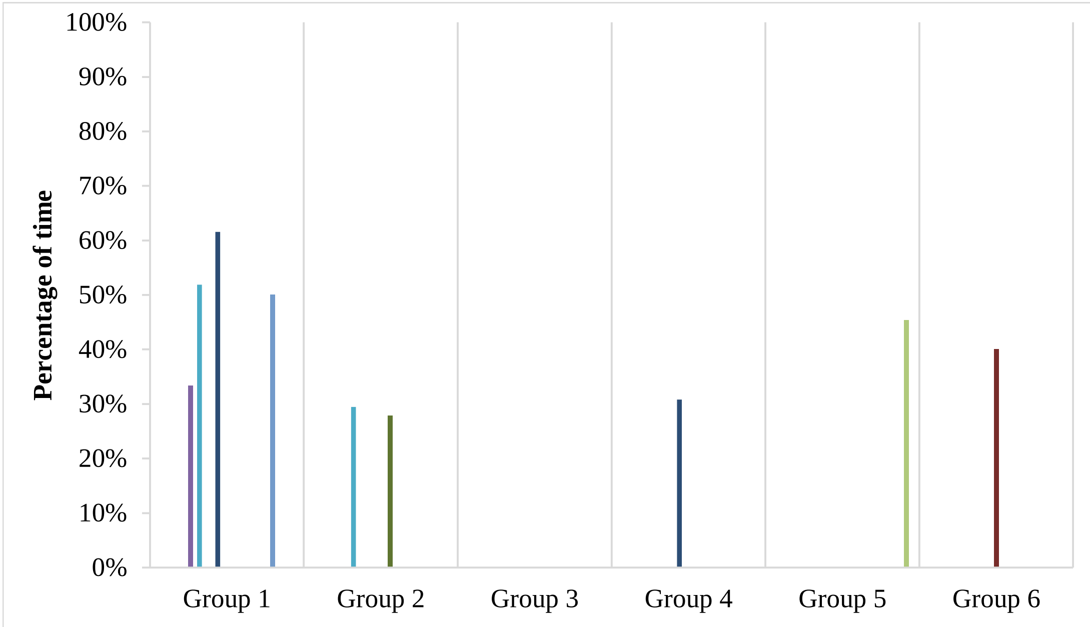


Figure 13: Percentage of fixation duration on the study ROI at scenario 2

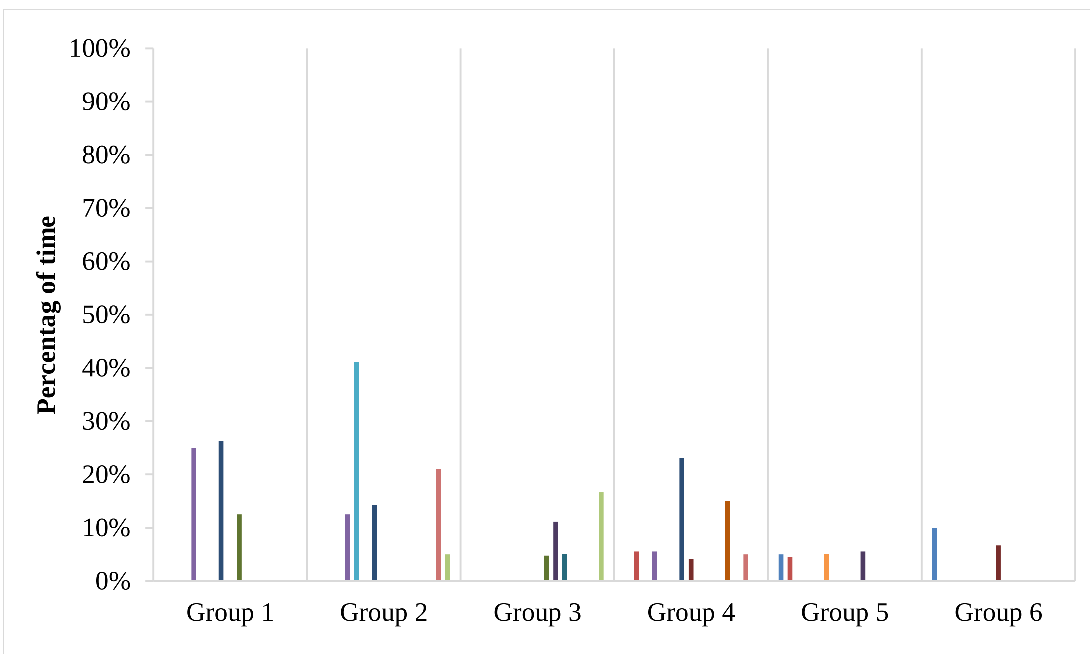


Figure 14: Percentage of gaze duration on the study ROI at scenario 2

Descriptive Statistics

Gaze Measures

The boxplot diagrams of the distribution of (a) percentage of the gaze duration, (b) mean gaze duration, (c) gaze rate, (d) percentage of time to first gaze have been provided in Figure 15.

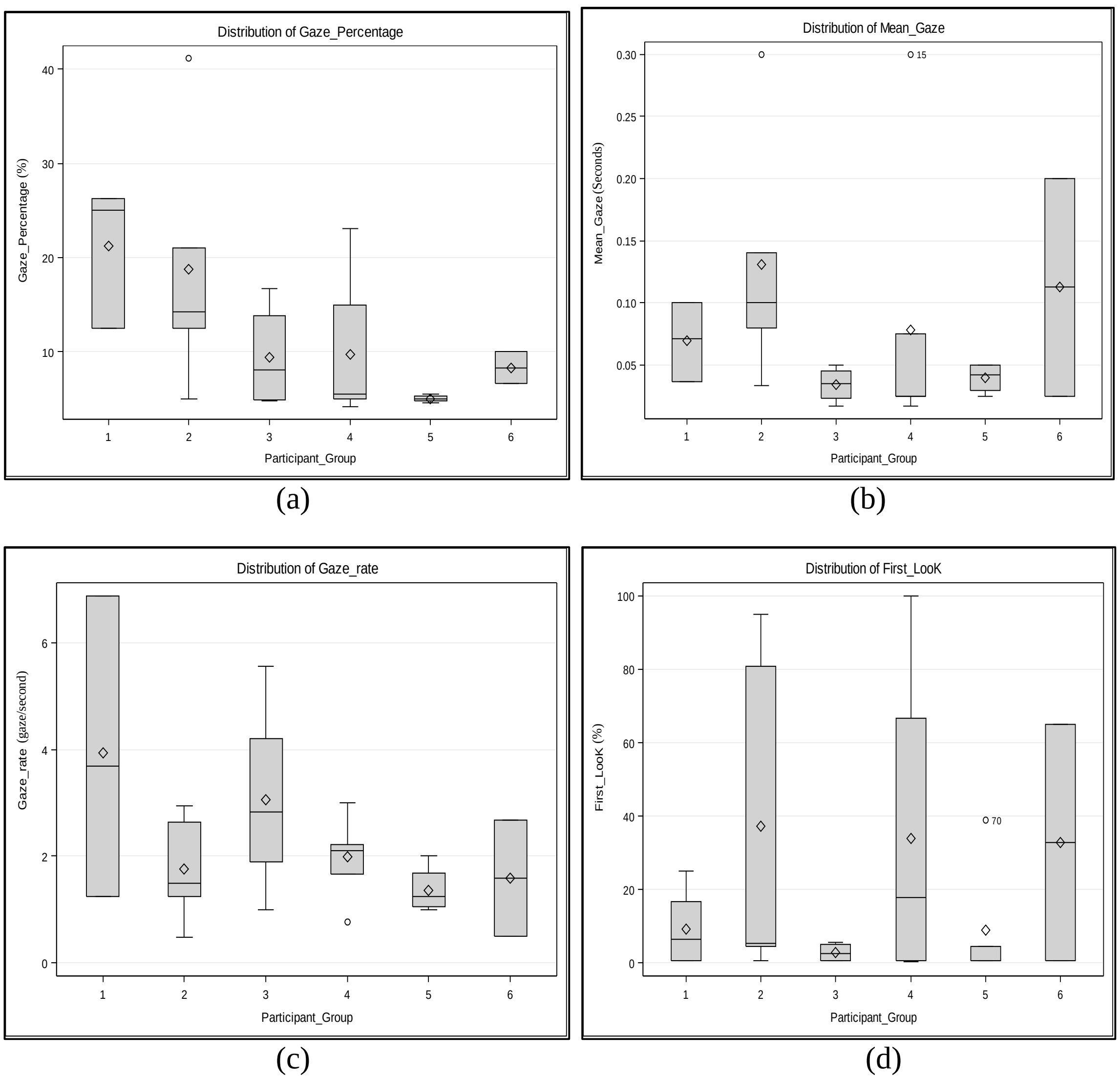


Figure 15: Boxplot diagram of the distribution of (a) percentage of the gaze duration, (b) mean gaze duration, (c) gaze rate, (d) percentage of time to first gaze

The summary statistics of each of these measures are given in Table 18, 19, 20 and 21 respectively. It appeared from the Figure 15 (a) that the average amount of time spent on looking at the ROI had a decreasing tendency across the young drivers groups (Group 1-5).

On an average, Group 1 spent highest amount of time viewing the ROI, Group 5 was the least followed by Group 6. Similar pattern was observed (except the Group 2) in terms of the gaze rate measure. Experienced drivers were looking at the ROI less frequently than the inexperienced drivers as indicated by their respective gaze rate. However, mean gaze duration (Figure 15 b) was found to be the highest for the Group 2, that is, on an average Group 3 participants were paying relatively more attention each time they looked at the ROI. Though Group 3 had the lowest mean gaze duration, this Group took the lowest time to make the first gaze. As indicated by the mean score (Table 20), Group 3 participants glanced at the ROI almost immediately after it had appeared.

Table 18: Descriptive statistics of percentage of gaze duration

Group	**Mean**	**Standard Deviation**	**Range**	**Inter Quartile Range**
Group 1	21.27%	7.63%	0.58%	13.82%
Group 2	18.80%	13.75%	1.89%	36.18%
Group 3	9.38%	5.67%	0.32%	11.90%
Group 4	9.73%	7.67%	0.59%	18.91%
Group 5	5.03%	0.41%	0.02%	1.01%
Group 6	8.33%	2.36%	0.06%	3.33%

Table 19: Descriptive statistics of mean gaze duration (seconds)

Group	**Mean**	**Standard Deviation**	**Range**	**Inter Quartile Range**
Group 1	0.07	0.03	0.06	0.06
Group 2	0.13	0.10	0.27	0.06
Group 3	0.03	0.01	0.03	0.02
Group 4	0.07	0.11	0.30	0.06
Group 5	0.04	0.01	0.03	0.02
Group 6	0.11	0.12	0.18	0.18

Table 20: Descriptive statistics of gaze rate (number of gazes/second)

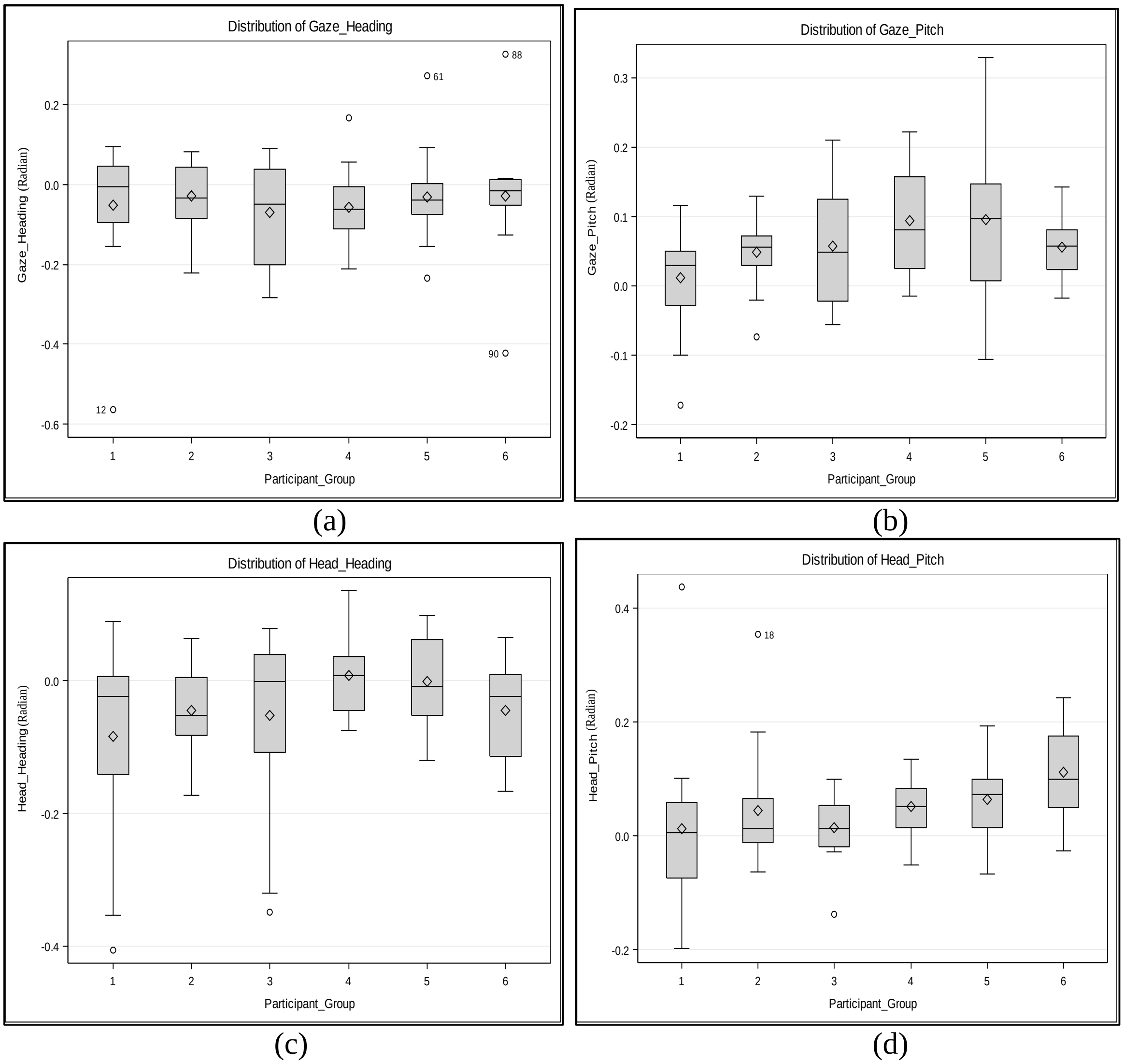
Group	Mean	Standard Deviation	Range	Inter Quartile Range
Group 1	3.94	2.82	5.63	5.63
Group 2	1.76	1.01	2.46	1.38
Group 3	3.05	1.88	4.56	2.32
Group 4	1.98	0.74	2.23	0.55
Group 5	1.37	0.45	1.00	0.63
Group 6	1.59	1.53	2.17	2.17

Table 21: Descriptive statistics of percentage of time to make first gaze

Group	Mean	Standard Deviation	Range	Inter Quartile Range
Group 1	9.31%	10.40%	24.47%	16.11%
Group 2	37.24%	46.62%	94.41%	76.58%
Group 3	2.84%	2.69%	5.06%	4.63%
Group 4	33.84%	41.00%	99.58%	66.17%
Group 5	9.00%	16.80%	38.39%	4.05%
Group 6	32.83%	45.49%	64.33%	64.33%

Rotation Measures

Figure 16 illustrates the distribution of the mean (a) gaze heading, (b) gaze pitch, (c) head heading, (d) head pitch (in radian). Corresponding summary statistics are provided in Table 22, 23, 24 and 25. It was observed that at Scenario 2 Group 1 participants were directing their gazes more closely to the center of the horizontal field of view, followed by Group 6. Opposite result was observed for the Group 1 participants regarding the head heading measure. They were found to be pointing out their head much wider from the center to the left corner compared to the other Groups. In general, participants were mostly directing their head and gazes toward the left corner, and thereby, away from the study region of interest.



(a) (b)

(c) (d)

Figure 16: Boxplot diagram of the distribution of mean (a) gaze heading, (b) gaze pitch, (c) head heading, (d) head pitch

However, like Scenario 1, participants were mostly looking at far ahead in their vertical field of view. Young experienced drivers were observed to be directing their gaze more upward than the inexperienced drivers. With an exception of Group 2, similar pattern was exhibited by the drivers in their head movement in vertical plane. Overall, these observations indicate that in the vertical field of view, less experienced drivers were focusing relatively closer to the vehicle than their experienced counterparts.

Table 22: Descriptive statistics of percentage of gaze heading

Group	Mean	Standard Deviation	Range	Inter Quartile Range
Group 1	-0.053	0.159	0.658	0.140
Group 2	-0.029	0.083	0.303	0.130
Group 3	-0.070	0.122	0.372	0.241
Group 4	-0.058	0.097	0.379	0.106
Group 5	-0.031	0.114	0.507	0.075
Group 6	-0.030	0.152	0.748	0.064

Table 23: Descriptive statistics of percentage of gaze pitch

Group	Mean	Standard Deviation	Range	Inter Quartile Range
Group 1	0.011	0.071	0.288	0.078
Group 2	0.048	0.050	0.203	0.042
Group 3	0.057	0.085	0.267	0.147
Group 4	0.093	0.077	0.236	0.132
Group 5	0.096	0.119	0.435	0.140
Group 6	0.056	0.045	0.159	0.057

Table 24: Descriptive statistics of percentage of head heading

Group	Mean	Standard Deviation	Range	Inter Quartile Range
Group 1	-0.084	0.140	0.020	0.146
Group 2	-0.044	0.064	0.004	0.087
Group 3	-0.052	0.129	0.017	0.147
Group 4	0.008	0.057	0.003	0.082
Group 5	-0.001	0.073	0.005	0.115
Group 6	-0.044	0.074	0.005	0.123

Table 25: Descriptive statistics of percentage of head pitch

Group	Mean	Standard Deviation	Range	Inter Quartile Range
Group 1	0.012	0.143	0.635	0.133
Group 2	0.044	0.110	0.416	0.079
Group 3	0.014	0.057	0.237	0.072
Group 4	0.051	0.054	0.185	0.069
Group 5	0.064	0.067	0.261	0.085
Group 6	0.112	0.081	0.269	0.124

Trend Analysis

The results of the Spearman's correlation analysis are given in Table 26. For the Scenario 2, significant association was observed in terms of percentage of gaze duration and head pitch measures. The correlation coefficient (r_s= -0.89), found for the indicator percentage of gaze duration, suggests that experienced drivers tended to spend less amount of time looking at the ROI at Scenario 2. Although not statistically significant, a moderate negative association between the gaze rate measure and driving experience level was further indicated by the corresponding correlation coefficient (r_s= -0.54).

However, in terms of the rotation measures, significant association was observed only between the mean head pitch and driving experience (r_s =0.94, p=0.047), i.e., the experienced drivers were moving their head in more upward region of the vertical plane compared to their less experienced peers. In addition, the correlation coefficient (r_s =0.71) observed for the head heading measure indicated a strong positive upward trend (though not statistically significant). This finding suggests that experienced drivers moved their head more closely to the center of the horizontal field of view than the inexperienced drivers while driving through the scenario.

Table 26: Trend analysis results

Variable Type	**Dependent Variable**	**Coefficient (r_s)**	**p-value**	**Remarks**
Gaze Measures	Percentage of Gaze Duration	-0.89	0.02	**Significant**
	Mean Gaze Duration	-0.09	0.87	Insignificant
	Gaze Rate	-0.54	0.26	Insignificant
	Time to First Gaze	-0.08	0.9	Insignificant
Rotation Measures	Gaze Heading	0.14	0.79	Insignificant
	Gaze Pitch	0.66	0.16	Insignificant
	Head Heading	0.71	0.11	Insignificant
	Head Pitch	0.94	0.04	**Significant**

Partial correlation analysis results (given in Table 27) did not reveal any significant association between drivers' age and any of the dependent measures. However, moderate but significant negative association (rs = -0.54) was observed between the factor driving experience in miles and gaze rate measures when age and driving experience in years were controlled. Such result indicates that the participants who drove more miles per annum tended to look at the stop ahead sign less frequently than their inexperienced counterparts.

The partial correlation analyses did not reveal compelling evidence that the primary trend analysis results were biased by the confounding effects of age and miles driven per year.

Table 27: Partial trend analysis results

Factor	Control	Dependent Variable	Coefficient (r_s)	p-value	Remarks
Age	Driving Experience in years and miles	Percentage of Gaze Duration	0.09	0.69	Insignificant
		Mean Gaze Duration	0.16	0.46	Insignificant
		Gaze Rate	-0.23	0.29	Insignificant
		Time to First Gaze	-0.04	0.81	Insignificant
		Gaze Heading	-0.18	0.08	Insignificant
		Gaze Pitch	-0.044	0.89	Insignificant
		Head Heading	-0.19	0.07	Significant
		Head Pitch	0.08	0.44	Insignificant
Driving Experience in miles	Age and Driving Experience in years	Percentage of Gaze Duration	0.009	0.96	Insignificant
		Mean Gaze Duration	0.37	0.08	Insignificant
		Gaze Rate	**-0.50**	**0.02**	**Significant**
		Time to First Gaze	0.21	0.29	Insignificant
		Gaze Heading	-0.13	0.21	Insignificant
		Gaze Pitch	-0.14	0.21	Insignificant
		Head Heading	-0.18	0.09	Insignificant
		Head Pitch	0.03	0.73	Insignificant

ANOVA Analysis

None of the data set of gaze measures satisfied the ANOVA normality and homogeneity of variance assumptions, even after necessary transformations. Thus, Kruskal-Wallis Test was performed for all gaze measures. The rotation measures, on the other hand, met the ANOVA assumptions. Hence, one-way ANOVA was administered for those data sets. The results of all ANOVA analyses are given in Table 28.

Table 28: ANOVA analysis results

Variable	Dependent Variable	Test Type	Test Statistics	p-value	Remarks
Gaze Measures	Percentage of Gaze Duration	Kruskal-Wallis	$\chi^2_{(5, n=24)} = 11.17$	0.048	**Significant**
	Mean Gaze Duration		$\chi^2_{(5, n=24)} = 7.98$	0.16	Insignificant
	Gaze Rate		$\chi^2_{(5, n=24)} = 5.01$	0.41	Insignificant
	Time to First Gaze		$\chi^2_{(5, n=29)} = 3.8$	0.57	Insignificant
Rotation Measures	Gaze Heading	One-Way Kruskal-Wallis	$F_{(5, 84)} = 0.29$ $\chi^2_{(5, n=90)} = 2.11$	0.92 0.83	Insignificant
	Gaze Pitch		$F_{(5, 84)} = 3$ $\chi^2_{(5, n=90)} = 12.74$	0.012 0.025	**Significant**
	Head Heading		$F_{(5, 84)} = 1.86$ $\chi^2_{(5, n=90)} = 6.92$	0.11 0.22	Insignificant
	Head Pitch		$F_{(5, 84)} = 2.39$ $\chi^2_{(5, n=90)} = 11.41$	0.044 0.041	**Significant**

In terms of the gaze measures, significant main effect of driving experience was found only on the percentage of gaze duration at five percent significance level (χ^2=11.17, p=0.048). Post hoc comparisons, using the Wilcoxon-Mann-Whitney test, indicated that the mean percentage of gaze duration of Group 1 was significantly different than the Group 5 and the highly experienced Group (Z = 1.96, p=0.049). Further, effect size value (r = 0.36) suggested a moderate practical significance.

However, the results of the one-way ANOVA analyses revealed significant effect of driving experience on both gaze pitch ($F_{(5, 84)}$ = 2.36, p=0.047) and head pitch measure

($F_{(5, 84)}$ = 2.39, p=0.044). Post hoc comparisons using the Bonferroni correction method did not indicate any difference among the study Groups. Hence, Tukey's HSD test was performed. The results of the test indicated that the mean score of gaze pitch for the Group 1 (M = 0.011, SD = 0.071) was significantly different than the highly experienced Group (M = 0.056, SD = 0.045). Cohen's effect size value (*d* =0.75) further suggested a moderate to high practical significance. Similarly, the mean head pitch value of Group 1 (M = 0.012, SD = 0.143) was found to be significantly different than the highly experienced Group (M = 0.112, SD = 0.081). Cohen's effect size value (d =0.86) indicated a high practical significance. These results were further supported by the non-parametric Kruskal-Wallis test results (Table 28). Similar to the parametric test outputs, driving experience was found to be significant for both gaze ($\chi 2$ = 12.74, p= 0.025) and head pitch measures ($\chi 2$ = 11.4, p = 0.041) at five percent significance level.

Siegel-Tukey Analysis

Siegel-Tukey test results did not reveal significant difference between any of the young drivers' groups and the highly experienced drivers with respect to their within-Group variability, except for gaze pitch measure. Test results for gaze pitch indicated that only Group 4 tended to have significantly dispersed or spread out data than the highly experienced Group (Z= 20.1, p=0.044).

Equivalence Analysis

The required threshold values in order to perform equivalence analysis were determined based on the same principle applied in determining the thresholds at Scenario

1. The threshold values that were utilized to perform equivalence tests are given in Table 29.

Table 29: Thresholds for Equivalence Analysis

Variable Type	**Dependent Variable**	**Threshold**
Gaze Measures	Percentage of Gaze Duration	6%
	Mean Gaze Duration	100 milliseconds
	Gaze Rate	1/second
	Time to First Gaze	15.35%
Rotation Measures	Gaze Heading	0.018 radian
	Gaze Pitch	0.032 radian
	Head Heading	0.034 radian
	Head Pitch	0.037 radian

Each one of the five young driver Groups was tested against the experienced Group with respect to all dependent variables. However, based on the results at five percent significance level, only Group 5 was found to be significantly equivalent to the highly experienced Group ($p=0.033$).

CHAPTER 5 – DISCUSSION

The present study was an attempt to investigate the hazard perception differences among young drivers and to explore the level at which the novice drivers' hazard perception skill matches with their experienced cohorts while driving through two on-road potentially hazardous scenarios. Four hypotheses were posited to test the connection between experience and the measured indicators. The hypotheses were examined with respect to eight indicators: percentage of gaze duration, mean gaze duration, percentage of time taken to make the first gaze to the study ROI, gaze rate, gaze heading, gaze pitch, head heading and head pitch. A total of 90 participants completed the study. Participants were split into six groups (15 each) on the basis of their driving experience. Discussions on the results are summarized based on the two objectives of the study.

Objective 1

The first objective of the study was to investigate the hazard perception differences of young drivers when compared against highly experienced drivers. It was observed from the data sets that all the participants were focusing mostly on the central region of their forward field of view while driving through the scenarios. This is consistent with the findings of some previous studies (e.g., Underwood et al., 2003; Mourant & Rockwell, 1972). Those studies reported that regardless of the experience level, the majority of drivers tended to direct their gazes/fixations straight ahead when driving in quieter and less demanding scenarios. Recently, Imtiaz & Stanley (2015) reported similar findings while investigating the hazard perception differences of less, intermediate and highly experienced adult drivers with 1-2 years, 2-5 years and over 15 years of experiences, respectively.

However, several studies (e.g., Falkmer & Gregersen, 2001; Crundall & Underwood, 1998; Wikman et al., 1998) indicated that busy, demanding road conditions bias the drivers' eye-scanning behavior due to increased cognitive load. Thus, the present study scenarios were selected to ensure that the drivers were not exposed to any additional cognitive load other than anticipating potential hazards.

At Scenario 1, the objective was to measure a driver's ability to recognize that pedestrians/bicyclist might emerge from behind a line of bushes that obscured a sidewalk on the right. While 87 % of novice and 93 % of limited experienced drivers were observed looking at the left corner of the scenario, only 40% and 53% of those drivers, respectively, looked on the right corner (study ROI). On the other hand, higher number of other young and experienced drivers were found to be looking at both corners. Pradhan et al. (2005) also reported similar findings. They found that 16-17 years-old drivers with six months of experiences often failed to show anticipatory eye glances than 19-29 year-old drivers with a couple of years of driving experience in situations with covert latent hazards. Thus, by comparing the finding of the current study with Pradhan et al.'s it can be inferred that even after two years of driving experience young drivers are still not much aware of the spots/sources of potential hazards.

However, the objective of the Scenario 2 was quite different than the Scenario 1. It was meant to determine whether drivers would pay attention to a "stop ahead" sign warning of an upcoming stop sign obscured by a curved road and roadside vegetation.

Unlike the Scenario 1, only 24 participants (20% of novice, 33% of limited experience, 27% of intermediate, 40% of moderate, 27% of experienced young, and 13% of highly experienced adult drivers) gazed on it. Such low responses might be attributed to the unthreatening nature of the scenario. The study ROI does not pose any hidden or immediate threat, rather it informs about them. Thus, most of the participants might have perceived it as non-essential and subsequently ignored. The novice drivers indeed looked at the ROI less than the other young drivers' groups, but they were not the least. The highly experienced group (13% only) was found to be the lowest. This can also be explained in terms of the drivers' perception about the scenario. Highly experienced drivers are likely to have greater knowledge about the potential locations for threats and thereby could overlook less or non-threating areas like the ROI at Scenario 2.

Anyway, the visual analysis of the plotted data provided some basis to make informal conjectures and simulated intuitive foundations for formal inferences. Regarding the first objective of the study, two hypotheses were developed and tested to provide formal inferences regarding the eye scanning differences across the drivers' groups. The following discussions are based on these two hypotheses regarding the first objective.

Hypothesis 1

It was stated as "significant trend or association will be observed between the measured indicators and driving experience". In terms of the gaze measures, the hypothesis was supported only for the percentage of gaze duration measure at Scenario 2. The Spearman's correlation analysis revealed significant strong negative association between mean gaze duration and driving experience. This result confirms the earlier observation made about the experienced drivers' tendency of paying less attention at Scenario 2. This result is partially in line with the finding reported by Champan and Underwood (1998). They suggested that at less demanding roads, experienced drivers characteristically spent most of their time looking straight ahead rather than searching peripheral areas for potential threats.

With respect to the rotation measures, significant association was observed only for head pitch measure at both scenarios. Head pitch represents the rotation of the head in the vertical plane of the forward field of view, the lower the value the more downward the head rotation is. The correlation coefficients (r_s=0.89 at Scenario 1 and r_s= 0.94 at Scenario 2) indicated that the drivers with higher experience intended to direct their head more upward than inexperienced peers. This result is in general agreement with the finding reported by Mourant and Rockwell (1972). They found that novice drivers tend to fixate their gaze much closer to their car than experienced drivers, though, a few studies (Miltenburg and Kuiken, 1990; Underwood & Crundall, 1998; and Falkmer & Gregersen, 2005) did not find any conclusive evidence supporting such fact. Since, the drivers of the current study exhibited significantly consistent pattern across two different road types (straight at Scenario 1 and road curved to the right at Scenario 2), it would be reasonable to believe that inexperienced drivers (novice and limited experienced) have the tendency of looking closer to the front of the car.

Although not statistically significant, moderate to strong positive association was observed between the gaze heading and driving experience at both scenarios. Gaze heading indicates the direction of the gazes in the horizontal field of view. A closer inspection of the distribution of the gaze heading data indicated that the novice and limited experienced drivers tended to direct their gazes towards the left side of their horizontal field of view whereas the other drivers were directing closer to the right side. Since both the study ROIs were located at the right side of the horizontal field of view, the novice and limited experienced drivers were less likely to look at the ROIs. Such interpretation was supported by the fact that at both scenarios, lower number of drivers from novice and limited experienced group were looking at the ROIs compared to the other study groups. Thus, it would be reasonable to conclude that drivers' visual scanning pattern improves with growing experience.

Hypothesis 2

It was posited as "inexperienced drivers will differ significantly with experienced drivers in regard to the measured indicators". In terms of the gaze measures, the hypothesis was supported for the measured mean gaze duration at Scenario 1 and for the percentage of gaze duration at Scenario 2. Mean gaze duration of highly experienced drivers was found to be significantly higher than intermediate, moderate and experienced young drivers. In fact, mean gaze duration was observed to be the highest (190 milliseconds) for the highly experienced group, with limited experienced drivers scoring the second highest (170 milliseconds), followed by novice drivers (120 milliseconds). Such findings are supported by the implication of a recent study conducted by Klauer et al. (2014). They suggested that at the early stages of driving, inexperienced 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 adopt different driving approach than their experienced counterparts.

However, at Scenario 2, novice drivers' percentage of gaze duration (21%) was found to be significantly higher than the experienced young (5.03%) and highly experienced drivers (8.33 %). This result could reflect the fact that experienced drivers do not need to allocate as much of their foveal attention to the less demanding traffic environment as inexperienced drivers do (Miltenburg & Kuiken, 1990). One possible explanation suggested by Crundall et al. (2012c) is that the effectiveness of a gaze made by an experienced driver is greater than that of an inexperienced driver. Thus, a short gaze might provide the experienced driver with information concerning a potential hazard whereas the same gaze for the inexperienced driver may not allow such deep level of processing.

In terms of the rotation measures, the hypothesis was supported for head pitch measure at both scenarios, and for gaze pitch at Scenario 1. In all three cases where the hypothesis was supported, the mean scores of head pitch or gaze pitch of novice drivers were found to be significantly lower than the highly experienced drivers. This result is consistent with the findings reported earlier under hypothesis 1, and thus could be attributed to the novice-drivers' tendency of pointing their eyes closer to the vehicle than their experienced counterparts.

Second Objective

The second objective was to explore the experience level at which novice driver exhibits hazard perception skill as well as their experienced counterparts. Learning a complex skill such as hazard perception may not proceed in a smooth and linear fashion, especially during the early years of driving. However, Groeger (2000) argued that most of the complex driving skills should develop and mature with added years of driving experience. Thus, with many years of experience, drivers are likely to develop a wide range of driving behaviors and schemata in the long term memory, and expected to exhibit behavior in a more homogenous way than the inexperienced drivers in complex driving conditions. Liu (2011) noted that behavioral variability might reduce from novice to experienced drivers and thus, could be recognized as improvement of performance. Wikman et al. (1998) and Imtiaz and Stanley (2015) also reported similar observation. Thus, it would be reasonable to assume that within-group variability of each of the young drivers' groups would be higher than the highly experienced drivers' group and such difference would reduce gradually as an indication of transition from novice to experienced drivers.

However, statistical significance testing only provides evidence whether two groups are different or not. It does not provide any suggestion about whether groups could be considered comparable to each other. Equivalence testing, on the other hand, is a statistical tool utilized when it is important to investigate whether observations from two groups are similar enough for practical purposes. Equivalence testing is frequently used in pharmaceutical and clinical studies to determine whether a new drug or method of treatment is as effective as another drug or method. Thus, the researcher was prompted to adopt equivalency testing procedure in the current study. Two hypotheses were devised regarding the within-group variability and group equivalency phenomena, and examined accordingly.

Hypothesis 3

It was stated as "there will be significant within-group variability between each of the young drivers' groups and the highly experienced group". The results of the pairwise comparisons of each of the young drivers' groups and highly experienced group were not as promising as expected. There were only 5 instances (all at Scenario 1) where the hypothesis was supported. However, a closer analysis of the descriptive statistics (standard deviation, range, interquartile range) and the distribution diagrams of the respective measures at those instances revealed that within-group variability of highly experienced group was actually higher in all cases. This result contradicts with the finding reported by Imtiaz & Stanley (2015). They observed that the within-group variability gradually decreased (though not statistically significant) across less experienced (1-2 years), intermediate (2-5 years) and highly experienced (over 15 years) groups in terms of the corresponding response measures. Such differences were probably due to the small sample size (4 participants in each group) employed by that study. Wikman et al. (1998), however, reported that novice drivers had larger variations in their glance duration, while driving on the less active roads, than the expert drivers. They measured glance duration of novice drivers while they were performing different in-vehicle tasks like changing a radio cassette, dialing a mobile phone or tuning the radio in addition to the primary task of driving the car. On the other hand, in the current study participants were only required to drive through the scenario as they normally would.

Thus, additional task-requirement while driving, possibly, is the main reason behind the novice drivers' greater group variability observed in the Wickman et al.'s study.

Hence, the results of the within-group variability analysis failed to provide any evidence that such measure could be considered as an indicator of the transition from novice to experienced drivers.

Hypothesis 4

It was hypothesized that young drivers with higher experience would be equivalent to the highly experienced group in terms of the measured indicators. The hypothesis was supported only at Scenario 2 with respect to the percentage of gaze duration measure. The young drivers' group with five years of experience were found significantly equivalent to the highly experienced drivers. In other words, young experienced drivers were paying comparably similar amount of attention on the study ROI like their highly experienced counterparts. ANOVA and within-group analysis results further supported this finding (i.e., there was no statistically significant difference). Unlike the other young drivers, who on an average spent similar amount of time looking at the ROIs at both scenarios, young experienced drivers spent significantly less amount of time at Scenario 2 (91milliseconds) than Scenario 1(490 milliseconds). That is, they adjusted their scanning strategy according to road conditions like the highly experienced drivers. This result is supported by the finding reported by Crundall and Underwood (1998). They found that only the experienced drivers adopt their driving approach based on the road complexity whereas inexperienced drivers exhibit inflexible approach regardless of situational demands. However, in their hazard perception study, Imtiaz and Stanley (2015) concluded that there might be a level of driving experience before or after five years of active driving at which the novice driver could exhibit eye-movement behaviors as adept at anticipating hazards as the highly experienced drivers. Thus, the result of the current study supports their assumption to some extent.

Nevertheless, young drivers, especially with five years of experience, were expected to be found more equivalent with respect to the other eye scanning measures. One possible reason of such rare outcome of the current study could be the threshold values utilized for the equivalence tests. In the domain of driving behavior research, no previous study was found employing equivalent analysis or suggesting any driving behavior-related acceptable minimum difference between groups. Lewis, Watson, and White (2009) reported ±20% as the most commonly used thresholds in the areas of bioequivalence and social science. Adopting such thresholds as a rule of thumb seemed irrational in the context of the current study. Several eye scanning related studies (e.g., Inhoff and Radach, 1998; Manor and Gordon, 2003) recommended 100 milliseconds as the standard time to look at a scene and perceived relevant information. Thus, if the mean gaze durations of two study groups differ more than 100 milliseconds, it would be reasonable to assume that one group paid more attention than others and they are not equivalent. Rest of the thresholds were set to the overall standard deviation of the corresponding indicators as a crude standard of minimum acceptable difference between two groups. Nevertheless, with reasonable selection of minimum acceptable difference, Equivalent Testing procedure could be an effective analysis tool in driving behavior research while comparing different groups of drivers.

Although considering 100 milliseconds as threshold may appear small at first sight, in a realistic driving situation it might take only a few milliseconds of taking eyes off the road and the driver may end up having a fatal accident. According to the National Highway Traffic Safety Administration, inattentions while driving is the cause of 80 percent of crashes. When people look at a view before them, for example while driving in a vehicle, very little information actually receives full analysis by human brains (National Safety Council, 2012). Research shows that humans are blind to many changes that happen in scenery around them, unless close and conscious attention are being paid to the specific details - giving them full analysis to get transferred into the working memory (Trick, Enns & Vavrik, 2004). Thus, attention to the road details appears to be the most important aspect in the context of safe driving. Brain researchers have identified "reaction-time switching costs" (Dzubak, 2008) which is a measurable time when the brain is switching its attention and focus from one task to another, like looking at one side mirror to another and then looking back to the forward field of view. The cost of switching could be a few tenths of a second per switch. When the brain switches repeatedly between tasks, these costs add up (Dzubak, 2008) and eventually can lead to significant risks from delayed reaction and braking time. Several studies indicated that an average estimation of perception-reaction time varies from 0.75 to 1.5 seconds and braking time from 0.3-0.5 seconds (Green, 2000). Hence, a millisecond can help in avoiding an accident, lessen an accident's effects, or simply lead to making the right maneuver for the current traffic conditions just at the right time. For example, if a vehicle is traveling at 40 mph, and if the hazard perception-reaction time and the brake execution time are 0.75 and 0.3 seconds respectively, then the car goes 61.6 feet before even the brake is being engaged to stop the vehicle. This equals four car lengths (an average car length is around 15 feet). Thus, spending extra 50 to 100 milliseconds worth of time in attention would help the driver to travel 3 to 6 feet less, which in turn could mean the difference between life and death.

CHAPTER 6 – CONCLUSION

The goal of this study was to examine the hazard perception difference of young drivers and thereby, to explore the experience time window after which novice young drivers could be considered comparable with highly experienced drivers. The general literature on young drivers' hazard perception ability is mostly focused on the novice drivers with at most one year of driving experience and do not provide much information about the hazard perception ability of young drivers having more experience. Thus, young drivers, with experience ranging from one to five years, were compared against the drivers with more than ten years of experience while driving through two different potentially hazardous scenarios. The indicators were measured in terms of both eye gaze duration (percentage of total gaze duration spent, mean gaze duration, gaze rate, time to first look) and gaze rotation measures (gaze heading, gaze pitch, head heading, head pitch). The gaze duration measures demonstrate the amount of attention allocated by a driver whereas rotation measures indicate the direction of such attentions. As a result, the collected data allowed the researcher to investigate the anticipatory scanning patterns of young drivers addressing the major aspects of eye movements in relation to latent hazards.

The results of the study indicated that none of the young drivers' groups are significantly different from each other in terms of the measured indicators. However, careful observations of the descriptive statistics and the distribution diagrams of the measured indicators across the two scenarios revealed that less number of inexperienced drivers (novice and limited experienced) looked at the study ROI than the other drivers' groups, an indication of these driver unawareness of the spots/sources of potential hazards. Besides, at both scenarios, novice and limited experienced drivers spent similar amount of time while other drivers' groups spent less time at Scenario 1 than at Scenario 2 (indication of change in search strategy). On the other hand, Young drivers with three years of experienced showed fairly consistent pattern of driving behavior across both the scenarios like the other young drivers' group, Thus, it appeared that young drivers' visual strategy remains inflexible even after two years of driving experience and probably start improving after some point around three years, necessitating further research to confirm the above assumptions.

Unlike previous studies that manifested significant differences between the novice and highly experienced drivers with respect to visual attention measures, in this particular study, novice drivers were mainly found to be significantly different in terms of their visual orientation. However, several studies reported that (e.g., Crundall et al., 2012; Underwood, 2007) when hazard is materialized, drivers with different level of experience behave differently. Further research with different road conditions are required to generalize such study findings.

However, several past studies suggested that with growing experience novice drivers' visual search pattern is likely to improve. The trend analysis results of the current study partially confirmed this argument and demonstrated that as young drivers grow with experience, they gradually learn to look far ahead and scan closer to the center of their horizontal field of view like the experienced drivers. As hazard perception training has proven effects both on a driving simulator (Pollatsek et al., 2006) and in the field

(Pradhan et al., 2006), such gradual learning effect of drivers could be augmented by hazard perception training, which, in turn, may contribute to reduce the high crash rates of inexperienced drivers at their early stage of driving.

The study finally attempted to quantify the experience level at which young drivers' hazard perception ability becomes comparable to that of the highly experienced drivers. No such study was found in the driving domain that ever had tried to quantify such experience level in terms hazard perception. The researcher thus adopted two different approaches, within-group variability and equivalence analysis. Few researches indicated that inexperienced drivers' group variability is greater than that of the experienced drivers. However, the study results contradicted with such findings and the results of the within-group variability analysis failed to provide any evidence that such measure could be considered as an indicator of the drivers' transition from novice to experienced status.

Equivalence testing is frequently used in pharmaceutical and clinical studies to determine whether a new drug or method of treatment is as effective as another drug or method. The main challenge of the equivalence testing was to determine the minimum experience level to compare two groups. Since no previous study has applied this test in the driving domain, there was no recommended threshold to compare groups in terms of hazard perception. The researcher attempted to select the threshold based on some rationale. However, more research is required in this field to justify the selection or application of those thresholds.

Nevertheless, the results of the equivalent tests on the young drivers' group with five years of experience were found to be significantly equivalent to those of highly experienced drivers. Though, such finding was partially supported by few previous studies, more research is required to generalize the crucial finding.

In summary, the findings of the study provided some clear understanding about how the different young drivers' groups differs in terms of their hazard perception ability. The results of the study indicated that novice drives do not differ significantly with other young drives but their visual search strategy remains inflexible even after two years of experience. Thus, novice drivers with 2 years of experience might require additional training, given that they had some training at theirs first year of driving.

However, with growing experience, young drivers learn to look farther ahead and scan more widely along their horizontal field of view. Based on the overall results and careful observation of descriptive statistics, the study concluded that after five years of driving experience young drivers' visual search pattern can be considered comparable to their experienced counterparts. Nevertheless, the small and unequal number of participants in each of the drivers' groups at Scenario 2 might have biased the results and limited the opportunity to engage in a thorough investigation regarding each of the young drivers' groups. Thus, more research, involving more participates, is required to generalize each of these findings.

Significance of the Study

Hazard perception is an important aspect of safe driving. Several studies indicated that such crucial skill is the explaining part of the difference in crash risk between novice and experienced drivers. To the best knowledge of the researcher, this study is the first attempt to quantify the driving experience gap between a novice and an experienced driver in the context of hazard perception. Young novice drivers quickly learn the physical skills of driving and, as a result, tend to believe that they have mastered it and are often over-estimate their driving ability. This study revealed that even after two years of active driving experience, young drivers still lack in adequate hazard perception skill, and only after five years of worth driving experience their hazard anticipation ability can be considered comparable to the experienced drivers. That is, a young novice driver should not consider himself/herself experienced until having at least five years of active driving experience, and should receive additional hazard perception training periodically to compensate their skill deficit. The driving licensing authorities might consider five years of active driving as an experience standard for the teen drivers to become eligible for a full licensure independent of their age. Furthermore, the implications of this study could be utilized to design and develop effective hazard perception training programs focusing on the driving experience level of young drivers. Implementation of such tailored programs could augment the hazard perception competency of the young drivers and, thereby, could reduce the high crash risks of young drivers substantially.

Limitations

This research has several limitations which hamper the generalizability of the findings presented. First, the study was semi-naturalistic in nature. Thus the participants knew they would be observed while driving. Such knowledge might influence the drivers to adopt conservative approach while driving. Participants were also driving a vehicle that was likely to be different than their normal vehicle. Second, participants were recruited based on how many years of driving experience they had at the time of participation. How many miles driven or travelled per annum was not considered for the study. With longer distances travelled, it is quite likely that drivers will experience a broader range of traffic scenarios and thereby such experience may help the driver in anticipating potential roadway hazards. Third, several studies indicated that gender has a considerable effect on driving style, however, for this study gender was not considered. Fourth, although same protocol was followed while collecting data for the referenced NSF and the current study, the data was collected by three different researchers at different time periods. Thus, inter-researcher variability and data collection time periods might have some effect on the results of the study. Another major factor to consider is the selection of the participants. All the participants were either from Bozeman or nearby areas, which represents a relatively rural environment. Thus, these results may not be applicable for the young drivers from urban environment. These issues could have significantly impacted the findings of this research and limited the generalizability of the findings presented here.

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APPENDICES

APPENDIX A

HUMAN SUBJECTS COMMITTEE APPLICATION

MONTANA STATE UNIVERSITY
Institutional Review Board Application for Review
(Revised 09/23/13)

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THIS AREA IS FOR INSTITUTIONAL REVIEW BOARD USE ONLY. DO NOT WRITE IN THIS AREA

Application Number: Approval Date:
Disapproved: IRB Chair's Signature:

****
****

Date:

I. Investigators and Associates (list all investigators involved; application will be filed under name of first
person listed)

NAME: **Ahmed Salman Imtiaz** TITLE: **Graduate Student**
DEPT: **MIE** PHONE #: **(406) 220-3424**
COMPLETE ADDRESS: **103 Grant Chamberlain Drive, Apt.:1C, Bozeman, MT 59715**
E-MAIL ADDRESS: **salman.imtiaz@coe.montana.edu**
DATE TRAINING COMPLETED: 2**/1/2013**

Do you as PI, any family member or any of the involved researchers or their family members have consulting agreements, management responsibilities or substantial equity (greater than $10,000 in value or greater than 5% total equity) in the sponsor, subcontractor or in the technology, or serve on the Board of the Sponsor? _____ YES _**X**_ NO

If you answered Yes, you will need to contact Pamela Merrell, Assistant Legal Counsel-JD at 406-994-3480.

II. Title of Proposal:

Hazard Perception Differences between Experienced and Less Experienced Drivers While Driving in Real World Hazards

III. Beginning Date for Use of Human Subjects: March 10, 2014

IV. Type of Grant and/or Project (if applicable)
Research Grant:
Contract:
Training Grant:
Classroom Experiments/Projects: **X**
Thesis Project:
Other (Specify):

V. Name of Funding Agency to which Proposal is Being Submitted (if applicable): **None.**

VI. Signatures

Submitted by Investigator
Typed Name: Ahmed Salman Imtiaz

Signature:

Date: 03-03-2013

Faculty sponsor (for student)
Typed Name: Laura Stanley

Signature:

Date: 03-03-2014

VII. Summary of Activity. Provide answers to each section and add space as needed. Do not refer to an accompanying grant or contract proposal.

A. RATIONALE AND PURPOSE OF RESEARCH (What question is being asked?)

Hazard perception skill, or the ability to anticipate traffic situations, is an important aspect of safe driving behavior. It was evident from the literature that such important skill develops in the drivers as they grow with driving experience. Several studies indicated that such skill differ significantly between the novice and experienced drivers, even after the novice drivers being trained and having a year of driving experience. Thus the question arises: when do the less experienced drivers start exhibiting essential hazard perception skill as good as their experienced counterparts.

However, no such literature was found that had addressed this question. This motivated the researcher to conduct a naturalistic real world driving study employing eye tracking technologies, which in turn might address the issue. Thus, the aim of this research is to study the differences in road scanning patterns between the in experienced and experienced drivers.

B. RESEARCH PROCEDURES INVOLVED. Provide a short description of sequence and methods of procedures that will be performed with human subjects. Include details of painful or uncomfortable procedures, frequency of procedures, time involved, names of psychological tests, questionnaires, restrictions on usual life patterns, and follow up procedures.

Upon arrival at WTI's driving simulator lab, the participant will be requested to read the consent form carefully and to sign if he/she wishes to participate; the participant will be asked to show the driving license to make sure its validity. The participant will require completing a vision exam using OPTEC 5000 (P) vision tester to ensure that his/her visual acuity level is at least 20/40 in each eye, which is the minimum requirement to receive a Montana Driver's License.

The participant will be then briefed about the experimental procedure and will be directed towards the instrumented vehicle. The eye scanning system will be calibrated and the participant will be asked to drive through a test route to make him/herself comfortable operating the vehicle. The eye scanning system doesn't require attaching any sensor or wire or anything to the participant. For this study, the participant is only required to drive the instrumented car as he/she normally drives his/her own vehicle. The researcher will accompany the participant in the test car throughout the study.

Once the participant is ready for the actual drive, he/she will be asked to drive through the two predetermined scenarios consisting of real, pre-selected location on Bozeman roads, in random order. The participant will be instructed to drive as he/she normally would and to drive straight through intersections unless being told to turn; all turning instructions will be given at least one block prior to the turn. The first scenario, "hidden crosswalk" determines if drivers can recognize that pedestrians may emerge from behind a line of bushes that obscures a sidewalk on the right. The driver's potential hazard in the "hidden crosswalk" scenario is the chance that a sidewalk user may emerge from the right. The second scenario, "curved stop ahead", determines whether drivers pay attention to a "stop ahead" sign warning of an upcoming stop sign which is obscured by a curved road and roadside vegetation.

All driving sessions for the study will be conducted during daylight hours avoiding heavily trafficked times and when it will not be snowing or raining. Exterior video camera lenses, vehicle windows, and vehicle headlights will be cleaned before every drive. The study route may take approximately 20-25 minutes. Once the participant drives through the hazard scenarios, he/she will be asked to come back to WTI and will be thanked cordially for his/her voluntary participation.

Statistical analysis will compare the recorded eye fixation duration and gaze frequencies of less experienced and experienced drivers' groups to find any significant difference.

C. DECEPTION - If any deception (withholding of complete information) is required for the validity of this activity, explain why this is necessary and attach debriefing statement.

No deception will be used for this study.

D. SUBJECTS

1. Approximate number and ages:
   How Many Subjects: **45**
   Age Range of Subjects: **18-25 years**
   How Many Normal/Control: **25/20 experienced (2-5)**

   Age Range of Normal/Control: **18-25/25-50**

2. Criteria for selection:

Valid US driving license; corrected vision to at least 20/40; between 18-45 years old; and no prior participation in hazard perception driving study.

3. Criteria for exclusion:

No valid US driving license; vision deficient for driving less than 20/40 in either eye; enough points on license to be ineligible to drive in state of Montana (resulting in loss of license) and prior participation in any type of hazard perception driving study.

4. Source of Subjects (including patients):

University community.

5. Who will approach subjects and how? Explain steps taken to avoid coercion.

Participants will be recruited through advertisements, posters and announcements in the different media of the university. Subjects will be given a phone number and email to contact if they are interested to avoid coercion. Subject providing their information will be contacted to schedule a discussion with research staff to explain the study and schedule participation in the study. This phone contact also provides an opportunity for research staff to answer any additional questions the subjects may have.

6. Will subjects receive payments, service without charge, or extra course credit? Yes or **No**
   (If yes, what amount and how? Are there other ways to receive similar benefits?)

7. Location(s) where procedures will be carried out.

Using Western Transportation Institute's Instrumented Vehicle on local Bozeman roads.

E. RISKS AND BENEFITS (ADVERSE EFFECTS)

1. Describe nature and amount of risk and/or adverse effects (including side effects), substantial stress, discomfort, or invasion of privacy involved.

In the study, there are no additional risks other than those typical for common driving conditions.

2. Will this study preclude standard procedures (e.g., medical or psychological care, school attendance, etc.)? If yes, explain.

No.

3. Describe the expected benefits for individual subjects and/or society.

There are no specific benefits anticipated for individual subjects. However, the results of this study may benefit in understanding the driver's hazard perception ability at various level of driving experience.

F. ADVERSE EFFECTS

1. How will possible adverse effects be handled?

All participants will get a short practice drive to make sure they experience no discomfort before proceeding to the main study. The instrumented vehicle is equipped with an additional brake at the passenger side which will enable the researcher to use if the participant fails to use the original brake for some reason.

By investigator(s):
Referred by investigator(s) to appropriate care: **X**
Other (explain):

2. Are facilities/equipment adequate to handle possible adverse effects? **Yes** or No
(If no, explain.)

3. Describe arrangements for financial responsibility for any possible adverse effects.

MSU compensation (explain):
While driving the research vehicle as a participant in this study, he/she will be covered by auto liability insurance as provided by Montana law to the limit of $750,000 per claim and $1,500,000 per occurrence. This auto liability insurance coverage does not include either medical payments coverage or uninsured/underinsured motorist coverage.

Sponsoring agency insurance:
Subject is responsible:
Any injury sustained, while operating the research vehicle, will be the responsibility of participant's own personal medical and vehicle insurance
Other (explain):

G. CONFIDENTIALITY OF RESEARCH DATA

1. Will data be coded? **<u>Yes</u>** or No

2. Will master code be kept separate from data? **<u>Yes</u>** or No

3. Will any other agency have access to identifiable data? Yes or **<u>No</u>**
(If yes, explain.)

4. How will documents, data be stored and protected?
Locked file: **X**
Computer with restricted password: **X**
Other (explain):

VIII. Checklist to be completed by Investigator(s)

A. Will any group, agency, or organization be involved? Yes or **No**
(If yes, please confirm that appropriate permissions have been obtained.)

B. Will materials with potential radiation risk be used (e.g. x-rays, radioisotopes)? Yes or **No**

1. Status of annual review by MSU Radiation Sources Committee (RSC). Pending or Approved
(If approved, attach one copy of approval notice.)

2. Title of application submitted to MSU RSC (if different).

C. Will human blood be utilized in your proposal? Yes or **No**
(If yes, please answer the following)

1. Will blood be drawn? Yes or No
(If yes, who will draw the blood and how is the individual qualified to draw blood? What procedure will be utilized?)

2. Will the blood be tested for HIV? Yes or No

3. What disposition will be made of unused blood?

4. Has the MSU Occupational Health Officer been contacted? Yes or No

D. Will non-investigational drugs or other substances be used for purposes of the research? Yes or **No**
Name:
Dose:
Source:
How Administered:
Side effects:

E. Will any investigational new drug or other investigational substance be used? Yes or **No**
[*If yes, provide information requested below and one copy of: 1) available toxicity data; 2) reports of animal studies; 3) description of studies done in humans; 4) concise review of the literature prepared by the investigator(s); and 5) the drug protocol.]*

Name:
Dose:
Source:
How Administered:
IND Number:
Phase of Testing:

F. Will an investigational device be used? Yes or **No**
(If yes, provide name, source description of purpose, how used, and status with the U.S. Food and Drug Administration FDA). Include a statement as to whether or not

device poses a significant risk. Attach any relevant material.)

G. Will academic records be used? Yes or **No**

H. Will this research involve the use of
Medical, psychiatric and/or psychological records Yes or **No**
Health insurance records Yes or **No**
Any other records containing information regarding personal health and illness Yes or **No**

If you answered "Yes" to any of the items under "H.", you must complete the **HIPAA worksheet**.

I. Will audio-visual or tape recordings or photographs be made? Yes or **No**

J. Will written consent form(s) be used? (**Yes** or No. If no, explain.) (Please use accepted format from our website. Be sure to indicate that participation is voluntary. Provide a stand-alone copy; do not include the form here.)

APPENDIX B

SUBJECT CONSENT FORM

Montana State University
Research Participant Information and Consent Form

Title of the Study: Hazard Perception Differences between Experienced and Less Experienced Drivers While Driving in Real World Hazards

Principal Investigator: Graduate Researcher Ahmed Salman Imtiaz (phone: (406) 220-3424, email:salman.imtiaz@coe.montana.edu)

DESCRIPTION OF THE RESEARCH

You are invited to participate in a research study about how people perceive hazards while driving in real world conditions. You have been asked to participate because you have healthy vision and have a valid (clean) US driving license.

This study will include both male and female licensed drivers from the local area aged 18 to 25 years.

The research will take place in an instrumented vehicle that you will operate along a specified route on roads in the Bozeman and Gallatin Valley area.

The purpose of the research is to compare hazard perception skill of the less experienced adult driver with the experienced driver while driving in the real world. You will drive as you would normally on real roads along a specified route using our research vehicle. We will collect and record data about your driving performances and eye movements. All materials will be kept secure and will not be identified with you personally. The recordings will be kept for one year before they are destroyed.

WHAT WILL MY PARTICIPATION INVOLVE?

If you decide to participate in this research you will be asked to attend a session based on your available time and the session will take approximately one hour. You will drive along an actual street route using our research vehicle.

WILL I BE COMPENSATED FOR PARTICIPATION?

You will be compensated with $25 for your participation.

ARE THERE ANY RISKS TO ME?

We are not aware of any additional social, psychological, legal, or economic risks associated with your participation in this study. Naturally, driving on real roads can include some risks to drivers. Thus, you are expected to drive as you would normally to be safe.

While driving the research vehicle as a participant in this study, you will be covered by auto liability insurance as provided by Montana law to the limit of $750,000 per claim and $1,500,000 per occurrence. This auto liability insurance coverage does not include either medical payments coverage or uninsured/underinsured motorist coverage. That is, any injury sustained while operating this vehicle will be the responsibility of your own personal medical and vehicle insurance.

ARE THERE ANY BENEFITS TO ME?

There are no direct benefits to you for participating in this study other than your own interest in participating in the research. However, the results of this study may benefit in understanding the driver's hazard perception ability at various level of driving experiences.

HOW WILL MY CONFIDENTIALITY BE PROTECTED?

While there may be publications or conference presentations as a result of this study, your name and participation in this study will not be identified. Only group characteristics (averages) will be reported.

WHOM SHOULD I CONTACT IF I HAVE QUESTIONS?

You may ask any question about the research at any time. If you have questions about the research after you leave today you should contact the Principal Investigator Ahmed Salman Imtiaz at (406) 220-3424. If you are not satisfied with the responses of the researcher, have more questions, or want to talk with someone about your rights as a research participant, you should contact the MSU IRB Office: Chair, Mark Quinn 994-4707, ***mquinn@montana.edu***

Your participation is completely voluntary. If you decide not to participate or to withdraw from the study it will have no effect on any relationship you may have with the university or with Western Transportation Institute.

AUTHORIZATION: I understand that my participation is completely voluntary. I understand that while driving the research vehicle as a participant in this study, I will be covered by Montana State University's auto liability insurance, but I am not covered by any medical payment coverage or uninsured/underinsured motorist coverage; any injury sustained while operating this vehicle will be the responsibility of my own personal medical and vehicle insurance.

I have read the above consent form and it has been explained to me. A copy of this consent form has been given to me. All of my questions have been answered to my satisfaction. I agree to participate in this study. I understand that I am free to withdraw at any time without penalty.

Name of Participant (please print):______________________________

Signature of Participant
__________________________ Date _______

Signature of Researcher
__________________________ Date _______