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Understanding and Improving Novice Drivers’ Hazard Perception Skills

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UNDERSTANDING AND IMPROVING NOVICE DRIVERS’ HAZARD PERCEPTION SKILLS

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Table of Contents
Chapter 1 Introduction................................................................. 1
Chapter 2 Related Research.......................................................... 4
  2.1 Definition of Hazard Perception (HP) ...................................... 4
  2.1 Hazard Perception (HP) and Vision Attention......................... 5
  2.2 Hazard Perception of Distracted Drivers ............................ 7
  2.3 Hazard Percepcion Training ........................................... 8
  2.4 Action Video Games and Driver Related Cognition .................. 13
  2.5 Summary ........................................................................ 14
Chapter 3 Hazard Perception Test (HPT) Design ......................... 16
  3.1 HPT Overview ............................................................... 16
  3.2 HPT System Setup ......................................................... 18
    3.2.1 Driving Simulator .................................................... 19
    3.2.2 Eye Tracking—Mobile Eye System ............................ 20
Chapter 4 Hazard Perception Training Game Design .................. 25
  4.1 Principles of Game Design ............................................... 25
  4.2 Tools ........................................................................... 28
  4.3 Creating Game Environment ........................................... 30
  4.4 Scenario Design ............................................................ 35
  4.5 Level Design ............................................................... 40
  4.6 User Interface and System Requirement ............................. 42
Chapter 5 Methodology ............................................................... 43
  5.1 Participants .................................................................. 43
  5.2 Hypotheses .................................................................. 47
Chapter 6 Data Analysis ............................................................. 49
  6.1 Experimental Data ......................................................... 49
  6.2 Group Characteristics .................................................... 51
  6.3 Hazard Perception (HP) Test Characteristics ....................... 52
  6.4 Statistical Analysis ....................................................... 52
    6.4.1 Miss Rate ............................................................. 52
    6.4.2 False Alarm Rate .................................................... 58
    6.4.3 Reaction Time ....................................................... 62
    6.4.4 First Notice Time ................................................... 66
    6.4.5 Visual Scanning Analysis ....................................... 69
  6.5 Questionnaire Analysis .................................................... 74
  6.6 Results ......................................................................... 76
Chapter 7 Conclusions ............................................................... 79
  7.1 Contributions of the Dissertation Work ............................. 79
  7.2 Future Work ................................................................ 81
References ............................................................................. 83
Related Publications & Academic Activities ............................... 88
Appendix A: Subject Forms ....................................................... 89
Appendix B1: Simulator Sickness Questionnaire .......................... 90
List of Figures

Figure 1.1 Fatal crashes by age, April 2001 to March 2002 1

Figure 2.1 A screenshot in the UK's hazard perception test 8

Figure 2.2 An urban scenario of DATS 12

Figure 2.3 Sample screen shot of a video-based traffic simulation 12

Figure 3.1 Hazard Perception Test screen shot 17

Figure 3.2 A Hazard in hazard perception test 18

Figure 3.3 The hazard Perception System schematic diagram 18

Figure 3.4 Driving simulator at Virtual Environment Laboratory, Northeastern University 20

Figure 3.5 Spectacle-mounted unit attached to the RMU and video recorder (Courtesy: ASL) 21

Figure 3.6 The eye vision user interface 22

Figure 3.7 Pupil display with overlay and pupil score (Courtesy: ASL) 23

Figure 3.8 The five points calibration map 24

Figure 3.9 Video file of the eye tracking system 24

Figure 4.1 The flow chart of game design 25

Figure 4.2 Interest curve for a well-designed experience 27

Figure 4.3 Unity3D editor 28

Figure 4.4 A 3D scene from Unity example 29

Figure 4.5 Wheel collider in Unity3D 29

Figure 4.6 Cheetah3D user interface 32

Figure 4.7 A city environment 33
Lists of Tables

Table 4.1 Results of performance testing 31
Table 4.2 Environmental elements and hazards in three game environments 36
Table 4.3 Level design 41
Table 6.1 Demographic statistic 51
Table 6.2 Type of hazards in HP Test 52
Table 6.3 Miss rate score in test 1 53
Table 6.4 Miss rate score in test 2 53
Table 6.5 Miss rate score in test 3 54
Table 6.6 T test of the experimental group’s miss rate in test 1 and 2 56
Table 6.7 T test of the control group’s miss rate in test 1 and 2 56
Table 6.8 False alarm rate in test 1 59
Table 6.9 False alarm rate in test 2 59
Table 6.10 False alarm rate in test 3 60
Table 6.11 Reaction time in test 1 63
Table 6.12 Reaction time in test 2 64
Table 6.13 Reaction time in test 3 64
Table 6.14 First notice time in test 1 66
Table 6.15 First notice time in test 2 67
Table 6.16 First notice time in test 3 68
Table 6.17 Times of wide scanning in test 1 71
Table 6. 18 Times of wide scanning in test 2  72

Table 6. 19 Times of wide scanning in test 3  72

Table 6. 20 Training questionnaire  74
ABSTRACT

Road safety is always of great concern throughout the world. Many efforts have been made by research and laws to keep traffic accident rates low. A topic of interest for many years has been driving behaviors of novice drivers. The accident rate of novice drivers, especially newly licensed teens, is much higher when compared to more experienced drivers. An important reason may be that novice drivers are more likely to fail to identify hazardous situations. My research focuses on how to better prepare teen drivers for real-world driving by improving their hazard perception skills.

Hazard perception skill may be a major factor in young novice drivers’ involvement in traffic crashes. In order to better understand hazard perception skill, we made a systematic review of hazard perception related factors and the state of current research on hazard perception training. We believe that novice drivers can be trained to have better hazard awareness skills. A driving game for novice drivers to improve their hazard detection skills has been developed as part of this thesis. The expected side-effects of the game was that 1) novice drivers would detect and react to potential hazardous situations quickly, and 2) the horizontal scan patterns of novice drivers would become wider and “intelligent” in terms of depending on particular driving situations. We found that the fun associated with game playing had positive side effects in terms of detecting hazards while driving.
In order to evaluate hazard perception ability, a hazard perception test has been made based on the US road conditions. The driving video clips in the hazard perception test were filmed in Boston, Massachusetts. Twenty-four Northeastern University undergraduate students participated in the hazard perception experiment in the Virtual Environment Laboratory. Half of the participants were trained using the hazard perception game, and demonstrated improvement in recognizing, and reacting to potential hazards when compared with participants that did not play the game. Also, the scanning strategies of the trained participants improved in terms of increased amounts of wide horizontal scanning. The experimental results conformed that hazard perception skill can be trained, and that our hazard perception game was an effective way to improve hazard perception skill.
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Chapter 1 Introduction

Novice drivers are particularly vulnerable to road traffic accidents. They are involved in more fatal crashes per miles driven then experienced drivers (Williams, 1999; Elliott, et al., 2001). Williams stated that the crash rate of 16 years old drivers was three times the crash rate of older teenagers, and almost 10 times that of middle aged drivers. Figure 2.1 shows the famous U-shaped curve of fatal crash rate by age (Insurance Institute of Highway Safety, 2008).

The U-shaped curve indicates two high-risk groups: the group older drivers more than 75 years old and the group of inexperienced younger drivers less than 25 years old.

![Figure 1.1 Fatal crashes by age, April 2001 to March 2002](image)

Compared with more experienced drivers, novice drivers have been reported to have cognitive deficiencies, psychosocial immaturity, and show risky driving behaviors (Kirk & Stamatiadis, 2001; Scott-Parker, et al., 2009; Ivers, et al., 2009). The risky
driving behaviors included speeding, driving under the influence of alcohol (Fry, 2008),
following too close, not wearing a seatbelt, carrying many teen passengers (Fu H &
Wilmot, 2008), and dangerous overtaking (Fernandes, et al., 2010). Another factor
related to younger drivers’ behavior is psychosocial maturation. Raymond et al. (2008)
reported that higher psychosocial maturation was associated with decreased problem
driving behaviors.

Another major factor in road accidents is hazard perception ability. Hazard perception
is considered as a higher-order driving skill, and the only component of the driving
skills that has been found to be related to accident involvement (Horswill and
McKenna, 2004). Hazard perception, also named risk awareness, is the ability of
identifying potential hazards. Field and experimental studies have indicated that hazard
perception skills of novice driver and experienced driver are very different
(Garay-Vega & Fisher, 2007).

Hazard perception is a cognitive process, which is hard to measure quantitatively. In
order to better understand hazard perception ability, researchers recorded drivers’ eye
search and scan patterns, and drivers’ reaction time to potential hazards. Other means
like Wallis and Horswill used a fuzzy signal detection theory to determine why
experienced and trained drivers respond faster than novices in a hazard perception
test.

Hazard perception relied heavily on driving experience. How to improve it before real
driving on the road is a topic of concern. Various training programs have been
developed for hazard perception training and for the assessment of drivers’ ability to
detect hazards. A review of these items is presented in the next section, Related
Research.

The objectives of the thesis were to explore the possibility of improving young novice
drivers’ hazard perception ability; build and evaluate the value of the serious game for
hazard perception training. Due to the immaturity of the teenagers psychological and
their enthusiasm to video games, we expected a serious game to be a better training
tool than others. Human subject experiments were done to assess the hazard perception
game effect.
Chapter 2 Related Research

This Chapter contains the literature reviews of hazard perception definition, hazard perception related factor: visual attention, and also hazard perception under distracted driving. These two aspects were stressed in our design. The prototype system in this thesis were related to a distracted driving, and the distractions were additional visual information while driving. Also different types of hazard perception training and test program were introduced in this chapter.

2.1 Definition of Hazard Perception (HP)

Hazard perception belongs to a more general concept, situation awareness (SA), which is defined as “the perception of environmental elements within a volume of time and space” (http://en.wikipedia.org). Endsley (1995) described three hierarchical levels of SA: Level 1 is perception of the elements in the environment; Level 2 is the comprehension of the current situation; and Level 3 is the projection of future status.

According to the SA model, driver information processing can be described as a series of stages: 1) detection (visual scanning, detecting path deviation); 2) perception (seeing with understanding, potential hazard recognition); and 3) evaluation (risk assessment, other users’ expectancies, attribution bias) (Lonero, 1995). Mayhew and Simpson (1996) attributed young drivers’ poor hazard perception primarily to deficiencies in the
process of detection (inadequate searching and scanning; less use of peripheral vision) rather than to deficiencies in perception or evaluation. However, Lynam and Twisk (1995) gave greater emphasis to perception and evaluation as described by Lonero (1995).

2.1 Hazard Perception (HP) and Vision Attention

Mourant & Rockwell (1970) were the first to record the eye movements of novice drivers as they drove on an Interstate highway. The results revealed that the eight drivers used peripheral vision to monitor lane position. Only 1% of their eye fixations fell directly on road markings. Before this study the role of peripheral vision with respect to vehicle control was largely unknown. However, the traditional role of peripheral vision, in terms of detecting sudden movements when driving, has always been recognized.

Another study by Mourant & Rockwell (1972) reported dramatic differences in the eye scanning behavior of novice and experienced drivers: 1) Novice drivers made a large number of eye fixations on road edge markings, and used the moving lane markers as targets for tracking eye movements. This indicates that the novice drivers had not learned to use peripheral vision for monitoring a vehicle’s lane position. 2) The range of eye fixations along the horizontal axis of the scene was much smaller for novice drivers than experienced drivers. This suggests that novice drivers would not be able to detect potential and immediate hazards found in many driving environments. 3)
Novice drivers seldom sampled their mirrors. Mirror sampling is necessary for a driver to maintain situational awareness. Similar results have been confirmed by some recent studies.

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 argue that novice drivers do not recognize a risky situation when they see one. Fisher and Pollatsek believe that novice drivers can be trained to recognize risky scenarios.

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. Experienced drivers increased the frequency of scanning based on situational demands. They suggest this may 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. That is, the ‘useful field of view’ is evidently smaller in inexperienced drivers, just as it is among those older drivers who experience deterioration in their information processing capacity (e.g. Owsley et al, 1998).

2.2 Hazard Perception of Distracted Drivers

Besides inexperience, another factor affecting drivers’ hazard perception abilities is distraction. The sources of distractions are cell phone conversations, in-vehicle devices, and talking with passengers et al. Driving distraction will increase cognitive load, and cause the decrease of drivers’ sensitivity to changes (Yi-Ching, et al., 2007). However some of these distractions are quite common, such as looking at the map in a navigation system.

Research has showed that in-vehicle technologies (IVTs) have some influence in other tasks like hazard perception. The use of a head-down display (HDD) and an auditory display caused slow responses to hazard events (Horrey & Wickens, 2004a). Hazard perception and in-vehicle tasks require focal vision, while vehicle control mainly relies on ambient vision. Horrey and Wickens (2004b) explained this task interference as the result of focal visual resource competition between in vehicle and hazard perception tasks. Horrey also pointed out that an optimal scanning strategy may help users to time
share effectively.

2.3 Hazard Perception Training

Since November 2002, the UK has had a hazard perception element as part of its theory test to obtain a driver’s license (Directgov, 2010). Examinees watch a video, and are asked to respond to developing hazards as soon as possible. For a car and motorcycle license, examinees are presented 14 video clips. Each video clip has at least one potential hazard, and examinees need to respond by clicking a button or using a mouse. A typical scenario from a test video clip is shown in Figure 3.2.1, the video was made from a driver’s point of view. The cyclist is about to move to the middle of the road to avoid the truck. This scenario requires a driver to take action. If the driver does not respond properly, an accident may occur.

![Screenshot in the UK's hazard perception test](image)

Figure 2.1 A screenshot in the UK’s hazard perception test

The Institute for Road Safety Research in the Netherlands reports that after one year of
hazard testing in the UK, accidents of young drivers were reduced by 3% (SWOV, 2008). Beginning in 2009, the Netherlands has incorporated testing hazard perception in the theory examination section of acquiring a driver's license. In the USA there is no hazard perception test in the driver’s licensing procedure. However, researches are trying to find ways to improve young drivers’ hazard perception abilities.

Many different hazard perception training programs have been developed as possible means to reduce crash risk during the past decades. Encouraging results have been reported (Haworth et al, 2000; McKenna & Crick, 1997). For example, McKenna and his colleagues (2006) examined the effect of their hazard perception training program on drivers’ risk taking behaviors. They found that there was a decrease in risk taking for novice drivers after training. In their experiment, they found that the trained drivers slowed down only at the specific points containing potential hazards. They concluded that this decrease was due to a specific improvement in hazard perception but not a nonspecific reduction in risk taking.

A Risk Awareness and Perception Training (RAPT) program was developed by Pradhan, et al. (2006). The training program was designed to whether a PC based training program can teach younger driver to scan for information that will reduce the likelihood of a crash. Participants were given 10 general driving scenarios containing three types of risks: 1) obstructions, 2) signs ahead, and 3) visible pedestrians and vehicles. In the latest version of RAPT, scenarios were displayed using a top-down
schematic view, which included some perspective screenshots. A participant needed to use a red circle or a yellow oval to markup the scenarios. The red circle area enclosed an area where drivers should pay attention. A yellow oval enclosed an area where a driver’s point of view is blocked by an obstacle.

The effectiveness of RAPT has been demonstrated in a number of studies (Pradhan & Fisher, 2006; Pradhan & Pollatsek, 2009; Pollatsek & Narayanaan, 2006). These studies involved both driving simulator and field research. They found that the trained groups had more eye gazes (64.4%) to the potential risk areas than the untrained ground did (37.4%). This indicated that the treatment effect was successful in increasing novice drivers’ perception skills.

RAPT can be used in the absence of an instructor. It is easily installed or downloaded to a personal PC, and is simply to operate. However, when the target users are teen drivers aged between 16 and 20, screenshots and text instruction may not be enough to motivate self-learning. Another issue is that users have to transfer the knowledge learned from text and 2D into a 3D real world. This process takes time before hazard perception skills can be transferred into real life.

Another system, DATS (Driver Assessment and Training System), was developed and evaluated by Allen, Park, et al. (2003). This system also focused on cognitive and perceptual skill deficiencies. The training system includes features for subject
registration, orientation and familiarization, simulator runs, a data recording system, and performance assessment and feedback. Like a game, a participant passed the training if she has no accidents and less than one ticket on the sixth trail. If a participant does not meet these criteria, she was given three more chances to be successful. If the participant failed on the ninth trail, the system would suggest that she drive carefully and pay attention to tips. The standardized training scenarios that included varying roadway alignment, cross sections, interactive traffic and pedestrians, and traffic control devices (i.e., signs, signals and delineation).

The primary objective of their research was to develop and demonstrate a PC-based driver training system that can be routinely run outside of the research laboratory by non-research personnel. Allen and Park (2003) used three different simulator configurations: a single monitor, a desktop system with three displays, and a cab with a wide field-of-view curved display. Training data of 111 high school students were analyzed to compare the effectiveness of different simulators. The authors analyzed the results in terms of: performance measures, simulator sickness and experience involved in implementing driver-training simulators. Performance measures included accidents, speeding, road edge incursions and time-to-collision. This study suggests that a low cost PC based simulator may have the potential of providing training in skills required for safe driving.
Isler and Starkey (2009) have developed and evaluated video-based road commentary training in a dual task. Like Figure 2.3, detecting and reacting potential hazard scenarios was the primary task, keep tracking of a moving target was the secondary task. They found after the road commentary training, the mean percentage of hazards detected and identified by the young drivers improved to the level of the experienced drivers. Also when compared with driving experience and age matched young drivers, the trained group shown the improvement in hazard detecting.
2.4 Action Video Games and Driver Related Cognition

For younger novice drivers, a video game may be more attractive than other forms of training programs. The perceptual and cognitive consequences of video game play have been investigated by several researchers. Encouraging results showed that playing video games improved cognitive skills.

Visual attention refers to a selective mechanism when observing a visual scene. Because a human’s attention resource is limited, a reasonable distribution of visual attention helps drivers to have better awareness of the road environment. However, novice drivers tend to just look straightforward, while experienced drivers have a wider scanning pattern (Mourant, 1972).

Literatures by Green, and Bavelier (2012) has shown that “Action video game-induced effects are notable for their generalization across varieties of attentional tasks and systems. Changes are noted not only when subjects have to select items in space, but also when they have to sustain attention over several objects or attend to specific events in time.” They attributed the improvements to a remarkable enhancement in the ability to efficiently deploy endogenous attention. Other research found that video games can increase the overall capacity of the visual attention system (Pylyshyn & Storm, 1988). They found that video game players can track two more objects than non-video game players when tested on a multiply object tracking paradigm.
Greenfield et al. (1994) demonstrated the effectiveness of video games in helping to develop the ability to divide and switch attention. In their study, subjects should press a button as soon as they saw a briefly flashed target stimulus. They were told that the stimulus could only appear at two locations, A and B. In 80% of the trials it would appear at location A and would only appear 10% of the trials at location B (on the remaining 10% of trials the stimulus appeared on both sides). By manipulating the probability of occurrence at each location, subjects became biased and allocated more attention to the high probability location. As a result, subjects were generally faster to respond to high probability targets and much slower to respond to low probability targets, which is taken to reflect the difference in attention allocation.

Another issue for novice drivers is reaction time. Reduced reaction times mean a longer braking time when approaching a hazard. A number of studies have confirmed that video game players have faster reaction times than non-video game players (Bialystok, 2006; Orosy-Fildes & Allan, 1989).

2.5 Summary

The above literature in this chapter addresses different aspects of hazard perception. The core of the multi defined concept hazard perception is perception ability on time and space while driving. The visual scanning pattern of novice drivers was different from that of experienced driver, novice drivers shown lower sensitivities to road condition. When facing dual tasks driving, the hazard perception ability was dropped
by a visual resource competition between different driving tasks. For novice drivers
this means an increased dangerous situation.

Researchers and institution have been making a continuous effect to improve novice
drivers’ hazard perception abilities. The methods include commentary training, a 2D
or 3D simulation. Those programs are presented in the forms of test, laboratory study,
or training targeted. What we built in this thesis was expected to be a game having
induced effects on driving hazard perception.

The proposed game simulated hazard situations in a virtual environment, asked a
game player to maintain driving task using keyboard in the virtual world, while
finishing challenging tasks by collecting objects using a mouse. We hope the game
could attract young drivers to achieve a spontaneous learning on hazard perception
skills. In order to evaluate the training effect of the game, a hazard perception test has
been developed in Chapter 3. The game design and human subject experiment are
introduced in Chapter 4 and Chapter 5. In Chapter 6 and Chapter 7, experimental data
has been analyzed and a final conclusion has been done.
Chapter 3 Hazard Perception Test (HPT) Design

3.1 HPT Overview

As introduced in Chapter 2, there is no standard hazard perception assessment system in the US. In order to evaluate participants’ hazard perception ability, we designed a HPT based on the US road condition. The HPT system can be run on both personal PC and driving simulator.

Our HPT presents a series of short driving video clips and asks a driver to identify potential hazards. Each video clip is about 60 seconds long and contains one or two potential hazards. A potential hazard is defined as an object that may cause the driver to slow down or change direction. Participants watch 12 clips in a HP test. As soon as realized it is becoming a hazard, the participant makes a response by clicking the mouse anywhere on the screen, and he will see a red flag at the right down corner as the result of a mouse input (Figure 3.1). The participant will have eight attempts to find the correct hazard in each video clip. Mouse input will be recorded into a database file. The eye movements of the participants will also be recorded for future analysis.
36 driving scenes were selected from the source videos filmed in general encounter environment in Boston, Massachusetts, 2011. Filming was during daytime, clear weather, and on clear road or snow road. A Flip UltraHD Video camera was used to recorded road conditions while driving. The camera was mounted inside of a Dodge Minivan, and secured in the right side of the front car glass in order to present driver's point of view. Resolution of the video clips is 80 * 720 at 60 frames per second, after compression, the frame rate is 30 frames per second. We chose about one minute long video contained one or two hazards as a driving scene. Hazards include scenarios like pedestrians walking across the street on your green light, double parked cars partly on your lane, vehicles emerging from side roads, meeting oncoming vehicles on narrow roads, junctions and roundabouts, etc.

Here is an example: in Figure 3.2 there is a lady in the middle of the road waiting to go
across the road. In real life driving, you need to slow down as you are on a narrow road. As soon as you realize this, you need to click on the screen.

Figure 3. 2 A Hazard in hazard perception test

3.2 HPT System Setup

Hazard perception test can be played on a PC. Since we are interested in participants' eye movement in the research, we choose to carry on HPT on a driving simulator, and monitor participants' eye movement using an eye camera system. The system setup is shown in Figure 3.3.

![Figure 3. 3 The hazard Perception System schematic diagram](image-url)
The controlling PC has been connected with the driving simulator. Hazard perception test has been projected onto the screen of the driving simulator. The participant watches the test, and uses the mouse to detect potential hazards. The participant is required to wear an eye movement glasses during the test, which has been connected with the eye tracking system.

### 3.2.1 Driving Simulator

The driving simulator at Northeastern University is shown in Figure 3.4. The cylindrical screen with a diameter of 12 feet can provide a 180 degree of view. A racing seat is mounted on an AC servo actuator at the center of the cylindrical screen. The steering wheel, gas and brake pedals were mounted on the seat and connected to the simulator’s computer via USB. The computer rendered the scene with inputs from these devices to calculate the heading and velocity of the vehicle. Three LCD projectors were combined to produce a 180 horizontal degree field of view (FOV). A distortion correction algorithm was applied for matching the images to the inside of the cylindrical screen. A software based edge blending algorithm was also implemented to eliminate banding across the display.
Figure 3.4 Driving simulator at Virtual Environment Laboratory, Northeastern University

Instead of driving in the simulator, participants just need to seat in the racing seat and react by clicking the mouse. Participants do not need to use the steering wheel, gas or brake pedals. A Macintosh Computer with 2*2.8 GHz Quad core Intel Xeon processor, 4GB RAM, NVidia GeForce 8800 GT graphics card. The middle projector was connected to the computer, projected the HPT image on the middle part of the cylindrical screen, and provides a 60 degree of view.

3.2.2 Eye Tracking—Mobile Eye System

In hazard perception test, eye tracking module consists of a Spectacle Mounted Unit (SMU, Figure 3.5), Recordable Mounted Unit (RMU), Sony GV-D10000E Digital Video Cassette Recorder and the analysis computer. The basic configuration of the analysis computer is Windows XP installed, 2 GHz core duo Intel processor, and 1GB
SMU was connected to it through RMU, SMU driver and user interface have been installed on the Windows PC. SMU contains a scene camera, an eye camera, and a short-distance audio microphone (Figure 3.5). The eye camera records the eye tracking data while the scene camera records the scene observed by the user. The sampling rates are 30 HZ. The eye tracking data includes information about where the user looked at, the x, y coordinate in the screen coordinate system.

![Figure 3. 5 Spectacle-mounted unit attached to the RMU and video recorder (Courtesy: ASL) From Operation Manual MobileEye, Manual Version 1.33, 8 June 2007.](image)

The eye tracking system uses the Dark Pupil Tracking Technology. This method uses the relationship between two eye features, the pupil and a reflection from the cornea (Corneal Reflection, CR), to compute gaze within a scene. A set of three harmless near infra-red (IR) lights is projected on the eye by a set of LEDs in the SMU. The near IR
light is not visible to the user so it will not cause a distraction, however it is visible to the eye camera on the SMU. A portion of these three lights will be reflected by the cornea and will appear to the camera as a triangle of three dots, called the Spot Cluster, at a fixed distance from each other.

The software EyeVision (Figure 3.6) is preinstalled on the Analysis Computer, is the data processing and user interface of the eye tracking system. A logged data file (.csv) and Video files (.avi) are the output of the system. The logged data file stores the eye and scene data generated by the analysis. The video files are video data from the scene camera and the eye tracking camera.

![EyeVision User Interface](image)

**Figure 3.6 The eye vision user interface**

The ASL eye movement camera required calibration for each subject. The video contrast level of the eye image needed to be adjusted so that the boundary between the
pupil and the iris was well defined; The contrast level of the eye image and the
goggles position are adjusted in order to ensure that the three corneal reflections are
clearly visible and their relative positions need to be defined (Figure 3.7).

![Image of eye with overlay and pupil score](image)

**Figure 3.7 Pupil display with overlay and pupil score (Courtesy: ASL)**

The Scene Calibration function maps eye movement against scene data by relating the
positions of eye features (the pupil and CR cluster) to known positions within the
scene image. A five point calibration (Figure 3.8) was used in the experiment.
Once the system was set up and calibrated, EyeVision analyzed the eye image and calculates gaze direction relative to the corresponding field of scene data. The gaze direction was the output as a Point of Gaze marker (red circle in Figure 3.9) superimposed on the scene video image and, using the DataLog facility, as an ASCII format (.csv) data file.
Chapter 4 Hazard Perception Training Game Design

The hazard perception training game we designed may be considered a “hybrid” game in that we hope it will be fun for the players and that learning will take place via side-effects. The skills we hope players will develop are: 1) quicker recognition of driving hazards; 2) better use of peripheral vision to detect driving hazards; and 3) more intelligent search and scan patterns with respect to driving hazards.

4.1 Principles of Game Design

The training system involves interdisciplinary research in the areas of human factors engineering, ergonomics, human computer interaction, computer graphics, and video game design. System design should consider different theories from different research areas.

![Figure 4.1 The flow chart of game design](image-url)
In order to design a game efficiently and effectively, we need to understand the standard game design progress (Fullerton, 2008). The first step is conceptualization followed by prototyping and digital prototyping. After interacting with beta testers, designers can obtain useful knowledge to revise their system. The testing and revising steps should be an iterative process to achieve the final goal (Figure 4.1).

Prototyping is crucial to good game design. Prototyping helps game designers to execute their ideas, test system feasibility, and adjust scenarios in future development. The early involvement of prototyping leads to time savings and reduces unnecessary work caused by design deficiencies. There are several types of prototypes (Fullerton, 2008): paper prototypes, physical prototypes, software prototypes, etc. A project may need more than one prototype, because each prototype has its own advantages and disadvantages. Designers should choose suitable prototypes according to their requirements.

Play-testing is another important activity during game design. It is used to exam how much the goal is achieved by the current version. Play-testing involves not only playing the game and giving feedback; it also incorporates more preparation, recruiting, and analysis. The tested content should include functionality, completeness, balance, and fun.

We had five people from the Mechanical and Industrial Engineering Department at
Northeastern University who tested three versions of our prototypes. They tried the system to find software bugs and provide design ideas.

An “interest curve” (Schell, 2008) is used to measure someone’s interest over time in an entertainment experience. Interest curves can help designers improve their product. An interest curve of a well-designed experience can be seen in Figure 4.2 (Schell, 2008).

Typically, there are three stages of a well-designed experience: the hook, lesser trials, and a major trial. When a user first has a certain amount of interest, she or he got excited by the experience at point B. This experience is called the hook. During the lesser trials (points B to point F), if the experience is well crafted, users’ interest will keep rising through facing the challenges, and they will learn skills. At point G, there is a climax in the major trial. The final challenge was solved, and the user was satisfied.

Figure 4.2 Interest curve for a well-designed experience

It is not necessary for every good design to follow the same interest curve, but interest curves should have some elements that resemble those in Figure 4.2.
4.2 Tools

With the rapid development of computer graphics, the technology of building a 3D virtual environment has gradually matured. Unity3D (www.unity3d.com) is an advanced game development engine with an integrated graphical environment (Figure 4.3). You can develop your game from modeling, programming, and publishing in Unity3D.

Figure 4.3 Unity3D editor

The excellent terrain engine and assets in Unity3D turns the possibility of building a complex virtual environment by a single person into reality. All terrain assets including texture, sound, and scripts are free. Figure 4.4 is a terrain in the example provided by Unity Company. Realistic 3D models of trees, grasses, stones, water, and hills are all opened to be used.
Figure 4.4 A 3D scene from Unity example

Besides, Unity is a good tool of developing driving game. It has a dedicated wheel collider (Figure 4.5, http://unity3d.com/support/documentation/Components/class-WheelCollider.html) simulating the traction model of real car tires. It has built-in collision detection, wheel physics, and a slip-based tire friction model. With the help of Wheel Collider, we have built a realistic car dynamics model.

Figure 4.5 Wheel collider in Unity3D
4.3 Creating Game Environment

Making a computer game run well and look good is a basic guideline in game design. Frames per second (FPS) is often used to measure whether humans perceive smooth motion when traversing a virtual environment. Thirty FPS is the minimum requirement for video games. http://en.wikipedia.org/wiki/Frame_rate. Frame rate is determined by graphic complexity, render passes, and trigger events that cause the creation of new assets, collision detection, and so on. There is an unavoidable trade-off between frame rate and graphic quality. When designing the game, next items needs to be paid attention to:

- Draw Calls

Draw calls are the major factor determining game performance. We tested the relationship between draw calls and frame rate in Unity3D on a Mac Pro (4 GB memory; 2 Quad-Core Intel Xeon; NVIDIA Geforce 8800 GT). The result is shown in Table 4.1. The frame rate dropped dramatically with increased draw calls. When draw call number increased about 5 times, the frame rate dropped from 134 to 20, in spite of keeping the number of vertices low.

A draw call is the process of the CPU sending information to the GPU and rendering. Strategies for optimizing performance in Unity3D is needed.
Table 4.1 Results of performance testing

<table>
<thead>
<tr>
<th>FPS</th>
<th>Draw Calls</th>
<th>Vertices</th>
</tr>
</thead>
<tbody>
<tr>
<td>133.9</td>
<td>469</td>
<td>2.5 M</td>
</tr>
<tr>
<td>65</td>
<td>1045</td>
<td>17.1 M</td>
</tr>
<tr>
<td>19.7</td>
<td>2480</td>
<td>3.8 M</td>
</tr>
</tbody>
</table>

- Modeling a Large Urban Environment

In a driving or racing game, a large urban environment is the basic environment. In our game, we have suburban, highway and city environments. The first two environments can be modeled taking advantage of Unity’s build-in terrain toolkit (http://unity3d.com/unity/engine/terrains.html). A city environment is more complex. It is based on a few elements: streets, buildings, landmark structures, props, traffic, and pedestrians. Polygon numbers have a direct impact on frame rate, so we choose low polygon models when less detail is needed, technologies such as LOD and mipmap are used.

- Modeling and Animations

All of our potential hazards are in the form of 3D characters animation. The main modeling tools we used are Cheetah3D (Figure 4.6, http://www.cheetah3d.com/) and Google Sketchup
(http://sketchup.google.com/), part of the 3D buildings were online resources, terrain assets were from Unity3D, and the rest of 3D models were made by the Virtual Environments Laboratory at Northeastern University.

Unity3D’s animation system allows users to create fine animations on 3D characters, and import animations from other modeling software. Users can control animations both from the animation editor and script.

![Cheetah3D user interface](http://itunes.apple.com/app/cheetah3d/id402708753?mt=12)

**Figure 4.6 Cheetah3D user interface**

The game system focused on modeling a variety of complex road conditions and potential hazards. In our current system, we have a rich context of scenarios, realistic road environments, and different weather conditions. Figure 4.7 shows a picture of the city environment with fog and snow. When running the game on a Laptop with 2GB
memories, 2.4 duo CPU, and average frame rate is above 30 frame per second (fps), 60 fps can be achieved when facing low polygon scenes.

Figure 4. 7 A city environment

There are three types of virtual environments in the game: city, suburb and highway. Suburb and highway environment look like Figure 4.8 and Figure 4.9. Suburb environment focused on modeling potential hazards like brushes, hidden driveways, people on the play yard, and pats etc. Highway environment contained hazards like car merging from side roadway, road work, and lane closed etc. City environment was more complicated: pedestrians, oversized vehicles, intersections, bike, and double parks cars and so on.
Figure 4. 8 A suburb environment in the HP training game

Figure 4. 9 A highway environment in the HP training game
4.4 Scenario Design

The objective of the training game is to improve users’ hazard perception skills. It is a challenge to insure that users will learn something by playing the game, so modeling the real life road hazards are the key part of the game. Typical risky situations include hidden objects, sudden events, and bad weather conditions. Such as:

- A person walking in fog.
- A car driving out behind bushes.
- A car suddenly driving out from an interaction.
- A bicycle at dusk with no lights on it.
- A ball rolls out onto road
- A parked car that is partially in your lane
- A parked car where the driver’s door opens
- Night time driving but the car in front of you has no tail lights
- Car in front of you suddenly stops
- Car from the side street acts like it will pull out in front of you
- An over-sized vehicle coming towards you

Figure 4.10 is the comparison of real life situation and 3D simulations in our training
game. Pictures on the right side are screen shots of the training game. Potential hazards in the game are animations of risky situations in real life. The high realistic simulation tries to reproduce real dangerous scene.

![Figure 4. 10 Comparison of real life situations and simulated situations in virtual world](image)

Users have to avoid those hazards. In our game those potential hazards are magnified in speed compared with potential hazards on road, and more dangerous scenarios with higher cognitive load (larger horizontal angle on screen, more sudden, and faster) are designed to shown at higher levels. Those hazards are expected to train users to pay attention to typical risky area, make wider horizontal scans, reduce reaction times, and time sharing skill.

Table 4. 2 Environmental elements and hazards in three game environments
<table>
<thead>
<tr>
<th>Environmental Elements</th>
<th>Highway</th>
<th>Suburb</th>
<th>City</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trees and Grass,</td>
<td>Trees and grass,</td>
<td>Trees,</td>
<td></td>
</tr>
<tr>
<td>Hills,</td>
<td>Houses,</td>
<td>Buildings,</td>
<td></td>
</tr>
<tr>
<td>Highway road</td>
<td>Curve road,</td>
<td>Intersections,</td>
<td></td>
</tr>
<tr>
<td>Traffic signs</td>
<td>Driveway,</td>
<td>Traffic signs,</td>
<td></td>
</tr>
<tr>
<td>Cars,</td>
<td>Cars,</td>
<td>Cars,</td>
<td></td>
</tr>
<tr>
<td>Sun Flare</td>
<td>Pedestrians,</td>
<td>Pedestrians,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cyclists,</td>
<td>Cyclists,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dog,</td>
<td>Train,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Jogger,</td>
<td>Running people,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Child,</td>
<td>Bus stop,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Playground</td>
<td>Traffic lights</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hazards Type</th>
<th>Highway</th>
<th>Suburb</th>
<th>City</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road work,</td>
<td>Pedestrian,</td>
<td>Pedestrians,</td>
<td></td>
</tr>
<tr>
<td>Other traffic.</td>
<td>Cyclist,</td>
<td>Cyclist,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Jogger,</td>
<td>People running across the street,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Unleashed Dogs,</td>
<td>Narrow road condition,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cars driving out of the drive way,</td>
<td>Train,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>School bus,</td>
<td>Intersections,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Intersections</td>
<td>Car door opening,</td>
<td></td>
</tr>
</tbody>
</table>

**Fun Elements in a Serious Game**

The primary goals of a serious game are education, training and informing. In order to
find out how we can get people motivated to learn on their own, we examine a study by Michael and Chen (2005). In their study, sixty-three respondents from game development, education, business, and other fields completed a survey. One question in the survey was to rate the “element of fun” in serious games. More than 80% of the people (Figure 4.11) thought fun is important or very important in serious games. The element of fun provides players the motivation to keep playing.

![Figure 4.11 Serious games survey result (Michael and Chen, 2005)](image)

Elements making a game fun include challenges, play, and story (Fullerton, 2008). Story serves as an emotional element in games, but is not necessary for every game. Challenges include exceeding goals, competing against opponents, stretching personal limits, exercising difficult skills, and making interesting choices. Besides presenting challenges, there are different types of play aimed at different types of players. Some games are aimed at providing freedom, pleasure, and romance. While others provide a
platform for social interaction, etc. When developing a serious game for a single type of players, we can deepen the play by focusing on the users.

According to the above guidelines, we enhance our game in terms of fun elements while keeping functionality. We put some fuel cells into the game, the task of the game is to collect certain number of fuel cells and reach the finishing line before time limit. It is a dual-tasks training. Player needs to reach a destination in limited time, while the secondary task was watching out for potential hazards, and searching for fuel cells. This will be a challenge and stimulate people's interest on the game.

![Image of fuel cells in the game](image)

**Figure 4.12 Fuel cells in the game**

These fuel cells are actually designed to help users acquire hazard perception skills. Fuel cells are located in high risky areas in a wide horizontal range and hidden behind obstacles. In higher levels, we make the fuel cells harder to detect. We can see three shining fuel cells around the yellow arrows in Figure 4.12. The left one is hidden...
behind the red car, you can gradually see it when you approaching the red car. This place is the driveway which is worth to be pay attention to, because cars may come out from driveways. The left fuel cell is the hardest one of three, because of its biggest scanning angel. The wider you scan, the faster you will find the fuel cell.

4.5 Level Design

The training game system has three different parts, and each part has several levels. The three parts are from simple hazard detection in low complexity driving environments, to hazard detection in complex driving environments. Perceptual load is increased as a user advances to higher levels. The difficulties increase from part 1 to part 3 in the way:

1. More difficult hazards located in both central and peripheral areas. It requires wider horizontal scanning. As we mentioned before, novice drivers tend to focus on central areas, and scan less on peripheral areas. They also lack the ability to react to a sudden event, such as Figure 4.13 presents, car door suddenly opens, basketball rolling to the middle of the road. Bushes, parked cars, or buildings may obscure a potential risk. Wider visual scanning would help identify such hidden potential risks.
2. Tasks are harder:
   - Time limits decrease;
   - Number of hazards and speed increase,
   - Required number of fuel cells increases, and total number of fuel cells provided decreases.

Here is a table (Table 4.3) shown our level design:

**Table 4.3 Level design**

<table>
<thead>
<tr>
<th></th>
<th>Part 1</th>
<th>Part 2</th>
<th>Part 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Level No.</td>
<td>2 (city, highway)</td>
<td>2 (suburb, city)</td>
<td>4(city, suburb)</td>
</tr>
<tr>
<td>Required Fuel Cell No. /Total Fuel Cell No.</td>
<td>5/8</td>
<td>5/6</td>
<td>8/8</td>
</tr>
</tbody>
</table>

In order to avoid players memorizing game setting, three different modes are randomly shown in each level. The place of the fuel cells and types of potential hazard are different in each mode. If game players replay the same level, one of the three modes would appear randomly, anything else keeps the same.
A game player needs to pass the current level before being able to advance to the next level. If failed to collect required number of fuel, or to meet the time constraints at some level, a player needs to start from the very beginning of that part. This method will force users practicing more.

4.6 User Interface and System Requirement

We have a friendly user interface, including instructions, settings, and menu bar. After player testing, testers found no problem in understanding and manipulating the game.

![Instruction page of the HP game](image)

**Figure 4.14 Instruction page of the HP game**

The hazard perception training game has two versions: Mac version and Windows version. It can be run on Windows 7/XP/2000, Mac OS system.
Chapter 5 Methodology

5.1 Participants

There are thirty four subjects aged from 18 to 20 applied for the study, eight subjects’ eye movement were not able to be tracked as a result of light eyes. Two subjects failed to finish all study sessions. Twenty four subjects are qualified in the study.

All of subjects are Northeastern University undergraduate students, and have a valid driver’s license or a learner's permit. They had less than 3 months of driving on a daily basis, and lived in the US during the last 5 years. All subjects had reported to have 20/20 or corrected to about 20/20 vision. There were 10 female and 14 male in twenty four participants. Each subject was paid an honorarium of $25 for participation in the whole research.

Twenty-four participants have been randomly assigned to either an experimental group or a control group with the consideration of near male-to-female ratio.

The experimental participants have 1) been tested for Hazard Perception (HP) ability by HP test, 2) played the Hazard Game on their computer for about two weeks, 3) been tested a second time for hazard perception by HP test, and 4) been tested a third time.
three weeks from the second test. The control group followed the same procedure except 2).

5.2 Procedure

The study includes laboratory sessions and self training session. The self training session was the video game training session for the experimental group. The laboratory sessions was conducted in the Virtual Environments Laboratory at Northeastern University for three times. The time intervals were two weeks, and three weeks. Each laboratory session was about 35 minutes.

For a laboratory session, upon arriving at the laboratory, subjects read and signed a consent form. Then they filled out a simulator sickness questionnaire (SSQ) and pre-test questionnaires. Questionnaires are different for different study sessions; detailed questionnaires can be found in Appendix B.

After filling out the forms, the subject was asked to get into the simulator. The eye movement camera was mounted and calibrated for each subject. Calibration of the eye movement camera involved a number of steps and took less than 10 minutes for each subject. If the eye tracking system failed to capture his or her eye movement, the subject was no long valid for the study. The subject then took the hazard perception test (sitting in a virtual environment fixed-based driving simulator, watching 12 video clips of driving, and reacting by clicking the mouse). At the completion of the HP test,
participants filled out the SSQ and the End of Experiment Questionnaire.

The whole study procedure is described in Figure 5.1:

Figure 5.1 Hazard perception study sessions

- First Laboratory Session (Time Zero)

Upon arrival at the Virtual Environments Laboratory, participants filled out a background form. All participants must have a valid driver’s license obtained within the last 30 days and no more than 10 hours of on-the-road driving experience after they received their driving license. Participants were given the instructions for the hazard perception test and asked if they have any questions. During hazard perception testing the participant’s search and scan patterns (eye movements) test were recorded.

The instructions that the participants were given at the HP test was listed below: “The hazard perception (HP) test presents 12 one-minute long driving
video clips. Each video clip contains one or two potential hazards.

As soon as you realized an object is becoming a hazard, please left click on the screen by using the mouse. You have eight chances to click in each video. A potential hazard is defined as an object that may cause the driver to slow down or change direction. Sometimes it is hard to determine what a potential hazard is. But try your best to detect them all.”

2. Self-training Session (Playing the HP Game)

After finishing the HP test, the participants of the experimental group downloaded the HP Game, and practiced at home for two weeks. The goal of this two weeks training was to finish all three game levels. At the end of two weeks, the participants in the experimental group are not supposed to play the HP Game anymore.

The whole training game is separated into three parts. In the beginning, the subject received an email with an internet link to download the first part. When the subject finished each part, he would find a code word on the screen. The rest two parts were only sent to the subject after he sent back the code word from the previous game part.

3. Secondary Laboratory Session

All participants in both the experimental and control groups again were given
hazard perception test. Like the session at time zero, their eye movement data were recorded. All participants filled out a form which includes the following: 1) time of hours driven during the last two weeks, 2) number of accidents during the last two weeks and 3) a description of every near accident during the last two weeks. The participants in experimental group were also asked some questions about the satisfaction of the training program.

4. Third Laboratory Session

In order to test the retention rate of visual skills acquired while playing the Hazard Perception Game, all participants in the experimental group took the Hazard Perception test three weeks after the completion of training session. As usual, their search and scan patterns were recorded during the testing. All participants filled out a form which includes the following: 1) time of hours driven during the last month, 2) number of accidents during the last month and 3) a description of every near accident during the last month.

All participants were required to follow the same time interval, however, there were noises about the dates, six participants were rescheduled once.

5.2 Hypotheses

1. At time zero, there are no differences in the average value of variables observed (reaction time, false alarm rate, miss rate, and times of wide horizontal scanning) between the experimental and control groups.
2. After two weeks, the average variables values of the experimental group will be significantly higher than those of the control group.

3. After two weeks, the average variables values of the experimental group will be significantly higher than their scores at time zero.

4. After two weeks, the average variables values of the control group will not be significantly different than their scores at time zero.

5. After five weeks, the average variables values of the control group will not be different than their scores after the first two weeks.

The above hypotheses will be tested using one-tailed t-tests at the 0.05 level of confidence in Chapter 6. Similar hypotheses can be formed and tested with other dependent variables such as the average width of horizontal eye search and scan patterns. After playing the video game for two weeks, the experimental group participants are expected to have wider horizontal eye search and scan patterns than the control group.
Chapter 6 Data Analysis

6.1 Experimental Data

Experimental Data is composed of two parts: the eye movement data collected during the HP test, questionnaires before and after each HP test. We expect to see changes in participants' search and scan pattern and reaction times after the game playing training.

When comparing the eye movement data before and after the game playing training, we focused on the following issues:

1) Whether the users paid attention to the high-risk areas by more attention on these areas;

3) Whether they do wide horizontal scanning;

4) Whether they find potential hazards in time.

Participants' eye movement during the HP test was recorded into a set of video clips. A typical eye movement video clip looks like Figure 6.1. The red circle indicated where a participant was looking. Therefore where and how long a participant gazed at an object can be obtained. The red flags on the lower right corner on the screen shows the users' mouse input. They clicked the left mouse button whenever they thought they detected a potential hazard.
Figure 6. 1 The Eye movement recorded during a hazard perception test

Data reduction refers the process of extracting useful information from data source. Here we are interested in the flowing parameters in terms of analyzing the training effect:

A. First Click on a hazard: The time from the video frame when hazard first becomes visible until the mouse button is clicked.

B. First Gaze on a hazard: The time from the video frame when hazard first becomes visible until the subjects first eye gaze longer that 333 ms on the hazard.

C. False Alarm: User inputs on undesired situations. The multiply clicks on one hazard are not belong to false alarm. When checking the video frame by frame, a correct input was accompanied by eye gaze on the hazards. Those inputs accompanied by eye gaze on other objects are considered as a false alarm.
D. **Total numbers of wide scanning:** Any eye movements greater than 20 degrees from center. A transparent grid mesh was overlapped on the videos to analyze the wide scanning frame by frame. Each time a participant moved his/her head, the position of the grid mesh moved correspondingly.

When the eye movement data was lost at critical point, we discarded the data in the current session, such as the eye movement data lost at the beginning of a hazard becoming visible, the data was invalid in calculating B.

### 6.2 Group Characteristics

Twenty four subjects are assigned to two groups randomly with the consideration of similar gender ratio. The characteristics of two groups are shown in Table 6.1.

<table>
<thead>
<tr>
<th></th>
<th>Experimental Group Mean (SD)</th>
<th>Control Group Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr)</td>
<td>19.67 (0.65)</td>
<td>19.42 (0.79)</td>
</tr>
<tr>
<td>Gender ratio (M/F)</td>
<td>7/5</td>
<td>7/5</td>
</tr>
<tr>
<td>Years of licensure</td>
<td>2.00 (1.21)</td>
<td>1.125 (1.09)</td>
</tr>
<tr>
<td>Driven distance (miles)</td>
<td>1890.91(2804.45)</td>
<td>1981.82 (4243.43)</td>
</tr>
</tbody>
</table>

Two groups had the same gender ratio; slight, not significant differences on age, and driven distance. Though the mean values of years of licensure have relatively large difference, the driven distance of the two groups were quite similar. All of the subjects
are around 19 years old with little driving experience. It was less than three years since each of them obtained the drivers’ license.

6.3 Hazard Perception (HP) Test Characteristics

There were three times of HP test in the whole study process. Table 6.2 shows the type of the hazards in three tests. All three tests have 16 hazards, but the specific hazards are not the same type.

Table 6.2 Type of hazards in HP Test

<table>
<thead>
<tr>
<th>Type of Hazards</th>
<th>Test 1</th>
<th>Test 2</th>
<th>Test 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pedestrians</td>
<td>7</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Cyclists</td>
<td>3</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Double parked cars</td>
<td>5</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Road work</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Others</td>
<td>1</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Total No. of Hazards</td>
<td>16</td>
<td>16</td>
<td>16</td>
</tr>
</tbody>
</table>

6.4 Statistical Analysis

6.4.1 Miss Rate

A miss is recorded when a participant fails to identify a hazard in desired time duration. A valid input is a mouse input between the first time a hazard can be seen until the hazard cannot be seen on the screen or becomes a normal situation. Miss Rate is the average of all control or experimental group members’ miss numbers. In order to
examine training effect on miss rate, we did the one-tail T-test for each of the three tests at the 0.05 level of confidence.

**T test by HP test**

➢ Test 1

Table 6. 3 Miss rate score in test 1

<table>
<thead>
<tr>
<th>Group/Subject</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>Mean</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental</td>
<td>1</td>
<td>4</td>
<td>2</td>
<td>9</td>
<td>3</td>
<td>6.5</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>0.5</td>
<td>1</td>
<td>1</td>
<td>2.92</td>
<td>6.77</td>
</tr>
<tr>
<td>Control</td>
<td>0.5</td>
<td>1</td>
<td>4</td>
<td>3.5</td>
<td>0</td>
<td>2</td>
<td>1.5</td>
<td>7</td>
<td>4.5</td>
<td>2</td>
<td>0</td>
<td>4</td>
<td>2.50</td>
<td>4.55</td>
</tr>
</tbody>
</table>

\[ df = 2 (n-1) = 22; \]

\[ t_{test} = \frac{\text{Mean}(E) - \text{Mean}(c)}{\sqrt{\frac{\text{Var}(E + \text{Var}(C))}{df}}} = 0.58 \]

\[ t(0.05, 22) = 1.72, \]

We do not reject the null hypothesis. Before the game playing training there is no significant difference between experimental group’s miss rate and control group’s.

➢ Test 2

Table 6. 4 Miss rate score in test 2

<table>
<thead>
<tr>
<th>Group/Subject</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>Mean</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental</td>
<td>0</td>
<td>6</td>
<td>0</td>
<td>3</td>
<td>3.5</td>
<td>4</td>
<td>0</td>
<td>6</td>
<td>1.5</td>
<td>0</td>
<td>4</td>
<td>2.33</td>
<td>5.65</td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>4</td>
<td>4</td>
<td>3.5</td>
<td>5</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>9</td>
<td>3</td>
<td>5</td>
<td>1.5</td>
<td>1.5</td>
<td>3.79</td>
<td>3.93</td>
</tr>
</tbody>
</table>

\[ df = 12-1 + 12-1 = 22; \]
t_{test} = \frac{(\text{Mean}(E) - \text{Mean}(c))}{\text{Sqrt}((\text{Var}E + \text{Var}C)/\text{df})} = -2.2098

t(0.05,22) = 1.72,

We reject the null hypothesis, and there is significant difference after training between two group’s miss rate. From the mean value, we can tell the training program do help users to recognize potential hazards.

➢ Test 3

Table 6.5 Miss rate score in test 3

<table>
<thead>
<tr>
<th>Group/Subject</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>Mean</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental</td>
<td>3</td>
<td>9</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>7</td>
<td>1</td>
<td>5</td>
<td>6</td>
<td>2</td>
<td>5</td>
<td>4</td>
<td>6.17</td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>7</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>0</td>
<td>4</td>
<td>11</td>
<td>5</td>
<td>5</td>
<td>3</td>
<td>6</td>
<td>5</td>
<td>6.00</td>
</tr>
</tbody>
</table>

df = 12-1 + 12-1 = 22;

t-test = \frac{(\text{Mean}(E) - \text{Mean}(c))}{\text{SQRT}((\text{Var}E + \text{Var}C)/\text{df})} = -1.3447;

t(0.05,22) = 1.72,

We do not reject the null hypothesis; there is no significant difference between the experimental group’s miss rate and control group’s three weeks after training.

About the miss rate, we have the following conclusion from the experimental data:

1. No significant difference between experimental group and control group in test 1;

2. A significant difference between experimental and control group’s miss rate in test 2.

Miss rate of the experimental group is smaller than that of the control group;
3. No significant difference between experimental group and control group in test 3, which shows the training effect on recognizing potential hazards faded off three weeks after training.

For the nature of the study, we expect to see that reducing on the miss rate for the experimental group, and no significant change for the control. However, when we checked the average miss rate by groups, the miss rates of the control group were growing largely, and that of the experimental group were not going down as shown in Figure 6.2.

Figure 6.2 The average miss rate by group

16 hazards are presented in all three tests. A possible explanation is the difficulties shown in the three tests are not equivalent. For example, some hazards in test 2 are harder to detect than that in test 1. If this assumption was true, the comparison of the
three tests became meaningless, because the control variable has changed. In order to verify this assumption, we did another one-tail T-test by group for test 1 and test 2, at the 0.05 level of confidence.

Table 6. 6 T test of the experimental group’s miss rate in test 1 and 2

<table>
<thead>
<tr>
<th>Test 1</th>
<th>Test 2</th>
<th>d=test1-test2</th>
<th>d-mean(d)</th>
<th>d-mean(d)*d-mean(d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0.416667</td>
<td>0.173611</td>
</tr>
<tr>
<td>4</td>
<td>6</td>
<td>-2</td>
<td>-2.5833</td>
<td>6.673611</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>2</td>
<td>1.416667</td>
<td>2.006944</td>
</tr>
<tr>
<td>9</td>
<td>3</td>
<td>6</td>
<td>5.416667</td>
<td>29.34028</td>
</tr>
<tr>
<td>3</td>
<td>3.5</td>
<td>-0.5</td>
<td>-1.0833</td>
<td>1.173611</td>
</tr>
<tr>
<td>6.5</td>
<td>4</td>
<td>2.5</td>
<td>1.916667</td>
<td>3.673611</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0.416667</td>
<td>0.173611</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>2</td>
<td>1.416667</td>
<td>2.006944</td>
</tr>
<tr>
<td>4</td>
<td>6</td>
<td>-2</td>
<td>-2.5833</td>
<td>6.673611</td>
</tr>
<tr>
<td>0.5</td>
<td>1.5</td>
<td>-1</td>
<td>-1.5833</td>
<td>2.506944</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0.416667</td>
<td>0.173611</td>
</tr>
<tr>
<td>1</td>
<td>4</td>
<td>-3</td>
<td>-3.5833</td>
<td>12.84028</td>
</tr>
</tbody>
</table>

\[ t_{test} = 0.82; \]
\[ t (0.05,11) =1.8; \]
\[ t_{test} < t (0.05, 11) \]

Table 6. 7 T test of the control group’s miss rate in test 1 and 2

<table>
<thead>
<tr>
<th>Test 1</th>
<th>Test 2</th>
<th>d=test1-test2</th>
<th>d-mean(d)</th>
<th>d-mean(d)*d-mean(d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>4</td>
<td>-3.5</td>
<td>-2.2083</td>
<td>4.876721</td>
</tr>
<tr>
<td>1</td>
<td>4</td>
<td>-3</td>
<td>-1.7083</td>
<td>2.918391</td>
</tr>
<tr>
<td>4</td>
<td>3.5</td>
<td>0.5</td>
<td>1.79167</td>
<td>3.210081</td>
</tr>
<tr>
<td>3.5</td>
<td>5</td>
<td>-1.5</td>
<td>-0.2083</td>
<td>0.043401</td>
</tr>
<tr>
<td>0</td>
<td>3</td>
<td>-3</td>
<td>-1.7083</td>
<td>2.918391</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>-1</td>
<td>0.29167</td>
<td>0.085071</td>
</tr>
<tr>
<td>1.5</td>
<td>3</td>
<td>-1.5</td>
<td>-0.20833</td>
<td>0.043401</td>
</tr>
<tr>
<td>----</td>
<td>---</td>
<td>------</td>
<td>----------</td>
<td>----------</td>
</tr>
<tr>
<td>7</td>
<td>9</td>
<td>-2</td>
<td>-0.70833</td>
<td>0.501731</td>
</tr>
<tr>
<td>4.5</td>
<td>3</td>
<td>1.5</td>
<td>2.79167</td>
<td>7.793421</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>-3</td>
<td>-1.70833</td>
<td>2.918391</td>
</tr>
<tr>
<td>0</td>
<td>1.5</td>
<td>-1.5</td>
<td>-0.20833</td>
<td>0.043401</td>
</tr>
<tr>
<td>4</td>
<td>1.5</td>
<td>2.5</td>
<td>3.79167</td>
<td>14.37676</td>
</tr>
</tbody>
</table>

$t_{test} = -2.35$;

$t (0.05,11) = 1.8$;

$| t_{test} | > t (0.05,11)$.

T tests result shows that there is no significant difference in the experimental group’s miss rate after game playing training, and significant difference in the control group without training. In the questionnaire session, we found subjects did not attend other driving training program during our experimental period. We concluded that the difference was caused by hazard perception test itself. In other word, there are significant difference between test 1 and test 2.

When designed the hazard perception test, it should be better to keep the same difficulties for three tests. Keeping each type of hazards the same number may help eliminating the difference among three hazard perception tests. Based on the analysis of the hazard perception test design, we will not do analysis by group anymore, because the analysis based on the changes of control variable (difficulties in each test) was meaningless. The training effect will only be examined by comparison of the data from two groups in each test.
6.4.2 False Alarm Rate

The accuracy of detecting a hazard is described using false alarm rate. A false alarm is a user input on non-hazard scenarios. Multiply inputs on one hazard are not considered as a false alarm. False alarm rate is the false alarm number per test run.

Examining the mean value of the false alarm rate in Figure 6.3, we found that:

![Figure 6.3 The average false alarm rate by group](image)

1. False alarm rate of experimental group and control are similar in test 1 before game playing training;

2. False alarm rate of control group is about 1.5 times of that of experimental group in test 2 after the experimental group received game playing training;

3. False alarm rate of control group is about 2.3 times of that of experimental group in
test 3.

A one-tail T-test for each of the three tests at 0.05 significance level is done in order to check the training effect statistically.

T-test by HP test

Test 1

Table 6. 8 False alarm rate in test 1

<table>
<thead>
<tr>
<th>Subject</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>Mean</th>
<th>ss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental</td>
<td>30</td>
<td>2</td>
<td>12</td>
<td>4</td>
<td>9</td>
<td>2.5</td>
<td>14.5</td>
<td>17</td>
<td>5</td>
<td>9</td>
<td></td>
<td></td>
<td>10.5</td>
<td>654</td>
</tr>
<tr>
<td>Control</td>
<td>14</td>
<td>40.5</td>
<td>9.5</td>
<td>6.5</td>
<td>12</td>
<td>29</td>
<td>11</td>
<td>4</td>
<td>6</td>
<td>3</td>
<td>9</td>
<td>8.5</td>
<td>12.75</td>
<td>1338.25</td>
</tr>
</tbody>
</table>

There are two subjects’ data invalid in experimental group, so the degree of freedom df = 10 + 12 - 2 = 20;

t(0.05,20)=1.725;

t = -0.52651;

We reject non hypothesis, which means before training there is significant difference between experimental group’s false alarm rate and control group’s.

Test 2

Table 6. 9 False alarm rate in test 2

<table>
<thead>
<tr>
<th>Group/Subject</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>Mean</th>
<th>Var</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exp</td>
<td>2</td>
<td>11</td>
<td>1.5</td>
<td>2</td>
<td>1</td>
<td>8</td>
<td>1.5</td>
<td>1</td>
<td>2</td>
<td>3.5</td>
<td>1</td>
<td></td>
<td>3.14</td>
<td>10.85</td>
</tr>
<tr>
<td>Control</td>
<td>8.5</td>
<td>1</td>
<td>4.5</td>
<td>8.5</td>
<td>25.5</td>
<td>4</td>
<td>1</td>
<td>3.5</td>
<td>1.5</td>
<td>3</td>
<td>3.5</td>
<td>5.86</td>
<td>49.05</td>
<td></td>
</tr>
</tbody>
</table>
df = 11-1 + 11-1 = 20;

t-test = (\text{Mean}(E) – \text{Mean}(c))/ \sqrt{(\text{Var}E+\text{Var}C)/\text{df}} = -1.65;

t(0.05,20) = 1.725,

We reject non hypothesis, which is after game playing training there is significant difference between experimental group’s false alarm rate and control group’s in Test 2.

➢ Test 3

<table>
<thead>
<tr>
<th>Group/</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>Mean</th>
<th>Var</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exp</td>
<td>3</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>3</td>
<td>1</td>
<td>1.42</td>
<td>1.90</td>
</tr>
<tr>
<td>Control</td>
<td>3</td>
<td>6</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>21</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>4</td>
<td>3.42</td>
<td>33.90</td>
</tr>
</tbody>
</table>

df = 12-1 + 12-1 = 22;

t-test = (\text{Mean}(E) – \text{Mean}(c))/ \sqrt{(\text{Var}E+\text{Var}C)/\text{df}} = -1.57;

t(0.05,22) = 1.72,

We failed to reject the null hypothesis, and there is no significant difference between experimental group’s false alarm rate and control group’s in Test 3.

The above three T test results show that the false alarm rate are significantly different between two groups in all of three tests. Although the false alarm rate of the experimental group has changed after training, due to the unequal false alarm rate before training, we cannot conclude that there is training effect on subjects’ ability of
detecting a hazard accurately in the statistical sense. However, the average false alarm rate of the experimental group is lower than that of the control group.
6.4.3 Reaction Time

Reaction time is the hazard detection time related to driving perception skill. A start point and an end point are set up for each hazard. Time duration (time between start point and end point) is different from each hazard according to specific situations. Usually, the start point is the point subject can see the potential hazard object. The end point is the point hazard objects cannot be seen or the dangerous behavior is not a threaten one anymore. According to the definition,

\[ \text{Reaction time} = \text{First click on a hazard} - \text{Start point} \]

For a hazard, the same time duration is used for all subjects. In order to minimize calculation error, the same trigger point for the hazard is used for all subjects. From Figure 6.4, we can conclude that after training, the reaction time of experimental group was shorter than that of the control group, and the training effect maintained until three weeks later.
**Figure 6.4** Average reaction time by group

**T-test:**

- **Test 1**

**Table 6.11 Reaction time in test 1**

<table>
<thead>
<tr>
<th>Group</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>Mean</th>
<th>ss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exp</td>
<td>6.16</td>
<td>3.16</td>
<td>2.33</td>
<td>3.70</td>
<td>3.91</td>
<td>5.07</td>
<td>5.42</td>
<td>3.98</td>
<td>5.01</td>
<td></td>
<td></td>
<td></td>
<td>4.31</td>
<td>11.6</td>
</tr>
<tr>
<td>Control</td>
<td>2.44</td>
<td>5.10</td>
<td>4.90</td>
<td>4.16</td>
<td>4.14</td>
<td>2.85</td>
<td>2.92</td>
<td>5.54</td>
<td>5.73</td>
<td>3.46</td>
<td>4.47</td>
<td></td>
<td>4.15</td>
<td>12.6</td>
</tr>
</tbody>
</table>

\( df = +11-2=18; \)

\( t = (0.05, 18)=1.734; \)

\( t = 0.293, \)

We failed to reject the null hypothesis, and state that there is no significant difference between experimental group’s reaction time and control group’s before training.
Test 2

Table 6. 12 Reaction time in test 2

<table>
<thead>
<tr>
<th>Group</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>Mean</th>
<th>Var</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exp</td>
<td>8.12</td>
<td>2.99</td>
<td>8.54</td>
<td>5.28</td>
<td>6.92</td>
<td>6.34</td>
<td>7.01</td>
<td>6.50</td>
<td>4.19</td>
<td>4.88</td>
<td>5.89</td>
<td>6.06</td>
<td>2.72</td>
</tr>
<tr>
<td>Control</td>
<td>9.27</td>
<td>11.66</td>
<td>8.32</td>
<td>6.55</td>
<td>5.09</td>
<td>5.02</td>
<td>7.33</td>
<td>8.78</td>
<td>6.00</td>
<td>5.78</td>
<td>9.12</td>
<td>7.54</td>
<td>4.35</td>
</tr>
</tbody>
</table>

df = 11-1 + 11-1 = 20;

t-test = (Mean(E) – Mean(c))/ SQRT((VarE+VarC)/df) = -2.61;

t(0.05,20) = 1.725,

We reject null hypothesis, and state that there is significant difference between experimental group’s reaction time and control group’s after training.

Test 3

Table 6. 13 Reaction time in test 3

<table>
<thead>
<tr>
<th>Group/ Subject</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>Mean</th>
<th>Var</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exp</td>
<td>6.22</td>
<td>5.59</td>
<td>4.72</td>
<td>6.74</td>
<td>5.10</td>
<td>6.23</td>
<td>5.82</td>
<td>5.08</td>
<td>5.61</td>
<td>8.90</td>
<td>5.14</td>
<td>6.38</td>
<td>5.96</td>
<td>1.23</td>
</tr>
<tr>
<td>Control</td>
<td>8.75</td>
<td>4.67</td>
<td>5.09</td>
<td>10.62</td>
<td>7.28</td>
<td>4.46</td>
<td>5.55</td>
<td>7.31</td>
<td>6.06</td>
<td>7.30</td>
<td>5.90</td>
<td>10.62</td>
<td>6.97</td>
<td>4.48</td>
</tr>
</tbody>
</table>

df = 12-1 + 12-1 = 22;

t-test = (Mean(E) – Mean(c))/ SQRT((VarE+VarC)/df) = -1.98;

t(0.05,22) = 1.72,

We reject null hypothesis, and state that there is significant difference between experimental group’s reaction time and control group’s in Test 3.
The game playing training effect on reducing subjects’ reaction time is significant. The experimental group has a shorter reaction time than the control group right after and three weeks after training. We believe that our training game helps users reducing reaction time facing a potential hazard situation.
6.4.4 First Notice Time

How fast subjects picked up hazard objects is also analyzed, and measured by the average first notice time as shown in Figure 6.5. The first notice time was defined as the time beginning from a hazard becomes visible until the first eye gaze longer than 333.3 ms. The faster drivers pay attention to a developing hazard, the bigger chance they will have to avoid an accident.

Before game playing training, both groups took the similar time to find a hazard; after training, the experimental group took shorter time compared with the control group.

![Average first notice time by group](image)

**Figure 6.5 Average first notice time by group**

**T-test:**

- Test 1

<table>
<thead>
<tr>
<th>Test</th>
<th>Experimental</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test 1</td>
<td>1.14</td>
<td>1.13</td>
</tr>
<tr>
<td>Test 2</td>
<td>1.09</td>
<td>1.59</td>
</tr>
<tr>
<td>Test 3</td>
<td>1.45</td>
<td>1.71</td>
</tr>
</tbody>
</table>

Table 6.14 First notice time in test 1
df=8+9-2=15;

$t (0.05,15)=1.753$;

t= 0.066,

We failed to reject the null hypothesis, and state that there is no significant difference between experimental group’s reaction time and control group’s before training.

Test 2

Table 6. 15 First notice time in test 2

<table>
<thead>
<tr>
<th>Group/Subject</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>Mean</th>
<th>Var</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exp</td>
<td>1.53</td>
<td>0.79</td>
<td>1.18</td>
<td>1.29</td>
<td>0.51</td>
<td>2.09</td>
<td>1.24</td>
<td>0.74</td>
<td>0.92</td>
<td>1.05</td>
<td>0.62</td>
<td>1.09</td>
<td>0.21</td>
</tr>
<tr>
<td>Control</td>
<td>1.62</td>
<td>1.36</td>
<td>1.73</td>
<td>1.71</td>
<td>1.46</td>
<td>1.14</td>
<td>2.15</td>
<td>1.61</td>
<td>1.57</td>
<td>1.61</td>
<td>1.51</td>
<td>1.59</td>
<td>0.06</td>
</tr>
</tbody>
</table>

$df = 11-1 + 11-1 = 20$;

t_test = $(\text{Mean}(E) - \text{Mean}(c))/ \text{SQRT}((\text{Var}E+\text{Var}C) / df) = -4.5$;

t(0.05,20) = 1.725,

We reject the null hypothesis, and state that there is significant difference between experimental group’s first notice time and control group’s in Test 2.

Test 3
### Table 6. 16 First notice time in test 3

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>Mean</th>
<th>Var</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Exp</strong></td>
<td>1.44</td>
<td>1.36</td>
<td>0.54</td>
<td>1.27</td>
<td>0.75</td>
<td>0.98</td>
<td>1.03</td>
<td>1.25</td>
<td>0.83</td>
<td>2.67</td>
<td>0.61</td>
<td>1.14</td>
<td>1.16</td>
</tr>
<tr>
<td><strong>Control</strong></td>
<td>1.72</td>
<td>1.90</td>
<td>1.62</td>
<td>2.85</td>
<td>1.35</td>
<td>0.85</td>
<td>0.86</td>
<td>2.34</td>
<td>2.01</td>
<td>1.67</td>
<td>1.22</td>
<td>2.06</td>
<td>1.71</td>
</tr>
</tbody>
</table>

$$df = 12-1 + 12-1 = 22;$$

$$t\text{-test} = \frac{(\text{Mean}(E) – \text{Mean}(c))/ \text{SQRT}((\text{Var}E+\text{Var}C)/df)} = -3.17;$$

$$t(0.05,22) = 1.72,$$

We reject the null hypothesis, and state that there is significant difference between experimental group’s first notice time and control group’s in Test 3.

We can conclude that the hazard training program is effective in helping users building up hazard models, which makes users more sensitive to hazard situations.
6.4.5 Visual Scanning Analysis

Previous research (Mourant & Rockwell, 1972) has found that the range of eye fixations along the horizontal axis of the scene was much smaller for novice drivers than experienced drivers. Due to lower level of skill development, the ‘useful field of view’ is evidently smaller in inexperienced drivers (Underwood, 2007). The driving game we designed is dedicated to improve young novice drivers scanning strategies. This part of the thesis examined whether more times of wider scanning had happened in the experimental group than the control group.

Numbers of wide eye glance (any eye glance over ±20 degrees field of view) was calculated also from the videos recorded using the ASL eye movement camera. Videos were analyzed using an equal width grid system (Figure 6.6). The driving seat was mounted at the center of the cylindrical screen with the distance of 3 feet. The equal width grid system ignored the error caused by the cylindrical screen under the consideration of small distance from the camera to the cylindrical screen.
The transparent grid mesh was overlaid over the video; the right edge of the grid mesh was always lapped over the right edge of the screen in the video clip. Each grid represents a horizontal angle and vertical angle of 5 degrees. The field of view of the single projector driving simulator is 60 degrees. The range of the grade system is -30 degree to 30 degree.

The number of wide eye glance was defined as the sum of a sequence of eye fixations within our interested area. Here we were interested in eye glances over + or - 20 degrees. Any eye glance over ±20 degrees field of view was considered as a wide scanning.

Generally, a HP test has several video clips, and lasted for 12 minutes. In order to simplify the calculating, I sampled two video clips from each test run to analyze the wide scanning strategies. The sampled data are two selected video clips in HP test,
including intersections on a straight busy road.

From Figure 6.7, the mean value showed that more times of wide eye glances happened in the experimental group than the control group after training. T tests would examine the statistic characters of the wider scanning strategies.

![Figure 6.7 Numbers of wide eye glance by group](image)

**T-test:**

- Test 1

<table>
<thead>
<tr>
<th>Group/Subject</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>Mean</th>
<th>SS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exp</td>
<td>5</td>
<td>3</td>
<td>4</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td>4.31</td>
<td>11.6</td>
</tr>
<tr>
<td>Control</td>
<td>4</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td></td>
<td>4.15</td>
<td>12.6</td>
</tr>
</tbody>
</table>

df = 9+11-2=18;

t = (0.05, 18)=1.734;
\[ t = 0.293, \]

We failed to reject the null hypothesis, and stated that there is no significant difference between experimental group’s times of wide scanning and control group’s before training.

- **Test 2**

**Table 6. 18 Times of wide scanning in test 2**

<table>
<thead>
<tr>
<th>Group/ Subject</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>Mean</th>
<th>Var</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exp</td>
<td>9</td>
<td>7</td>
<td>8</td>
<td>5</td>
<td>8</td>
<td>7</td>
<td>8</td>
<td>8</td>
<td>7</td>
<td>5</td>
<td>8</td>
<td>7.27</td>
<td>1.62</td>
</tr>
<tr>
<td>Control</td>
<td>6</td>
<td>7</td>
<td>6</td>
<td>8</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>6</td>
<td>8</td>
<td>8</td>
<td>6</td>
<td>6.64</td>
<td>1.05</td>
</tr>
</tbody>
</table>

\[ df = 11-1 + 11-1 = 20; \]

\[ t_{test} = (\text{Mean(E)} - \text{Mean(c)})/ \sqrt{\text{(VarE+VarC)/df}} = 1.826; \]

\[ t(0.05,20) = 1.725, \]

We reject null hypothesis, and state that there is practically difference between experimental group’s times of wide scanning and control group’s after training.

- **Test 3**

**Table 6. 19 Times of wide scanning in test 3**

<table>
<thead>
<tr>
<th>Group/ Subject</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>Mean</th>
<th>Var</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exp</td>
<td>8</td>
<td>9</td>
<td>10</td>
<td>9</td>
<td>7</td>
<td>9</td>
<td>6</td>
<td>9</td>
<td>8</td>
<td>11</td>
<td>8</td>
<td>6</td>
<td>8.33</td>
<td>2.24</td>
</tr>
<tr>
<td>Control</td>
<td>7</td>
<td>9</td>
<td>8</td>
<td>9</td>
<td>5</td>
<td>7</td>
<td>8</td>
<td>6</td>
<td>7</td>
<td>10</td>
<td>8</td>
<td>7</td>
<td>7.58</td>
<td>1.9</td>
</tr>
</tbody>
</table>

\[ df = 12-1 + 12-1 = 22; \]

\[ t_{test} = (\text{Mean(E)} - \text{Mean(c)})/ \sqrt{\text{(VarE+VarC)/df}} = 1.728; \]

\[ t(0.05,22) = 1.72, \]
We reject null hypothesis, and state that there is significant difference between experimental group’s times of wide scanning and control group in Test 3.
6.5 Questionnaire Analysis

In each of the three HP test sessions, participants filled out pre and post test questionnaires. Different questionnaires were designed for different session. A simulator sickness questionnaire (SSQ) (Kennedy et al., 1993) is required in each session. If a participant reported a serious sickness during the test, he would ask to be stop the session. All of the 24 participants has finished three sessions. The SSQ analysis result shown that the simulator test session was tend to cause some oculomotor discomfort.

After game playing training, the experimental group members were asked to fill out a questionnaire on their game playing experience. We found that all of the twelve subjects believe that the training game can help them improve their hazard perception skills, but only two subjects thought they would play the game if it was not required to do so; three subjects said they maybe play it.

Table 6.20 Training questionnaire

<table>
<thead>
<tr>
<th>Subject ID</th>
<th>Time on Part 1 (hr)</th>
<th>Time on Part 2 (hr)</th>
<th>Time on Part 3 (hr)</th>
<th>Time on Game in Total (hr)</th>
<th>Fun</th>
<th>Reality</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>0.33</td>
<td>0.25</td>
<td>0.5</td>
<td>1.08</td>
<td>4/5</td>
<td>4/5</td>
</tr>
<tr>
<td>5</td>
<td>0.3</td>
<td>0.5</td>
<td>1.5</td>
<td>2.3</td>
<td>3/5</td>
<td>3/5</td>
</tr>
<tr>
<td>7</td>
<td>0.33</td>
<td>0.5</td>
<td>0.33</td>
<td>1.16</td>
<td>3/5</td>
<td>3/5</td>
</tr>
<tr>
<td>8</td>
<td>0.1</td>
<td>0.1</td>
<td>1</td>
<td>1.2</td>
<td>4/5</td>
<td>5/5</td>
</tr>
<tr>
<td>13</td>
<td>1</td>
<td>0.5</td>
<td>0.25</td>
<td>1.75</td>
<td>4/5</td>
<td>4/5</td>
</tr>
<tr>
<td>15</td>
<td>0.25</td>
<td>0.33</td>
<td>0.55</td>
<td>1.13</td>
<td>4/5</td>
<td>4/5</td>
</tr>
</tbody>
</table>
Table 6.20 shows their evaluation on their satisfaction in terms of whether the training game was interesting or simulated the real life driving scenarios. 5 point is the highest score. The average score of whether the game is fun is 3.42 out of 5, whether it is realistic is 3.92 out of 5. Subjects all finished three parts of the training game. The average time they spend on the whole training process is 90 minutes. They spend more time on the last part.

As a laboratory research program, this short time training showed a reasonable improvement on subjects’ hazard perception skill, and satisfied subjects’ need on realistic. A more complex, funny and enhanced training action game might have better effects in hazard perception training.
6.6 Results

We have analyzed four parameters: reaction time, first notice time, false alarm rate, and miss rate in this chapter. One tailed t-tests at the 0.05 level of confidence has been done for each parameter. The game playing training we used showed its effectiveness in the laboratory experiment when comparing two groups at each interval. We believe the training game can be used to improve novice drivers’ hazard perception skill in the following ways:

1. Helping young novice drivers develop better scanning skills.

   Recent research undertaken on a driving simulator in which eye movements were analyzed, indicated that younger drivers are often unaware of the areas of the roadway that they should be scanning (Pradhan et al. 2005). Our experimental results have shown that game training helped subjects have more times of wider horizontal scanning when driving compared with the control group, although not a significant improve.

2. Helping young novice drivers respond quickly to risky situations.

   Shorter reaction time is crucial in avoiding traffic accidents. The experimental group’s reaction time to a potential hazard shortened right after the game training compared with the control group, and lasted until three weeks later when comparing with the control group. This result indicated that the game training was significant in reducing subjects’ reaction time. Subjects have an improvement in
responding to risky situations on a roadway. The improvement on first notice time also shows the training effect on sensitive to potential hazards. Subjects found potential hazards quickly after training.

3. Helping young novice drivers build a mental model of dangerous conditions on road.

Subjects’ had relatively good satisfaction with the realism of the game. This shows the game’s success in simulating real life road conditions. Subjects also thought the game portrayed accident-prone areas well. The potential hazards simulation played a key role in helping subjects build to learn high risky areas, which lead to shorter reaction time, and better scanning strategies. The lower, although not significantly lower, miss rate and false alarm rate, also showed that game training had positive effects on recognizing potential hazards when driving.

There are also some limitations of this laboratory study. One was due to different false alarm rates for the two groups before training. This baseline error made the following analysis of game training effect on false alarm rates cannot be performed.

Another large limitation was that the difficulty level of the three HP tests was not the same. This made the comparison of game training effects by session hard to measure. For example, in Figure 6.4, the reaction times of the control group were significantly different in test 1 and test 2 (the scores are 4.02 and 7.54). This result was inconsistent with the hypotheses we made in Chapter 5.
Third, a powder analysis on sample size was lacked. When I chose 24 participants in the experiment, a powder analysis should be done first to decide whether 24 was an effective size.

“After two weeks, the average HP scores of the control group will not be significantly different than their scores at time zero.”

In the background form, the control group subjects stated that they had not much driving experience during the two weeks. Thus, we have reason to believe the difference was caused by the unequal difficulties in HP test 1 and test 2. A good HP (Hazard Performance) test design should keep the test difficulties at the same level. This would help make the within group analysis accurate.
Chapter 7 Conclusions

7.1 Contributions of the Dissertation Work

In this thesis, we focused on the topic of understanding and improvement of young novice drivers’ hazard perception skills. As an important road safety topic, researchers and institutes have put a lot of effort on young drivers’ hazard perception skill. This thesis reviewed the current status of world-wide hazard perception research, and tried to evaluate and improve novice drivers’ hazard perception skill. There are three major contributions of the dissertation: 1) development of a hazard perception test on the US roads, 2) development of a hazard perception skill-based training game, and 3) experimental finding that hazard perception skills can be trained.

In the United States, there is no hazard perception test required for driver licensing as in the United Kingdom. This thesis provided an evaluation test based on the US road driving. The hazard perception test contains twelve short driving video clips. Each video clip has one or two potential hazards. It can be run on a personal PC or used in a driving simulator. Users’ performance data can be recorded in a database file. Also, the test can be updated in terms of driving video clips. People can film new driving video clips, and add the new clips into the test in the format of .swf video files.

Another main section of this thesis was concerned with whether we can reduce risk
taking caused by lack of hazard perception skills. A 3D hazard perception training game was designed and built as part of this thesis. We expected the game to help improve users’ HP skill, and motivate young drivers’ enthusiasm of self-learning. The design guideline was to develop a realistic driving game, which simulates real life risky road conditions, and then learning will take place via side-effects. In our current version, the game has three parts, each part has two or four levels, and perceptual load is increased in higher levels. Players need to pass the current level before advancing to the next one. The risky road scenarios are based on real life potential hazards. The training game has been tested in a human subject experiment in the Virtual Environment Laboratory at Northeastern University before being used as part of this thesis.

Twenty-four young drivers aged from 18 to 20, participated in the thesis experiment that lasted for five weeks. Half of subjects have been chosen to have game playing training randomly, the other half of subjects had no training. All of the subjects have been tested for three times on the HP test. The aims of the three tests are: 1) baseline test, 2) training effect test, and 3) training effect persistence test. Subjects needed to fill out before and after test questionnaires. Meanwhile, their eye movements were recorded during each test run. The questionnaires, and the videos recorded using the ASL eye movement camera, were analyzed after the experiment.

In the questionnaire analysis, subjects felt satisfied with the realism and learning
effects of the game. Some of the subjects thought the game was interesting and fun to play.

The eye movement video recordings were analyzed to compare the experimental group and the control group on 1) reaction time, 2) first notice time, 3) miss rate, 4) false alarm rate, and 5) wide eye scanning. Results on reaction time, first notice time, and wide eye scanning were consistent with our hypothesis, and showed the game training effect on helping participants recognizing and quickly finding potential hazards on the roadway. Also there were improvements in the experimental group’s scanning strategies in terms of wider horizontal scanning. However, the training effects on the false alarm rate and miss rate were not as good as expected. Although the average value showed certain improvement, there was no statistical significance in these two parameters. Subjects were still having problems in evaluating risky situations. Overall, we believe novice drivers would benefit from our hazard perception training game.

**7.2 Future Work**

Hazard perception skill of the young novice drivers would be better as the growth of driving experience. However, a training program can also improve the skill before driving on the roadway. The idea of the hazard perception training was proved to be valuable in this thesis.
The future work of our research will be how to improve its educational functionality. As a laboratory study, the hazard perception driving game was a prototype system developed by a small amount of people. There were limitations such as lack of professional 3D model resources, and how to make the game more attractive by a better game level design. These elements are crucial to a popular video game. How to make the game more challenging is a future direction of our research. Also, the functionality of the training game will need to be continuously enhanced. This required further understanding on the principles of the hazard perception skills so as to build richer scenes of potential hazards.
References


trained to scan for information that will reduce their risk in roadway traffic scenarios that are hard to identify as hazardous? *Ergonomics*, 52, 657-673.


Tracy Fullerton, T., Game Design Workshop, 2nd edition, Morgan Kaufmann, 2008


Related Publications & Academic Activities


*A Game to Train Drivers in Hazard Detection*, Na Chen, Tanvi Chitnis, Beverly Jaeger, Ronald R. Mourant, research demo at IEEE Virtual Reality 2010, March 22, 2010, Waltham, MA, USA.

*Can Perceptual Skills Be Changed by Playing a Computer Game?* Na Chen, Poster, Research and Scholarship Expo 2010, March 24, 2010, Northeastern University, Boston, MA, USA.


*A 2D game using 3D characters*, Na Chen, Poster, Research and Scholarship Expo 2009, Poster, March 24, 2009, Northeastern University, Boston, MA, USA.
Appendix A: Subject Forms

Background Form

Subject Number: ______________________

Date of Birth: ________________

Gender: ________________

Driver’s License Issued Date: ________________

On-the road driving miles before license: _________

On-the road driving miles after license: _________

Do you like playing video games?  Yes  No

Have you driven on a daily basis (at least 5 out of 7 days a week) for a period of more than three months since you got your driver's license?

Yes  No

How many hours per week do you spend on video games? _____________

How many accidents did you have in past? If so, please describe each of them.

Do you have some near crashes? If so, please describe each of them.
# Appendix B1: Simulator Sickness Questionnaire

Subject number __________  Date __________

Please Check One:      Before Testing__________         After Testing _____________

Circle how much each symptom below is affecting you right now.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th>None</th>
<th>Slight</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>General discomfort</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>Fatigue</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>Boredom</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>Drowsiness</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>Headache</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>Eye strain</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>Difficulty focusing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>a)</td>
<td>Salivation increased</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>b)</td>
<td>Salivation decreased</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
<td>Sweating</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td></td>
<td>Nausea</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td></td>
<td>Difficulty concentrating</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td></td>
<td>Mental depression</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td></td>
<td>Fullness of the head</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>a)</td>
<td>Dizziness with eyes open</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>b)</td>
<td>Dizziness with eyes closed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td></td>
<td>Vertigo*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td></td>
<td>Visual flashbacks**</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td></td>
<td>Faintness</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td></td>
<td>Aware of breathing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td></td>
<td>Stomach awareness***</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td></td>
<td>Loss of appetite</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>22</td>
<td></td>
<td>Increased appetite</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>23</td>
<td></td>
<td>Desire to move bowels</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>24</td>
<td></td>
<td>Confusion</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td></td>
<td>Burping</td>
<td>NO</td>
<td>YES</td>
<td># of times:</td>
</tr>
<tr>
<td>26</td>
<td></td>
<td>Vomiting</td>
<td>NO</td>
<td>YES</td>
<td># of times:</td>
</tr>
<tr>
<td>27</td>
<td></td>
<td>Other</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Vertigo is experienced as loss of orientation with respect to vertical upright.
** Visual illusion of movement or false sensations of movement, when NOT in a simulator, car, or aircraft.
*** Stomach awareness is usually used to indicate a feeling of discomfort which is just short of nausea.

Describe other: ________________________________
## Appendix B2: The Experimental Group Questionnaire in Hazard Perception Test 2

<table>
<thead>
<tr>
<th>Question</th>
<th>Response Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Do you think the game is fun (1 is lowest, 5 is highest)?</td>
<td>1 2 3 4 5</td>
</tr>
<tr>
<td>2. How many hours have you spent playing the driving game?</td>
<td>Part 1</td>
</tr>
<tr>
<td></td>
<td>Part 2</td>
</tr>
<tr>
<td></td>
<td>Part 3</td>
</tr>
<tr>
<td>3. Do you think the game simulated some scenarios in real life driving?</td>
<td>(1 is lowest, 5 is highest)?</td>
</tr>
<tr>
<td>1. Do you think playing the game could help you improve your driving</td>
<td>(hazard perception) skills? If so, in what way?</td>
</tr>
<tr>
<td>2. Do you find any software bugs when playing the game?</td>
<td></td>
</tr>
<tr>
<td>3. Do you have any suggestions as to how the game could be improved?</td>
<td></td>
</tr>
<tr>
<td>4. Would you play the game if it was not required?</td>
<td></td>
</tr>
</tbody>
</table>
Appendix B3: End of Experiment Questionnaire in
Hazard Perception Test 2

<table>
<thead>
<tr>
<th>Subject Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Please describe hazards that appeared in the test:</td>
</tr>
<tr>
<td>a) ____________________</td>
</tr>
<tr>
<td>b) ____________________</td>
</tr>
<tr>
<td>c) ____________________</td>
</tr>
<tr>
<td>d) ____________________</td>
</tr>
<tr>
<td>e) ____________________</td>
</tr>
<tr>
<td>f) ____________________</td>
</tr>
<tr>
<td>g) ____________________</td>
</tr>
<tr>
<td>h) ____________________</td>
</tr>
</tbody>
</table>

2. How many miles have you driven during the past two weeks?

3. Do you have some (near) crashes in the past 2 weeks? If so, please describe each of them.

4. Do you think the driving game can help you identifying hazards in the hazard perception test? (Answer the question only if you are in the experimental group)