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The influence of personal navigation devices on drivers' visual attention on the road ahead and driving performance

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THE INFLUENCE OF PERSONAL NAVIGATION DEVICES ON DRIVERS' VISUAL ATTENTION ON THE ROAD AHEAD AND DRIVING PERFORMANCE

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LIST OF ACRONYMS

PND	Personal Navigation Device
POI	Point Of Interest
PDT	Percent dwell time
GPS	Global Positioning System
IM	Instant Messaging
PC	Personal Computer
GUI	Graphical User Interface
SUI	Speech User Interface
OEM	Original Equipment Manufacturer
HUD	Head Up Display
ARD	Augmented Reality Windshield Display
MOVE	Maps Optimized For Vehicular Environment
LCD	Liquid Crystal Display
IR	Infra Red

UNH	University of New Hampshire
SID	Screen Intersection Display
APDT	Average Percent Dwell Time
IPDT	Instantaneous Percent Dwell Time
TIPDT	Transformed Instantaneous Percent Dwell Time
ANOVA	Analysis of Variance

ABSTRACT

THE INFLUENCE OF PERSONAL NAVIGATION DEVICES ON DRIVER'S VISUAL ATTENTION ON THE ROAD AHEAD AND DRIVING PERFORMANCE

by

NEMANJA MEMAROVIC

University of New Hampshire, September 2009

Nowadays, personal navigation devices (PNDs) that provide GPS-based directions are widespread in vehicles. These devices typically display the real-time location of the vehicle on a map and play spoken prompts when drivers need to turn. While such devices are less distracting than paper directions, their graphical display may distract users from their primary task of driving. This thesis investigates the influence of two PNDs on driving performance and visual attention. In the experiments conducted with a high fidelity driving simulator, we found that drivers using a navigation system with a graphical display indeed spent less time looking at the road compared to those using a navigation system with spoken directions only. Furthermore, glancing at the display was correlated with higher variance in driving performance measures. We discuss the implications of these findings on PND design for vehicles.

CHAPTER 1

INTRODUCTION

1.1 Navigating with in-vehicle personal navigation devices: problem statement

In-vehicle Personal Navigation Devices (PNDs) provide a very convenient way of navigating from start to end destination while driving by visually displaying the vehicle's real-time location on an electronic map which is accompanied with turn-by-turn spoken prompt instructions. Over the last fifteen years PNDs have shifted from being a luxury to inexpensive off-the-shelf products that can be found in any store. This shift is continuing and car manufacturers are now offering vehicles with built in PNDs; it will not be long until we cannot imagine driving without them. If these devices are going to be a part of our daily driving, we have to make sure that they are safe and easy to use.

A typical interaction with a PND starts with entering the desired end destination. Drivers now have many ways of doing that, from entering a full street address (upper picture in Figure 1.1.1) to simply choosing a point of interest (POI) from a list of restaurants, hotels, gas stations and more (lower picture in Figure 1.1.1). When their end destination is chosen, the driver can start navigating with a PND. PNDs assist the driver in navigation by displaying the vehicle's real-time position on an electronic map with a highlighted traverse path along with turn-by-turn spoken prompt instructions. One example of a PND's interface is in Figure 1.1.2. We can see that besides navigation information, we can get information on vehicle's velocity, current time, the prediction for the destination arrival time, and POIs in the vicinity.

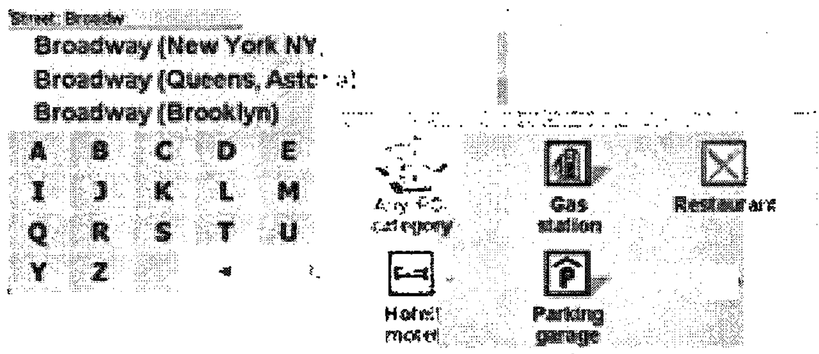


Figure 1.1.1 PNDs destination entry. Full address entry is shown in upper picture while lower picture shows choosing destination via point of interest (POI).

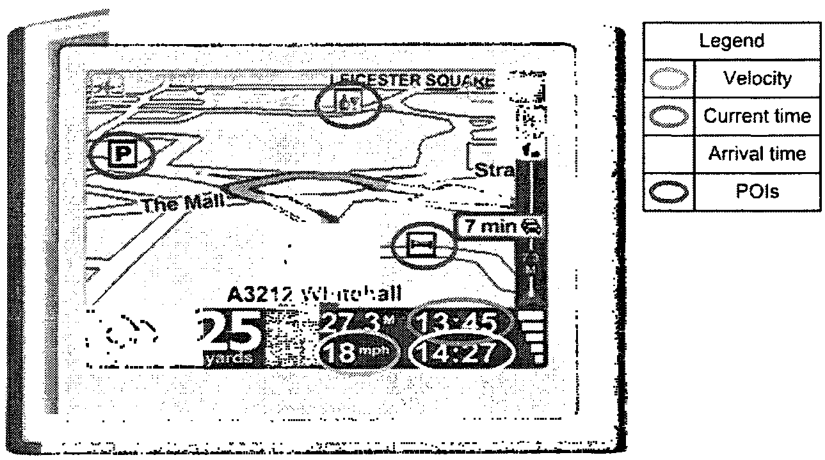


Figure 1.1.2 Example of a PND device showing vehicle's real time location

Although drivers receive spoken instructions for the direction and distance of the next turn, they often cast glances at the PND to check their location on the map or to see where the next turn is going to be. This shifting of attention from the road ahead to the PND is shown in Figure 1.1.3 and it can come in a potentially dangerous moment, especially in the urban city environment where it is likely that certain unexpected events might happen, like a pedestrian trying to cross the street outside of the crosswalk area or a vehicle in front pulling out suddenly. In other words, the main **problem** with PNDs is that they could potentially represent a new source of distraction because they require driver's visual attention.

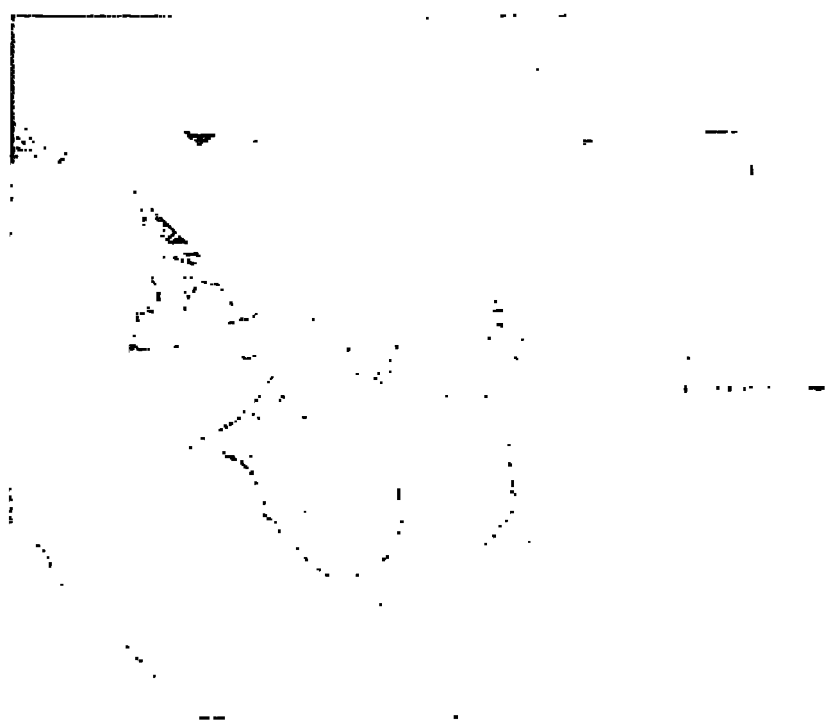


Figure 1.1.3 Driver shifting the attention from the road ahead to the PND.

1.1 Goals

Our **primary goal** is to measure scientifically the influence of two different in-vehicle PNDs on driving, i.e. the influence of a standard PND with a combined visual (electronic map) and spoken output, and the influence of a PND with spoken output only. We can break this general goal into two sub-goals. The **first goal** of this thesis is to find out if a PND with combined outputs (visual and spoken) causes drivers to spend less time looking at the road ahead than a PND that provides spoken output only. The **second goal** is to examine the effect of glancing at the PND's visual display on driving performance.

1.2 Hypotheses

Our **major hypothesis** is related to the **first goal** of the thesis. We hypothesize that a PND with combined output will influence the percent dwell time (PDT, time drivers spend looking) on the outside world negatively when compared to the PND with spoken output only, i.e. drivers will be more distracted by it (Figure 1.2.1). When navigating with a PND with combined output, drivers are visually distracted (shown in Figure 1.1.3) by the map displayed on the PND, thus they spend less time looking at the road ahead. On the other hand, PND with spoken output only doesn't have the map, so there's nothing to visually distract the driver.

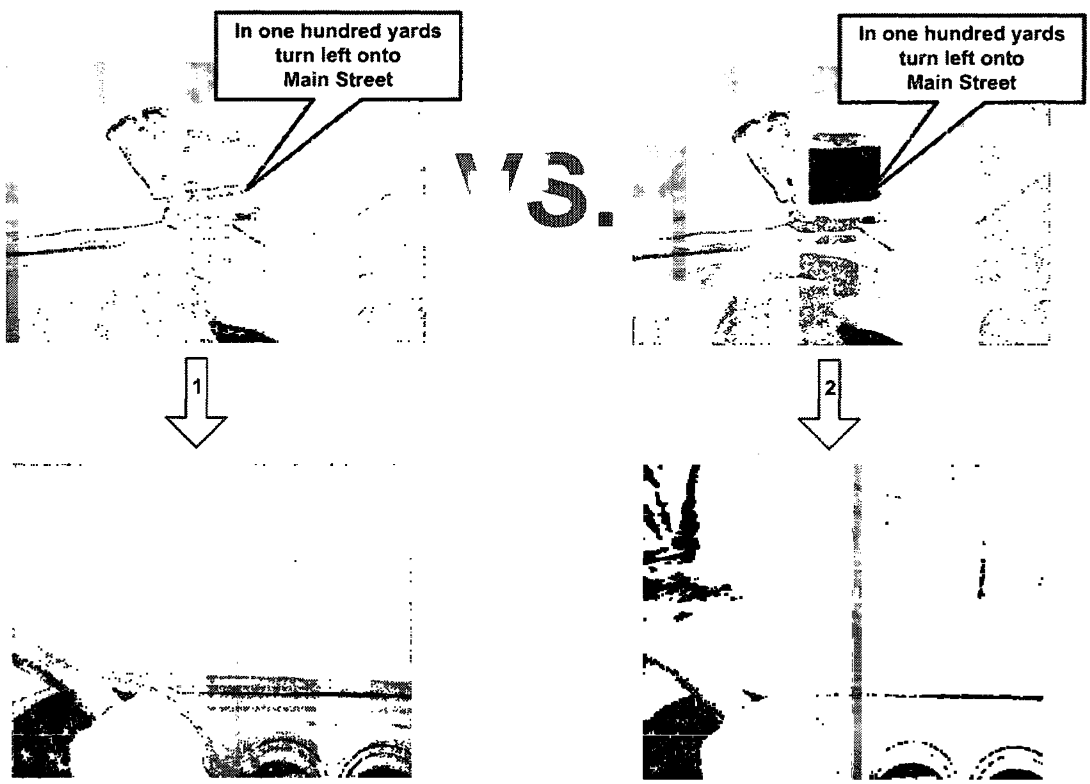


Figure 1.2.1 The influence of PND with combined output (1) and spoken output only (2) on PDT

The **second hypothesis** is related to the **second goal** of the thesis. We hypothesize that glancing at the PND's visual display will influence negatively the driving performance. More precisely, increase in the lane position and steering wheel angle variances will be correlated with instances when drivers look away from the road (Figure 1.2.2). The correlation between percent dwell time (PDT) reduction and the lane position variance is going to be more notable for the PND with combined output, because the driver will be more distracted by it. The same applies for the correlation between PDT reduction and the steering wheel angle variance.

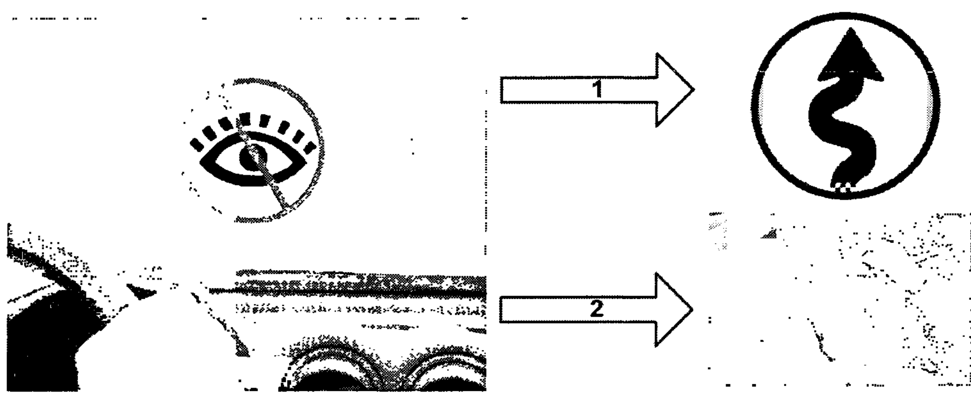


Figure 1.2.2. Looking away from the road increases variance in the lane position (1) and steering wheel angle (2)

1.3 Approach

In the pursuit and investigation of our goals and hypotheses we propose a within-subjects experiment in our high-fidelity driving simulator, shown in Figure 1.3.1, with counterbalanced usage of the two PNDs (combined visual and spoken output, and spoken output only) among male participants. For the purpose of this experiment driving scenarios were created to resemble urban, city-like environments with certain unexpected events, such as pedestrian crossing the street suddenly and vehicle in front pulling out, that will make the environment more realistic. The reason why we chose driving in an urban environment is because this environment typically has more turns than, for example, a rural environment, and participants are more likely to glance at the PND when they need to make a turn. All pertinent data was logged: lane position, steering wheel angle, velocity, and eye gaze information.

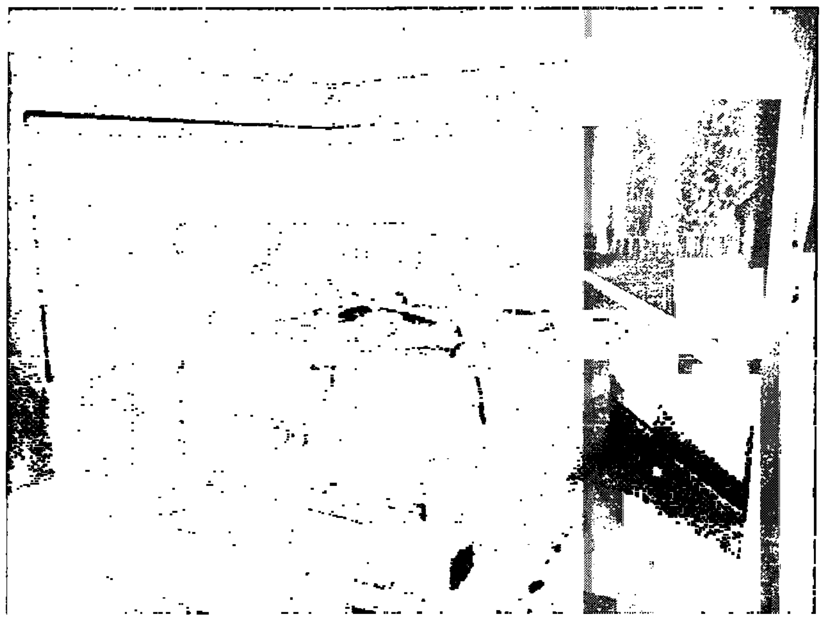


Figure 1.3.1 180° field of view driving simulator

Both quantative and qualitative methods will be used for data analysis. The qualitative analysis includes a post-experiment questionnaire concerning the participant's general views on their performance and preference for the two PNDs. The quantitative analysis examined standard driving performance measures (steering wheel angle, lane position, velocity), PDT on the outside world, and various cross-correlations between the PDT on the outside world and driving performance measures.

1.4 Thesis organization

The thesis is organized in seven chapters.

"Chapter 1 – Introduction" provides an introduction to the work carried out in this thesis including the problems addressed, goals, hypotheses, and the proposed approach for hypotheses testing.

"Chapter 2 – Background" provides a background overview and literature review on relevant issues for this thesis: overview and design guidelines for PNDs, in-vehicle devices and distraction, studies on electronic maps, and novice navigation methods.

"Chapter 3 – Experiment design" describes the equipment used in the experiment, driving scenario, experimental protocol, dependent and independent variables, and participants' demographics.

"Chapter 4 – Results and Discussion" explains the data analysis carried out in this thesis. It gives details on driving performance results and visual attention, and it explains various cross-correlations between PDT and driving performance measures that were necessary for the successful explanation of their causality.

"Chapter 5 – Conclusion" discusses implications of the results on PND design.

"Chapter 6 – Future work" gives suggestions for future work to expand and improve the efforts launched in this thesis.

"Bibliography" lists all referenced material used as the knowledge base in conducting this research. The references are given in the order in which citations appear in the text.

CHAPTER 2

BACKGROUND

Global Positioning System (GPS) is a Global Navigation Satellite System (GNSS) that transmits radio wave signals through a constellation of somewhere between 24 and 32 medium Earth orbit satellites to GPS receivers, and allows them to calculate their current time, location, and velocity. GPS is used in many areas: map-making, land surveying, tracking and surveillance…, but it is mostly used by consumers for positioning and navigation with in-vehicle personal navigation devices (PNDs). PNDs bring new convenience into driving because drivers don't have to memorize the route instructions, but they also distract them from the main task of driving. The main source of distraction is the electronic map displayed on the PND, and knowing how drivers read them would be useful in finding the solution for this problem. Overall information on current trends with in-vehicle PNDs might help in this search, as well as following certain design guidelines that can be found in the literature. There are also PNDs that are using novice navigation methods which could reduce the distraction. The following sections summarize the work that has been done in the areas of overview and design guidelines for PNDs, in-vehicle devices and distraction, studies on electronic maps, and novice navigation methods.

2.1 Introduction

As seen in Mark Weiser's vision of a ubiquitous computing world [1;2], computers are becoming integrated into our daily life: we can now shop online for almost anything, from buying a house to ordering food, keep in touch with relatives and friends from all over the world via email, instant messaging (IM), or video call, or we can "Google" the Earth and see the exact location of our hotel for the next summer vacation. All of that we can do from the comfort of our home on a standard desktop personal computer (PC), or in a public bus from a Blackberry, or in the field outside the library from a laptop. When we are interacting with computers in this kind of manner, the main focus of attention is the computer itself, but there are environments where we don't have such a luxury: when we are driving, the main focus of our attention is the road, not the interaction with a computer. This mobile environment requires different computers because issues of security, privacy, usability, and reliability have to be resolved [3] as well as finding the appropriate user interfaces [4]. There are systems that have addressed the problems mentioned above, like Project54 [5]. This system is installed in more than 1,000 police cruisers in the state of New Hampshire and it integrates all in-vehicle devices, such as radar, radio, and lights and siren, into one system with three different user interfaces: a speech user interface (SUI), graphical user interfaces (GUI), and device's direct hardware interface. But the Project54 system isn't publicly available; it is only installed in police cruisers. On the other hand, PNDs are widely available as both manufacturer-installed and off-the-shelf products. They represent the first step in in-vehicle computer interaction for the consumer.

According to "World GPS Market Forecast to 2013" [6], the PND market is going to exceed $75 Billion by 2013, meaning that by 2013 we'll have a PND in almost every car. In spite of the fact that the number of PNDs in vehicles is rapidly increasing we still think of them as something new in cars, something that's altering the driver's environment [7]. They disengage drivers from their environment, e.g. drivers don't need to worry about where they are anymore or where their destination is, but they also engage them in novel ways, e.g. enabling them to discover landmarks that are not visible from the road. Like with vehicle telematics or any new in-vehicle device, the main problem with PNDs is that they represent a new source of distraction. Drivers have to cast glances at the electronic map displayed on the PND to see where they are or where their next turn is going to be. Positioning, size, and other properties of the PND, like text size, map orientation, number of elements displayed on the map..., could also influence the number of glances drivers have to cast in order to interact with the PND. There are novice navigation aids, like an augmented navigation map on the windshield, which would reduce the distraction. To reduce the distraction caused by PNDs, it would be useful to review the literature for overview and design guidelines for PNDs. in-vehicle devices and distraction, studies on electronic maps, and novice navigation methods and aids. These topics are the main focus of this literature review.

2.2 Overview and design guidelines for PNDs

Design and operational characteristics of any device are closely related with its usability. In a mobile, hands-busy, eyes-busy environment, i.e. when driving, a device's usability assumes much greater imoprtance because it is tightly coupled with safety. Llaneras et al. wanted to understand better current trends in design and implementation of

PNDs and their likely impacts on driver distraction [8]. They have reviewed twenty eight PNDs, both Original Equipment Manufacturer (OEM) and aftermarket, and summarized characteristics on the number of overall (average slightly over 11) and navigation specific hard controls, mounting position (center area of the instrument panel, dash area over the center, low in the vehicle cab in the floor console), type (maps, maneuver lists with sequenced turn directions, and turn-by-turn guidance) and amount of information (road map, vehicle icon, landmarks...) on the display, characteristics of the auditory display (ranging from system interaction features to the format of auditory output), safety features (warning strategies for interactions while driving), data entry screens, and destination entry methods (street address, intersection, point of interest, address book entry, previous destination, city, manual selection, freeway entrance/exit, town center, phone number, and latitude/longitude). It is interesting to note that at the time when these PNDs were reviewed, only one of the PNDs was completely speech based (AudioNAV) and only one had voice recognition capabilities (Lexus LS 430).

While Llaneras et al. summarized interface characteristics of market-ready PNDs, Paul Green came up with design guidelines for them, focusing on the route guidance aspect of the interface [9]. According to these guidelines, guidance should be provided by turn-by-turn directions on a Head Up Displays (HUD) accompanied by voice instructions, minimum size of the on-screen text should be 6.4 mm, intersections should use plan or aerial view with maps heading up, landmarks should be present as well as the distance to the nearest intersection, and voice messages should be provided approximately 450 feet from an intersection when traveling 40 mi/hr. As concluded by Green, simply following these guidelines though is not enough. When designing a new user interface we have to include iterative testing and redesign as well as user feedback in the whole process. The conjunction of guidelines, testing, redesigning, and user feedback should lead to safe and easy to use PND user interfaces.

2.3 In-vehicle devices and distraction

The number of in-vehicle devices in cars is growing: we can now find PNDs and MP3 players in most newly manufactured cars. The main task while we are in a car is driving, but we still need to interact with in-vehicle devices. This interaction is distracting because drivers have to shift their attention from the road ahead to the in-vehicle device. Salvucci came up with a prediction model for the effects of in-vehicle interfaces on driver behavior using a cognitive architecture [10]. To validate his prediction model, he examined four methods of dialing a cell phone while driving: full digit manual dialing (entering every digit of a phone number), manual speed dialing (entering single "speed" digit number), full digit voice dialing (speaking every digit of a phone number), and voice speed dialing (speaking a name of the person whose phone number is going to be dialed). His prediction model closely fitted the dialing times gathered from an empirical study for all types of dialing, with some exceptions, but the results were still encouraging his approach.

Horrey et al. conducted two driving experiments in a study with a similar secondary task as Salvucci [11]. In the first experiment, the secondary task involved reading a seven digit phone number presented on the head-down display and voice-dialing the number, and in the second experiment, the task was to determine if the five or eleven digit number had more even or odd numbers (each choice had one button on the steering-wheel). The goal of the experiments was to investigate the influence of in-vehicle devices in general on the visual attention of drivers and driving performance. The results of the experiments showed that as the percent dwell time (the time that drivers spend looking) at the outside world decreased, the variability in lane position increased, which means that visual distraction negatively influences driving performance.

One of the devices that can be found in a vehicle is an MP-3 player. Chisholm et al. examined the effects of iPod interactions on driving performance over several sessions [12]. Participants were involved in two types of interactions with the iPod: easy (turning off the iPod, pausing a song, and scrolling ahead a couple of songs) and difficult (locating and playing a specific song) over the course of seven weekly hour-long sessions. They were also exposed to a number of critical events such as pedestrian incursions, lead vehicle braking, and vehicles pulling out. Participants made more and longer glances into the vehicle while engaged in the difficult iPod task, perception response time (time in seconds from the critical event onset until participant responded by applying pressure to the brake pedal) increased by 0.18s, or 16% over the baseline, along with higher frequency of collisions while interacting with the difficult iPod task. These results show that engagement with a difficult iPod task, like selecting a specific song from a playlist, is dangerous and should be avoided while driving.

Mobile radio transceivers can be found in police cruisers, commercial transportation trucks, and private vehicles of amateur radio and citizens band hobbyists. They have a manufacturer-provided manual user interface that allows changing radio channels using buttons or knobs. The change in radio channel can be confirmed on the display which is located on the faceplate of the radio. Medenica and Kun have compared the influence of the radio's manual user interface and the Project54 speech user interface on drivers' performance while interacting with a mobile radio [13]. They showed that interactions via the speech user interface degraded driving performance significantly less than the manufacturer-provided manual user interface. A general implication of their results is that even interactions with manual interfaces that drivers can reach easily may degrade driving performance significantly, especially if the driver needs to receive visual feedback from the interface.

Tsimhoni et al. have also evaluated user interfaces for the task of address entry into a PND [14]. They have compared three different methods for this task: word-based speech recognition, character-based speech recognition, and typing on a touch screen keyboard. Word-based speech recognition yielded the shortest total task time (15.3s), followed by character-based speech recognition (41.0s), and touch screen keyboard (86.0s). When performing keyboard entry, driving performance was degraded by 60% compared to the two speech interfaces. Tsimhoni et al. conclude that using a speech user interface is safe, but the combination of speech and visual interfaces shouldn't be considered risk free.

2.4 Studies on electronic maps

As can be concluded from the previous chapter, distraction with in-vehicle devices mostly comes when the interaction needs visual attention (studies on interaction with cell phones indicate that distraction is not due solely to visual distraction). PNDs are guiding drivers via electronic map and voice instructions, and drivers often glance and read the map to check their location or where the next turn is going to be. Tshimoni and Green wanted to gain insight into when reading an electronic map from a display can be distracting [15]. They used visual occlusion to assess the impact of reading an electronic map on driving performance and visual attention. When the driver wanted to read the map, they had to press a switch mounted on their finger and the road scene was replaced with a map (the experiment was run in a driving simulator). Map reading involved verbally answering questions that had three levels of difficulty (short, medium, and long answers required) under five different workload conditions (parked, straight road, easy curve, moderate curve, and sharp curve). The results showed that increasing visual demand (progressing from short to long questions) decreases the duration of in-vehicle glances, but increases their number as well as the time between them.

Paul Green and his colleagues from the University of Michigan Transportation Research Institute have also conducted a series of experiments to determine the time necessary to read electronic maps [16-18] and differences in glance behavior between turn-by-turn and electronic map navigation [19]. The results of the simulator studies [16;18] were prediction models for a driver's response time for various map reading tasks: identifying the street being driven as a function of age and street label point size; finding the name of the nth cross street as a function of age, number of streets on the display, and location of the target cross street; finding a street on the map as a function of age, number of streets on the display, point size used to label the streets, percentage of the labeled streets, location of the target street, and search result (penalty if the street wasn't found). The same map reading tasks were then performed in on-the-road experiments in day and night conditions and prediction models were updated with new factors [17]. The results from on-the-road experiments showed the validity of the simulator results for two of the three tasks (street being driven, finding street on the map). In the last study in the series Paul Green et al. performed on-the–road experiment to see the difference in glance behavior when navigating with turn-by-turn and electronic map display [19]. The turn-by-turn display was 3.75 times more frequently looked at than the electronic map display.

2.5 Novice navigation methods and aids

As with any electronic device, PNDs need constant improvement if we want to make them more usable and safer to use. These improvements come in the realm of novice navigation methods and aids. Kim and Dey investigated a in-vehicle navigation display system that displays navigation information directly onto the vehicle's windshield, thus creating an Augmented Reality Windshield Display (ARD) [20]. Their goal was to minimize a driver's cognitive load when interacting with a PND and reduce divided attention caused by the visual and spatial separation between the view of the road ahead and the PND's navigational display. Although they state that this navigation aid is meant for elder drivers, the fact is that it can be used by drivers of all ages. Kim and Dey evaluated the simulated version of this system against a standard PND with both younger and elder drivers (12 elder drivers (65+) and 12 younger drivers). The results showed significant reduction in navigation errors and reduction in time drivers spend looking below the windshield when interacting with the ARD. In other words, drivers spend more time looking at the road ahead with this novice navigation aid.

While Kim and Dey integrated a navigational map into a windshield to reduce the distraction, Hooland et al. removed it completely in their solution and relied only on a spatial audio user interface for navigation [21]. This solution, called AudioNAV, takes an audio signal and transforms it into a binaural signal received by the user through headphones. They assume that the route is navigable by proceeding in the direction of the next destination, like turn-by-turn navigation. Using spatial audio only without any kind of map brings two problems in question: direction and distance. The direction problem is addressed by panning a sound source across the stereo sound stage. In other words, the sound appears to come from a given environmental location that represents direction. Distance is represented in a "Geiger counter" or "hot/cold" fashion: the frequency of the spatial sound gives an indication of how far is the next waypoint. AudioNAV's usability was tested in two pilot trials. The results showed that this system is usable for locating targets on foot, but the system's response was too slow to cope with changes of direction when driving. If Hooland et al. could overcome this problem, this system should be very useful in reducing the distraction caused by the standard PND map if the audio cues are infrequent.

ARD and AudioNAV are examples of novice navigation aids that shift from today's standard PNDs. However, there are still other methods we could use to improve currently available PNDs and reduce the distraction caused by them. One of them is presented by Lee et al [22;23]. They have addressed the problem of reading a PND map while driving by optimizing it for vehicular environments. The MOVE (Maps Optimized for Vehicular Environments) in-car navigation display contextually adapts the current view of the map through techniques of selection (selecting features that will be presented on a map), simplification (reducing map details), displacement (avoiding overlaps in features presented on a map), smoothing (diminishing details and angularity), and enhancement (features of higher importance are emphasized). Their study showed that total map display fixations were reduced six-fold and the number of glances to interpret the display was decreased three-fold when compared to a static LineDrive map [24].

Although the work of Vainao and Kulju didn't address directly the problem of distraction reduction, their research brings a novel set of guidelines that could potentially help [25]. In their study, they observed nine taxi drivers over the summer of 2006. Their goal was to find out how to support drivers to navigate well in an urban environment and how to assists them so they could reduce the number of systematic navigation errors, e.g. errors in distance and direction. They argued that when designing navigational aids we shouldn't think only in terms of conventional maps, but rather explore the possibilities of utilizing architectural and spatial design guidelines, particularly the theory of designing episodes of motion [26]. Simply said, the theory of designing episodes of motion states that humans are trying to build a mind map by finding elements from the physical environment, such as landmarks, paths, edges, nodes and districts, and use this map to better navigate through it. As previously said, their research wasn't focused on driver distraction, but integrating this theory into design guidelines for newer versions of PNDs could potentially mean that drivers would spend more time looking at the outside world. It would be interesting to see if adopting the guidelines proposed by Vainao and Kulju would reduce the distraction caused by standard PNDs.

CHAPTER 3

EXPERIMENT DESIGN

Before we delve into the details of our simulator experiment, it is worth noting that we conducted a preliminary study comparing paper directions against a PND with and without a visual display [27]. In examining the ways in which a PND in general was better than paper directions, and observing how drivers with a visual display spent less time looking at the road than those with spoken directions only, we decided to conduct a follow-up experiment that could more thoroughly inspect the relationship between glancing and driving performance. We did this by making the simulation more typical of a city route, with short and long road segments, ambient traffic conditions characteristic of city driving, and pedestrians walking here and there. In other words, we developed a more "realistic" simulation populated with things to look at – primarily, other cars and people. We now describe the equipment used to conduct the experiment, driving scenario, experiment protocol and timeline, dependent and independent variables, and the way participants were recruited as well as their demographics.

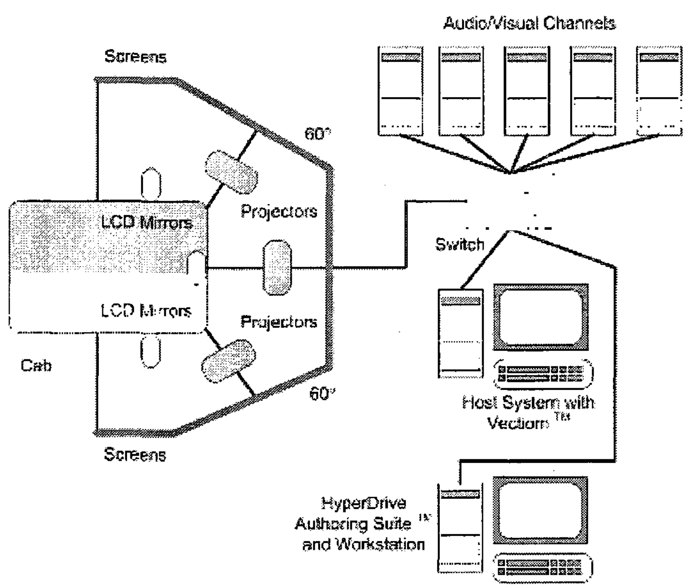
3.1 Research equipment

The experiment relied on seven research devices: a high fidelity driving simulator, two eye trackers, a 7'' LCD screen, and three camcorders. The manner of their operation, characteristics, and data obtained from them are described in the following section.

3.1.1 Driving simulator

The experiment involved driving in a high fidelity DriveSafety DS-600c simulator [28] shown in Figure 3.1.1.

a)



b)

Figure 3.1.1 DriveSafety DS-600c simulator (a) and system overview (b)

The key features of the simulator are:

- Wide field of view (180°)

- Ford Focus cabin
- Realistic vehicle dynamics (motion, vibration, and sound)
- Vection ™ real-time simulation system
- Audio/visual channel computers
- HyperDrive Authoring Suite ™

The **180° field of view** is produced by three aspheric mirror projectors. As seen in Figure 3.1.1, the projectors cast the simulation onto three screens mounted on the surrounding steel frame structure.

The **Ford Focus cabin** adds to the notion of real world driving by having a fully functional dashboard with speedometer and tachometer that are changing dynamically according to the speed gained in the simulation, gas and brake pedals with realistic feedback, steering wheel that provides force feedback using an electric motor, etc.

Realistic vehicle dynamics are crucial for the driving simulation. They are accomplished with a motion platform and authentic sounds and vibrations. The motion platform simulates pitching movement of the car by raising the front end for acceleration, and lowering it for deceleration. The car engine vibrations are simulated by 4 speakers, located in the front part of the cabin, and 2 transducers, one under the driver's seat and one in the steering column. Environmental sounds are produced with the same 4 speakers.

The **Vection ™ real-time simulation system** is the core of the simulator. It is in charge of advanced vehicle dynamics, scenario control (both scripted and autonomous traffic control), audio and visual subsystems, cab instrumentation, motion platform, and data collection. To create a **180° field of view** and realistic sound, the **Vection ™ real-time system** requires 5 dedicated computers which serve as **audio/visual channels.**

The **HyperDrive Authoring Suite ™** allows the design and programming of driving environment scenarios in a drag and drop manner. The scenario is designed by combining/connecting tiles. Tiles are classified as residential, rural, urban, sub-urban, commercial and industrial. Each classification has a tile with streets and intersections, freeways and freeway junctions, etc. Custom tiles can be created as well. Entities, such as pedestrians, vehicles, plants…, can be added to make the environment livelier. Vehicles can be part of the ambient traffic (created by the environment) or they can be programmed to traverse a specific path. The HyperDrive Authoring Suite ™ supports Tcl/Tckl programming language and enables developers to add more control to their scenario.

The DS-600c driving simulator produces **standard driving performance measures** at 10 Hz frequency. These measures include:

- **Lane position,** which constitutes the position of the center of the simulated car and is measured in meters.
- **Steering wheel angle,** which is measured in degrees.
- Vehicle's **velocity**, which is measured in meters/second.

These measures will be explained in more detail in section 3.4.

3.1.2 Eye tracker

Two state-of-the-art SeeingMachines faceLAB 4.6 eye tracking systems were used in the experiment [29]. Each system consists of a pair of stereoscopic cameras, an infra-red pod, mounting solution, and a laptop computer with pre-installed SeeingMachines software. The desktop setup of the system is shown in Figure 3.1.2.

The two eye tracking systems were necessary to ensure the quality of tracking participant's gazes. They were set up inside the simulator cabin on the dashboard as shown in Figure 3.1.3. The primary eye tracker was placed in the area above the speedometer and it was mainly used to record gazes at the outside world (although it can record gazes at the PND's display screen, but with lower tracking quality), while the secondary tracker was above the central console and its primary purpose was to record gazes at the PND's display screen. Both of them were using the same IR pod located above the speedometer.

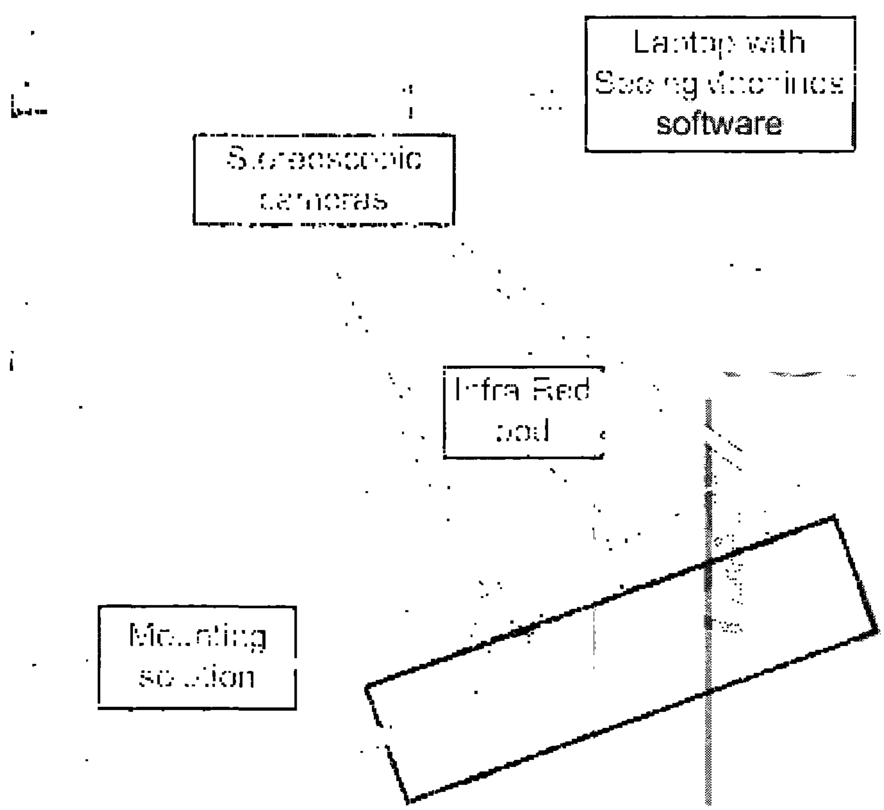


Figure 3.1.2 Eye tracker desktop setup

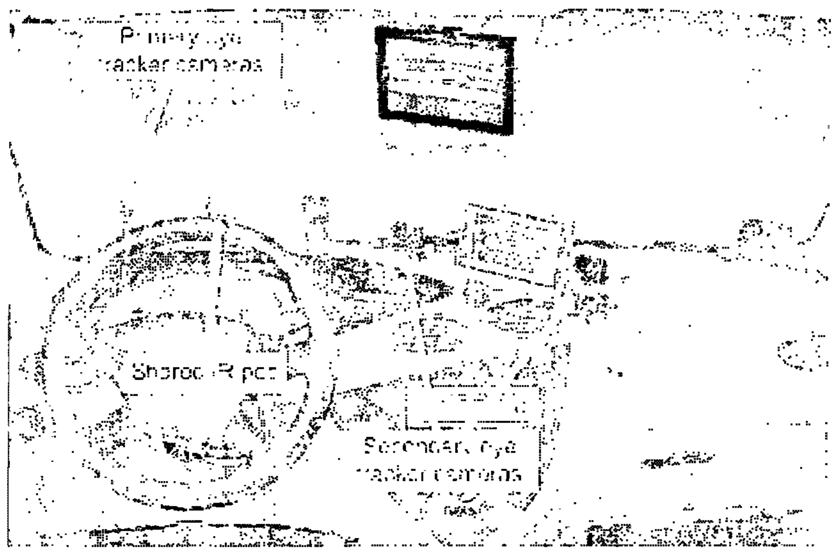


Figure 3.1.3 Eye tracker cabin setup

As stated at the beginning of the section, each eye tracker comes with a laptop that has pre-installed SeeingMachine's faceLAB 4.6. The main features of the faceLAB 4.6 software are:

- Modeling of real world objects with simple geometric shapes like rectangles and spheres in faceLAB's virtual world
- Extensive data logging of the head and eye movements

In order to log a participant's eye gazes, an appropriate "world" model had to be created in the faceLAB's virtual world, shown in Figure 3.1.4. All objects of participant's interest were modeled: PND, speedometer, steering wheel, etc. In Figure 3.1.4 we can see that a participant's head position and eye gaze direction are modeled as vectors. These vectors are very useful for various reasons, like checking eye tracking quality and overseeing a participant's gazes during the experiment.

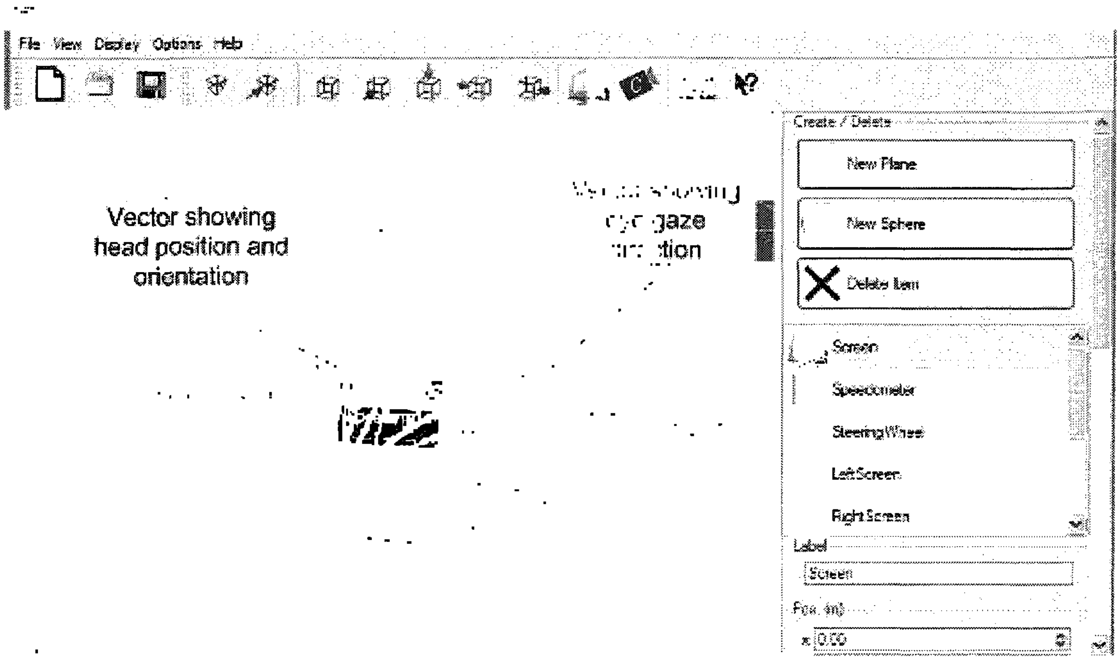


Figure 3.1.4 Simulator world model in faceLAB 4.6

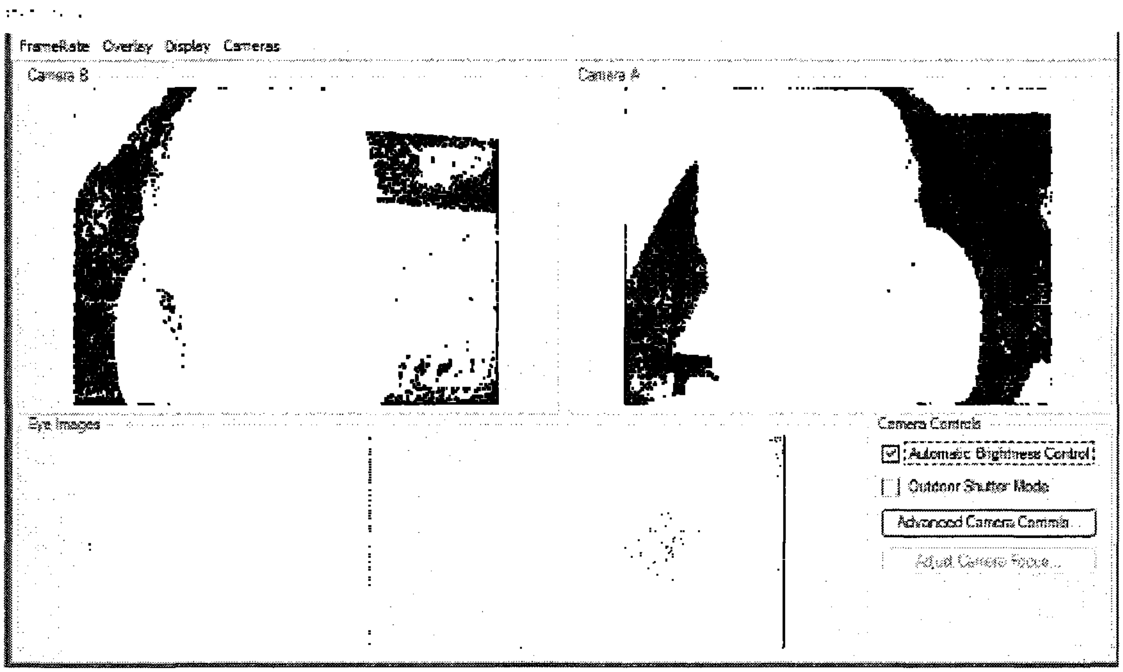


Figure 3.1.5 Pupil tracking method and real and virtual world mixture

The software offers two tracking methods: it can either track the **pupil**, or it can track the **iris**. In the lower portion of Figure 3.1.5 we can see the pupil tracking method.

The upper portion of the figure shows a mixture of the real and faceLAB's virtual world. faceLAB 4.6 logs all the data considering head and eye movement at 60 Hz: head position and orientation, eye gaze direction, eye rotation, gaze intersection with objects, saccade onset, etc.

Although each eye tracker was running faceLAB software on a separate laptop, they were connected into a single system through faceLAB Link 2.0 client-server application. Data from both eye trackers was logged into a single stream by taking data from the eye tracker with higher tracking quality in each point of time. This stream was then recoded in faceLAB's World View application to obtain the participant's gaze intersections with simulator world objects. This data was crucial for calculating **percent dwell time (PDT)**. The **PDT** is the percentage of time that the participant spent looking at items displayed on the three simulator screens (most importantly the roadway) and it will be explained in more detail in section 3.4.

3.1.3 LCD display

A Lilliput 7'' VGA 619GL-70NP monitor was used to display map information as shown in Figure 3.1.6.

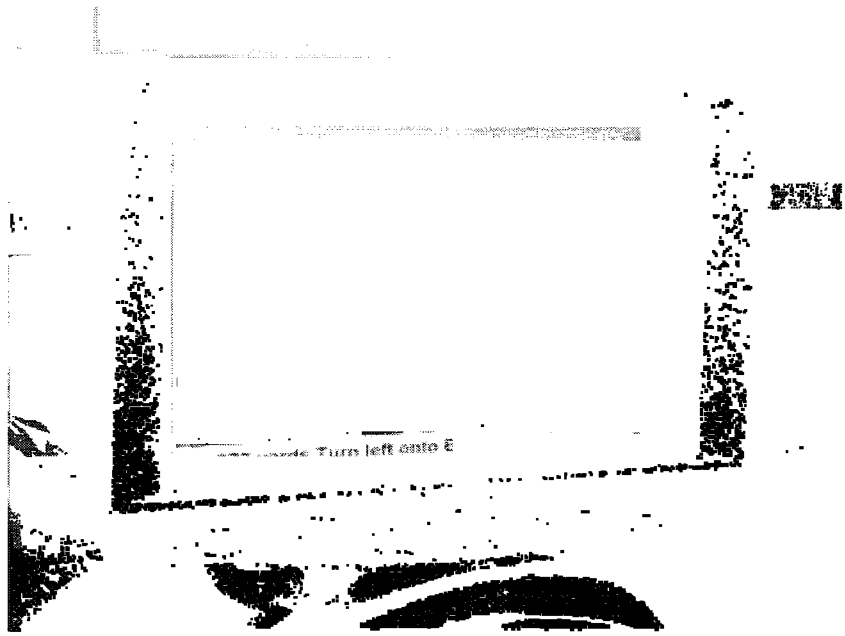


Figure 3.1.6 LCD screen displaying real-time location of the vehicle map

PNDs are typically mounted either on the windshield, on top of the dashboard, or are built into the dashboard. We decided to place the LCD screen on top of the dashboard because the gaze angle generally has to change less if the PND is located higher than if the PND is built into the dashboard. Although a 7'' screen is typically larger than most portable PNDs, our larger screen ensures that users can clearly see the map and read the street names. Indeed, the consumer market has exhibited a steady trend toward larger screen PNDs with greater multimedia functionality.

The map is displayed on the LCD screen via a Project54 application created for the purposes of our previous experiment [27]. This application communicates with the DriveSafety simulator and extracts the vehicle's absolute position inside the scenario. The same application simulates PND directions and shows the vehicle's position on the map.

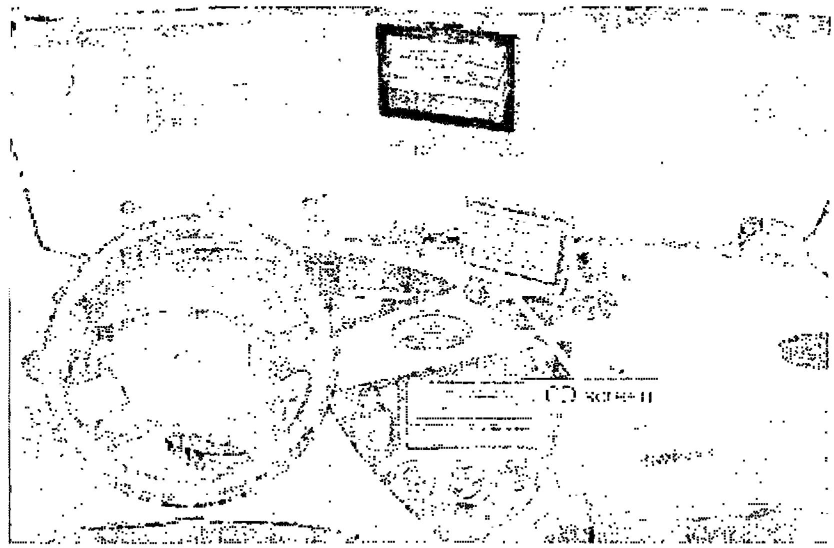


Figure 3.1.7 LCD setup inside the cabin

3.1.4 Camera setup

The experiment was recorded for presentation and data transcription purposes with three cameras:

- Sony HDR-HC3 HDV 1080i for the eye tracker video
- Panasonic PV-GS65 for the over-shoulder video
- Sony DCR-HC28 for the head and hands video

There were some situations when the eye trackers didn't a record participant's gazes, e.g. if participant's hand was covering the IR pod. In these cases, the video recordings were analyzed. The camera setup is shown in Figure 3.1.8.

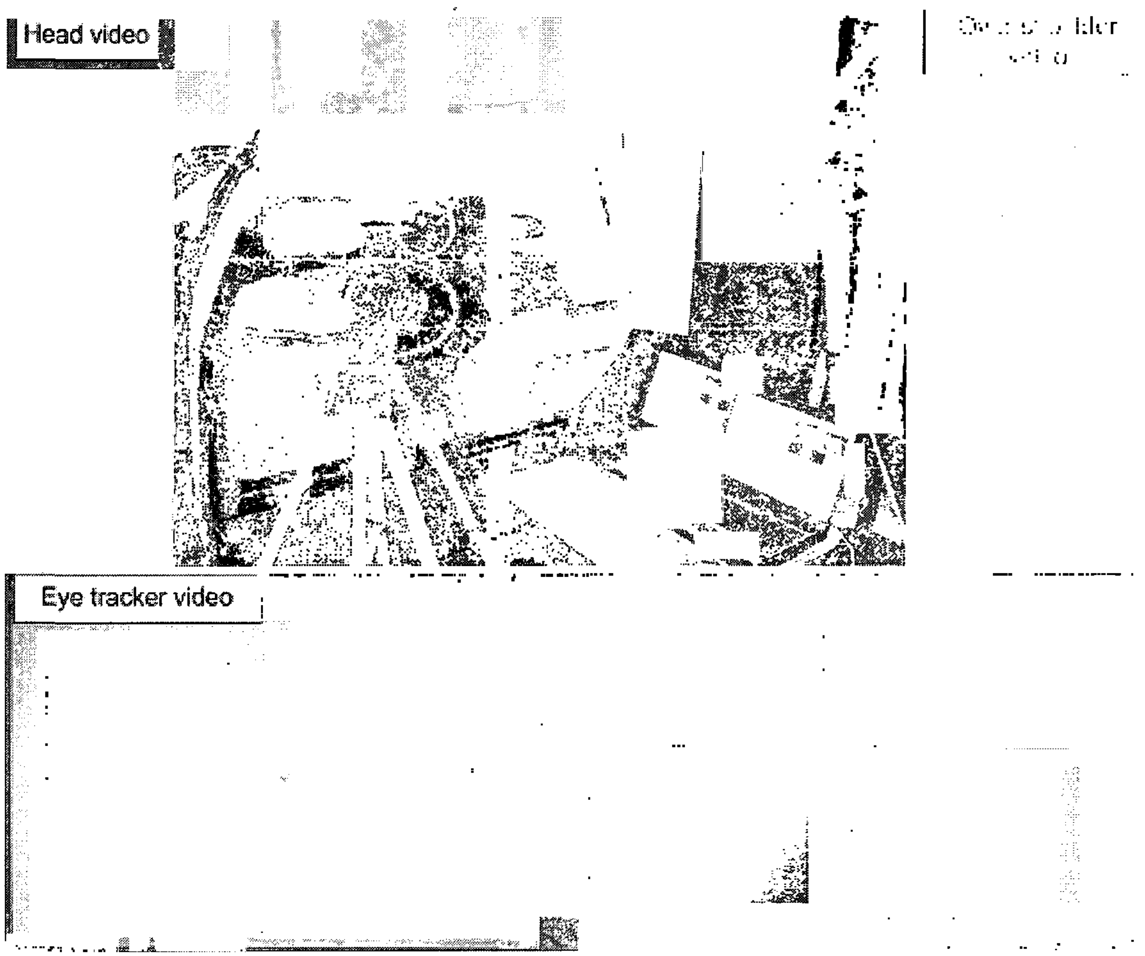


Figure 3.1.8 Camera setup

3.1.5 Equipment inside the simulator cabin

The same picture is used to show the eye tracker and LCD display setup. In both figures (Figure 3.1.3 and Figure 3.1.7) we can see more equipment than noted. Figure 3.1.9 summarizes all the equipment inside the simulator cabin.

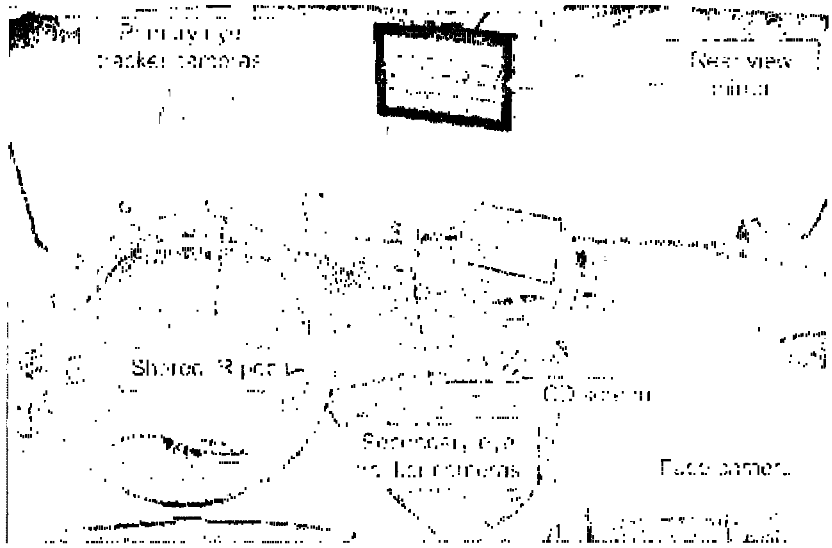


Figure 3.1.9 Equipment inside the simulator cabin

3.2 Driving scenario

As stated at the beginning of this chapter, it is worth noting that we conducted a preliminary study comparing paper directions against a PND with and without a visual display [27]. The experiment conveyed in this thesis represents a follow-up effort to more thoroughly inspect the relationship between glancing and driving performance. This was done by developing a more "realistic" simulation populated with things to look at – primarily, other cars and people, and adding unexpected events to which must drivers to react.

The scenario is shown in Figure 3.2.1, and it represents an urban city environment that has two-lane roads with lane markings. This environment was chosen because this type of road demands constant visual attention from drivers. This, in turn, means that driving performance measures and visual attention are likely to be affected by differences in the visual demands of the two navigation aids.

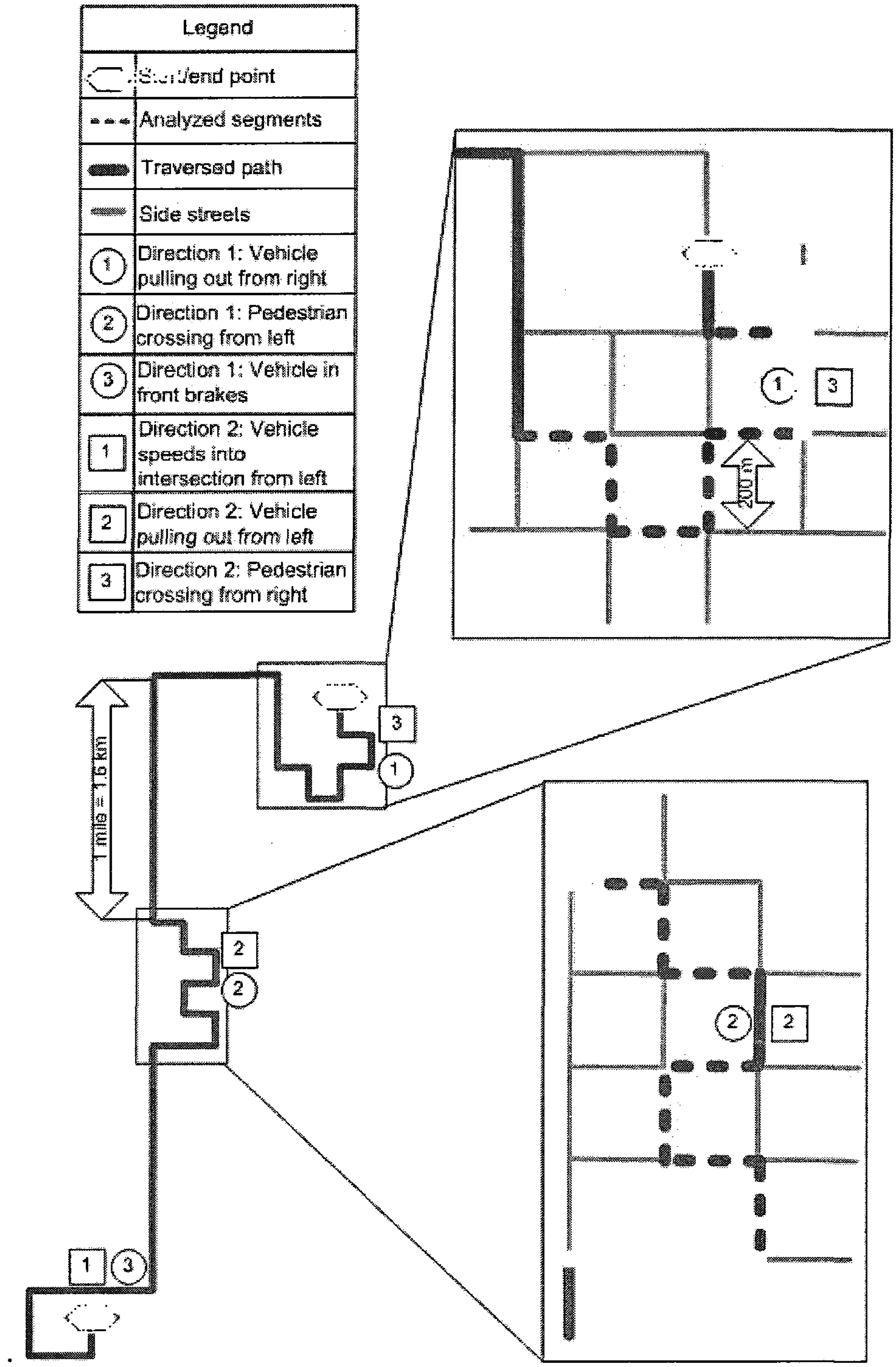


Figure 3.2.1 Driving scenario

The traversed path in the scenario consists of 17 short, 6 medium, and 2 long segments:

- short segments are 200 m,
- medium segments are 400 (three), 600, and 800 m (two),
- and long segments are 1600 m,

leading to the total road length of 10,000 m = 10 km. All segments are two-lane roads (one lane in each direction) with markings, each lane 3.6 m wide. Each segment ends up with a left or right turn onto a four way intersection, with exception for the start and end segments. Medium and long segments are made up of short segments and they have intersections in them, but participants go straight in these intersections. Additional streets were created parallel to each segment. There were two reasons for creating them:

1. Simulation is generating/showing objects 800 m in front of the driver. This could influence the driving experience, e.g. if there were no side streets when drivers are making a turn, it would appear as if there is nothing in front (or left or right) of them.
2. If participants make a wrong turn, they have to have a chance to get back on the route. If there were no side streets there would not be a way for them to do that.

On average, participants encountered 1.85 vehicles per short segment. The speed limit throughout the whole scenario was 35 miles/hour.

The scenario has two directions as can be seen in Figure 3.2.1: up-down (or north – south), and down-up (or south-north). In the up-down direction the upper symbol on the map in Figure 3.2.1 denotes the start point and the lower denotes the end. In the down-up direction it is the opposite (the lower symbol on the map in Figure 3.2.1

represents the start point and the upper represents the end point). In each direction participants traversed the same route.

To make the scenario more realistic, four events were created:

- Vehicle pulling out
- Pedestrian suddenly crossing the street (pedestrian is hidden behind the parked vehicle)
- Vehicle in front braking
- Vehicle speeding into intersection

These events are typical for the urban city-like environment and they were designed to be avoidable by an alert driver. Each route had three events, with two of them repeating on both routes, but from different directions (pedestrian and vehicle pulling out event). The location of the events and their order is shown in Figure 3.2.1.The up-down route had the events in the following order:

1. Vehicle pulling out from the right
2. Pedestrian crossing the street from the left
3. Lead vehicle braking

The down-up route had the events in the following order:

1. Vehicle speeding into intersection from the left
2. Vehicle pulling out from the left
3. Pedestrian crossing the street from the right

The pedestrian event is shown in Figure 3.2.2 and vehicle pulling out event is shown in Figure 3.2.3.

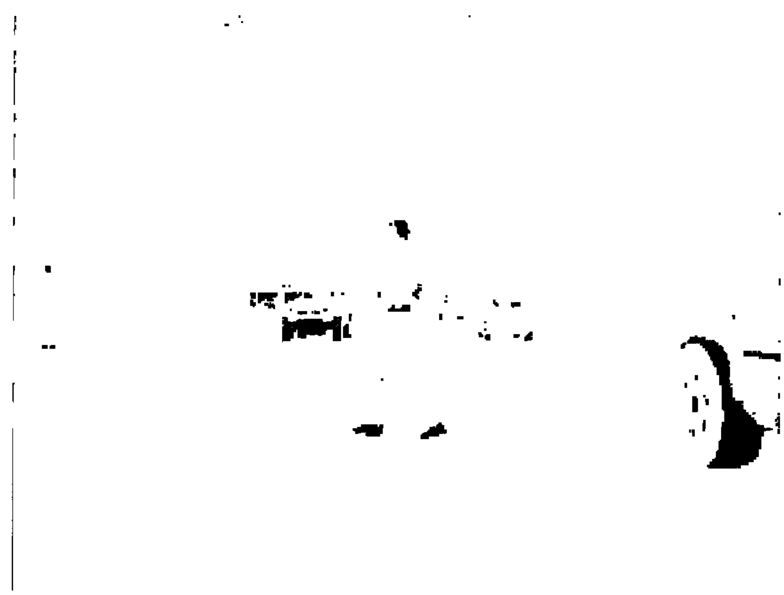


Figure 3.2.2 Pedestrian crossing the street event

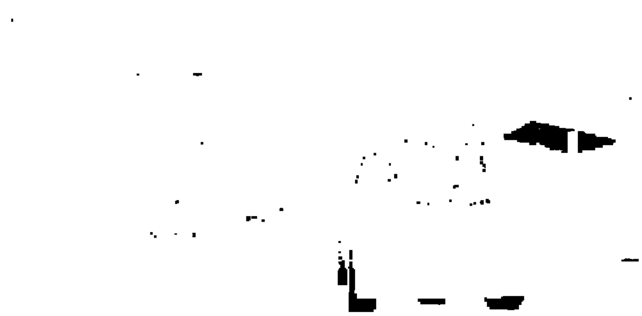


Figure 3.2.3 Vehicle pulling out event

3.3 Experiment protocol and timeline

Participants in the experiment interacted with two types of navigation aids:

1. **Standard PND directions**: Standard PNDs provide real-time map location as well as turn-by-turn spoken directions. Likewise, our LCD screen presented users with real-time location of the vehicle in the simulator world along with spoken prompts for impending turns. Figure 3.1.6 shows the LCD screen with map information. The map was presented in a dynamic, exocentric, forward-up view, where the car remains at the center of the screen while the road moves. In order to eliminate problems associated with the comprehension of synthesized speech while driving [30], spoken prompts recorded by a female voice talent were utilized.

2. **Spoken directions only**: The same spoken prompts were used as in the standard PND and no map information was displayed on the LCD. The spoken directions provided distances to the next turn (e.g., "In 100 yards turn right onto Fifth Avenue."). Because the simulator does not provide an odometer, we displayed odometer information on the LCD.

If participants would make a wrong turn, flashing yellow directional arrows would appear on the road (on the front simulator screen). The directional arrows would lead them to the previous known turn.

The experimental protocol proceeded as follows. Participants were given an overview of the simulator and the driving and navigation tasks, and were then trained in the driving simulator. Training consisted of driving in a city environment as shown in Figure 3.2.2 and Figure 3.2.3. Participants were instructed to drive as they normally would and to obey all traffic laws. It was explained to them that flashing yellow arrows would lead them back on route if they make a wrong turn. They first drove for about 5 minutes following directions from a standard PND and then another 5 minutes following directions from a PND with spoken directions only. During training, participants were exposed to two unexpected events, one for each navigation aid (pedestrian event and vehicle pulling out event). Participants were warned that they may encounter such events before they started the driving portion of their training.

After training, participants completed two routes, one for each of the navigation aids. Two routes were used to prevent participants from learning the directions over the course of the experiment. In order to keep the driving task complexity equal across routes, the two routes were identical, and participants simply traversed them in different directions for the two PNDs. Table 3.3.1 gives an example of how the experiment could be carried out with 8 participants where GUI marks standard PND and SUI marks the PND with spoken directions only.

Participant ID	Route 1:PND,direction	Route 2: PND, direction
01	GUI, up-down	SUI, down-up
02	SUI, up-down	GUI, down-up
03	GUI, down-up	SUI, up-down
04	SUI, down-up	GUI, up-down
05	GUI, up-down	SUI, down-up
06	SUI, up-down	GUI, down-up
07	GUI, down-up	SUI, up-down
08	SUI, down-up	GUI, up-down

Table 3.3.1 Experiment order for 8 participants

Actions performed for the completion of one experiment are summarized in Table 3.3.2. The table also shows the approximate time necessary for each step of the experiment.

	Approximate time (min)
Preparation before the subject arrives:	
1.Turn on the simulator	
2.Check if the eye trackers are calibrated	
3.If the eye trackers are not calibrated, perform calibration	
4.Check if the SID screen is projected	
5.Check if the SID screen is recorded	
6.Check if faceLAB Link application works	
7.Start SymConnect, P54 with NavApp, check if P54 is in silent mode	
8.Test-run scenario, check if data is being recorded into appropriate files	
9.Check time synchronization of P54 and simulator host computer	
10.Test video camera operation	
Preparation for the experiment:	
Subject arrives to the lab	1
Subject reads and signs the consent form	2
Subject fills in the personal information questionnaire	5
Subject reads the instruction sheet about the experiment	3
Experimenter repeats the instructions from the informational sheet	3
Sum:	14
Training:	
Subject is instructed how the two PNDs operate, while sitting in the simulator	1
Create head model for the primary eye tracker	3
Calibrate SID	1
Create head model for the secondary eye tracker	3

Subject drives in the urban environment with no sharp turns	5
Check if the navigational text instructions are clearly seen on the LCD screen	1
Subject drives in the training scenario and interacts with a standard PND	5
Subject drives in the training scenario and interacts with a spoken prompts only PND	5
Sum:	24
Experiment:	
Restart the NavApp, check if P54 is in silent mode and if the navigational text instructions are clearly visible on the LCD screen	1
Start video and SID recording, erase old files in SymConnect	1
Start faceLAB Link application	1
Experiment starts with subject interacting with one of the PNDs	15
Stop the simulation, video and SID recording, faceLAB Link application, and copy logged simulator data to the appropriate folder	1
Take a walk with the subject	5
Start video and SID recording, erase old files in SymConnect	1
Start faceLAB Link application	1
Experiment starts with subject interacting with one of the PNDs	15
Stop the simulation, video and SID recording, and copy logged simulator data to the appropriate folder	1
Sum:	42
Ending experiment:	
Experimenter turns off video recording, rewinds the tapes, disconnects the IR pod for safety reasons	1
Subject fills in the post experiment questionnaire	4
Experimenter discusses impressions about experiment	2
Sum:	7
Total time:	87 min

Table 3.3.2 Experiment timeline

3.4 Dependent and independent variables

The experiment was executed as a within-subjects factorial design experiment with the two navigation aids as our primary independent variable, **Nav**. The order of **Nav** was counter-balanced among the participants. The following dependent variables were measured.

Standard driving performance measures. As mentioned in section 3.1.1, the DS-600c driving simulator produces standard driving measures: lane position, steering wheel angle, and vehicle velocity. Their variances were calculated, and in each case, a higher variance represents worse driving performance. Mean travel velocity for each participant was also analyzed. A lower mean velocity may indicate harder perceived driving conditions.

Lane position constitutes the position of the center of the simulated car and is measured in meters. Poor driving performance is characterized with higher variance, since it indicates that participant weaved in his/her lane, and perhaps even departed from the lane.

Steering wheel angle is measured in degrees. Higher steering wheel angle variance doesn't necessarily show poor driving performance, e.g. if we drive on a curvy road the variance is going to be high because following a curvy road requires varying the steering wheel angle constantly. However, when comparing the performance of multiple participants on the same road, it can be used as a relative measure of driving performance. A higher variance is an indication of increased effort expended by a driver to remain in his/her lane.

Vehicle's **velocity** is measured in meters/second. As with steering wheel angle variance, higher velocity variance doesn't necessarily mean poor driving performance. However, when drivers are concerned about their safety (e.g. when driving on a narrow road), or when they are distracted (e.g. talking to a passenger), they will reduce the speed. This means that a low mean velocity for a portion of the road may indicate that the driver was concerned about safety or otherwise distracted.

Number of collisions is the number of instances when the participant's vehicle touched another object, such as a parked or moving vehicle, a pedestrian, etc. Based on the experience with simulator studies, collisions were not expected to happen during normal driving, but throughout the experiment they might occur when drivers are confronted with unexpected events. Since the unexpected events were designed to be avoidable by an alert driver, any collision during such an event may indicate distraction.

The **Percent dwell time (PDT)** on the outside world is the percentage of time that the participant spent looking at the outside world, which is represented by the three simulator screens. If participants are distracted, e.g. by the PND, it may negatively reflect on their PDT, which in turn could lead to collision. Apart from a participant's total PDT, changes in PDT as participants traveled between intersections were tracked. Changes in PDT that depend on proximity to a given intersection may shed light on what causes distractions and hopefully lead to better PND designs that can avoid these dips.

Cross-correlation peaks. Cross-correlation analyses were performed to identify time lags in increased variance for lane position and steering wheel angle (if any) in response to decreased PDT on the outside world. Peaks in the cross-correlation of the

PDT on the outside world and the variance of a driving performance measure may indicate a causal relationship between decreased PDT and increased variance.

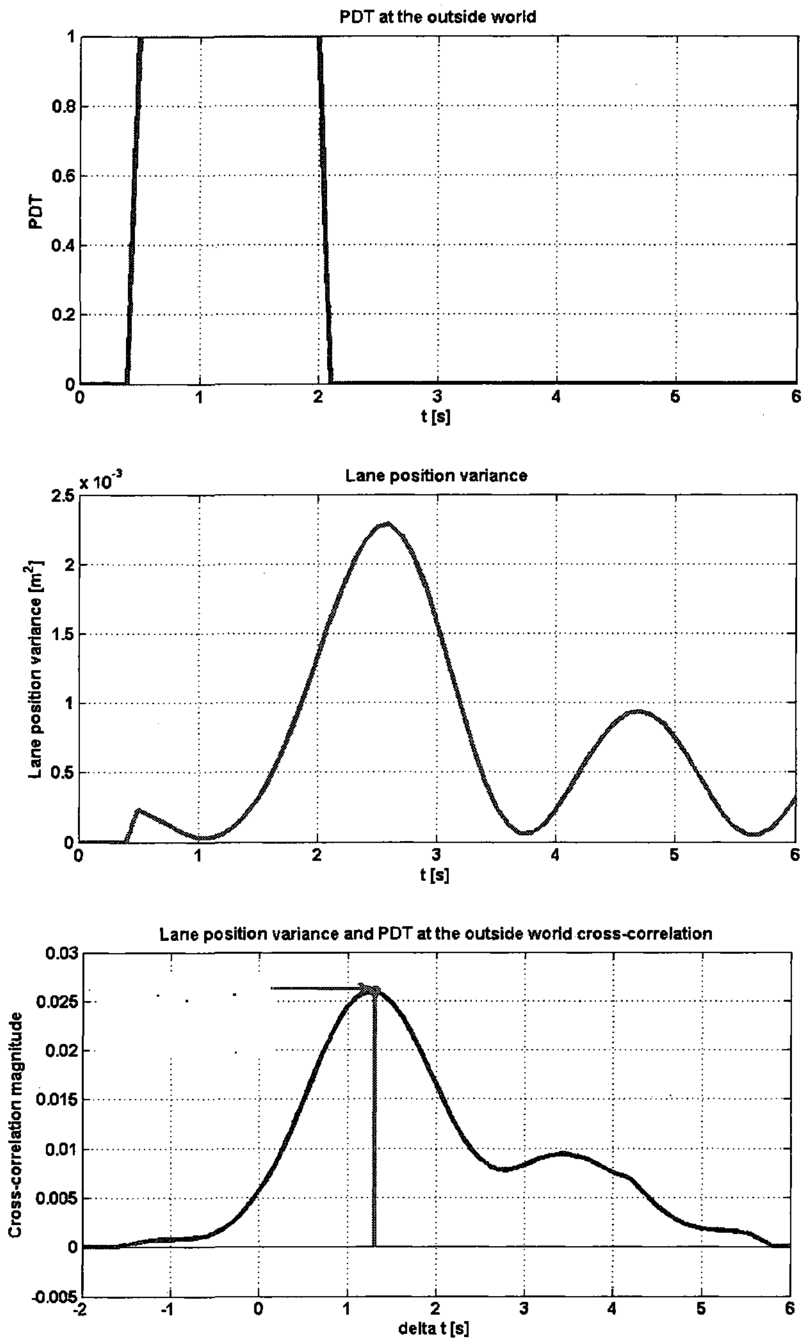


Figure 3.4.1 Example of the cross-correlation between lane position variance and PDT at the outside world

An example is illustrated in Figure 3.4.1. where 0 in the PDT signal indicates that participant's PDT is 100% on the outside world and 1 indicates that he is not looking at the outside world at all (100% not looking). If a peak exists for a given lag between the PDT and the variance of a driving performance measure, the lag (expressed in seconds) may indicate the time lag between the onset of decreased PDT on the outside world (e.g. due to a participant looking at the standard PND) and the increase in the variance of the driving performance measure. In the example shown in Figure 3.4.1 this lag is 1.3 seconds.

3.5 Participant recruiting and their demographics

Participants were recruited through flyers and promotional emails. Flyers were posted on public message boards throughout the University of New Hampshire's (UNH) campus (Morse Hall, Kingsbury Hall, Babcock graduate dorm, Parsons Hall, and public message boards around Thompson Hall and Whittemore School of Business). Promotional emails were sent to UNH students through department secretaries.

In order to motivate them to apply and perform well, participants were given a $15 BestBuy gift card for the experiment duration (roughly 1.5 hours). The only criteria participants had to satisfy was to own a driver's license. All participants who participated in the experiment received a gift card, although some of them didn't finish the experiment for one of the two following reasons:

- The eye tracker didn't track well for participants who had corrected vision and wore glasses.
- Participants felt motion sickness

Out of 29 participants who participated, 11 didn't finish the experiment because of the reasons mentioned above. Out of remaining 18, 10 were classified as outliers for the following reasons:

- Participant repeated the second route in the experiment because of the simulator crash, after driving almost halfway through it
- For two of them, the eye tracker was tracking their gazes with an offset while driving the second route
- Two of them had different eye tracking methods (iris) than the rest (pupil)
- Five were females while all the rest were males

The results presented in this thesis are based on the remaining 8 participants, because they performed under the same conditions. The demographic data presented in this section is based on the pre-experiment questionnaire that all participants had to complete. All of them were male American university students between the ages of 21 and 29 with the average age being 22.4. Seven of them were undergraduate students, and the eight was a graduate student. Two of them were left handed and six were right handed. They received their driver's licenses between 1997 and 2005 and drove between 600 and 15,000 miles annually (average 10,575 miles). Three of them have never been in the simulator study before and five have participated once or twice at UNH. Six of them don't own an in-car PND and two of them do. Five of them don't own any other GPS enabled device while three of them had a cell phone with GPS enabled software. One of them prints driving directions once a week, five of them once a month and two of them never print directions. One of them finds the printed directions very convenient, four of them find printed directions convenient, and three find them inconvenient. Two of them never play video games, one plays them once a month, three play video games once a week, and two of them play them daily. Two of the participants play sports once a month, three play once a week, and three play sports daily. All participants never get motion sickness as a passenger in the car or when on a boat, while two get occasionally sick when on a roller coaster.

CHAPTER 4

RESULTS AND DISCUSSION

The previous chapter explained preparations conducted before the experiment, i.e. scenario design, experiment protocol, participants' recruitment etc. This chapter describes work carried out after the experiment was finished, and it can be divided into three parts. The first part focuses on the preparation for the post-experiment analysis, and it reveals more details on the scenario segments that were used in it, and explains how the driving performance, visual attention (PDT), and cross-correlations were measured. The second part describes relevant results for the goals established in this thesis, i.e. standard PNDs influence on visual attention and driving performance. Whereas the first two parts give details on the quantitative analysis undertaken, the third part deals with qualitative analysis, and it will present some of the results from the post-experiment questionnaires.

4.1 Analyzed segments

As discussed in section 3.2, participants drove in routes typical for the urban city-like environment. The routes can be broken up into segments by treating roads between two intersections as separate segments. Figure 3.2.1 displays the route used in the experiments (bottom left side) and zooms in on the short segments of the routes used in the experiment (right). All the results, such as the variances and mean velocity, were calculated using data from 13 segments. These segments all had the same characteristics, thereby controlling factors that could potentially confound the results. In particular, the segments were short, with 200 meters separating the centers of adjacent intersections. Although longer segments were utilized in the routes to make the driving task feel more realistic, these segments were excluded from the analysis because it is most likely that participants' driving patterns (e.g. the frequency content of the vehicle velocity reflecting the acceleration and deceleration over a segment) and visual attention patterns (how often and where people look) would be different for segments of different lengths, making comparisons between them difficult.

Furthermore, at both the beginning and end of each segment, there was a four-way intersection where participants made either a right or left turn. Routes had short (200 m) segments that didn't meet this criterion, e.g. when participants entered some of the short segments by driving straight through a four-way intersection, thus these segments were excluded from the analysis. Driving performance and visual attention are likely to be different on these segments than on segments where one or both of the turns may be missing.

Finally, participants did not encounter an unexpected event in the analyzed segments. Unexpected events may require sudden braking and steering wheel motion, which in turn can result in very large variances for these measures, again making comparisons with other segments difficult.

In analyzing all of the segments, data collected close to the intersections was excluded. This was done because driving performance data at the beginning of a segment is typically dominated by the turning maneuver that is necessary to get through the intersection, and data collected at the end of a segment is dominated by deceleration before turning. Variances resulting from the effects of turning maneuvers and deceleration close to intersections are much larger than variances encountered in data generated away from the intersection, which of course makes it difficult to compare intersection and straight segment data. In particular, data generated 60 meters after exiting the previous intersection and 40 meters before an upcoming intersection was excluded, leaving (200 – 60 – 40) m = 100 meters for the data analysis.

4.2 Measurement

Raw data for the four driving performance measures were provided by the simulator and sampled at a 10 Hz rate. Participant's gaze angles were recorded throughout the experiment using the two eye trackers. Eye tracker data was sampled at a 60 Hz rate. Gazes were automatically classified as being directed at the outside world if the participant was looking at any of the simulator's front projection screens.

For the rare cases in which the eye tracker could not track a participant's gaze (e.g. when the participant's hand blocked the eye tracker's view of his/her eyes for an instant), video footage obtained from the eye tracker cameras as well as from the camcorder in the simulator (Figure 3.1.8) was reviewed and dwell times were hand-transcribed.

4.2.1 Driving performance

For each participant and navigation type, the variances of the driving performance measures (lane position, steering wheel angle and velocity) were calculated for each short segment. The same was done for average velocity. After that, the averages of the variances and velocities for the segments were calculated.

Simulator log files were searched for signs of collisions between the simulated vehicle and surrounding objects.

4.2.2 Visual attention

For each participant p and navigation aid **nav**, the average percent dwell time, $\mathbf{APDT_{p,nav}}$, on the outside world was calculated by finding the ratio of the sum of dwell times for all 13 segments and the sum of the total time spent traversing all 13 segments. The same approach was used in calculating the APDT with the standard PND for parts of the experiment when this PND was in use. Finally, an analogous approach was used to calculate how the APDT on the road ahead changed as participant vehicles traveled through five 20 meter segments between consecutive intersections (from 60 m after the preceding intersection to 40 m before the upcoming intersection).

4.2.3 Cross-correlation

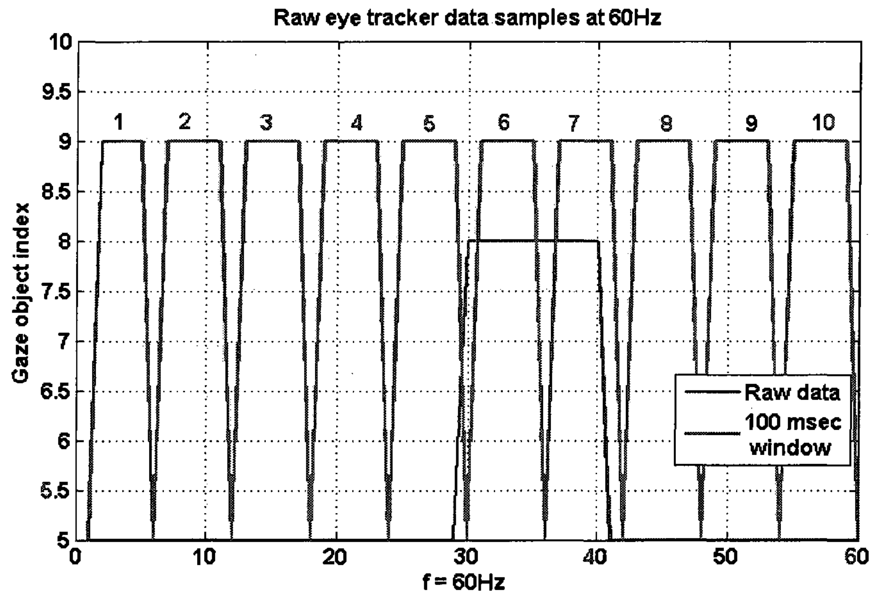
The cross-correlation between the instantaneous percent dwell time, IPDT, on the outside world and the short-term variance of two driving performance measures, lane position and steering wheel angle, were calculated. The IPDT was calculated at a 10 Hz rate by calculating a separate PDT for each consecutive 100 ms window of eye tracker data. Since the eye tracker data is recorded at 60 Hz, the instantaneous PDT was calculated using six eye tracker data samples at a time. For cross-correlation calculations, the transformed instantaneous percent dwell time, TIPDT, was used. TIPDT is a variable representing a fraction of time looking at the outside world, such that a value of 0 represented 100% IPDT (attention fully on the outside world), while a value of 1 represented 0% IPDT (e.g. when the participant is looking at the LCD screen). The example of this transformation is illustrated in Figure 4.2.1.

The upper (blue) signal in Figure 4.2.1 shows the raw eye tracker data. The x axis shows data samples through time (1 second = 60 samples) and the y axis shows intersection indexes between participants' gazes and objects in faceLAB's virtual world (Figure 3.1.4). The intersection indexes are listed in Table 4.2.1. In the example shown in Figure 4.2.1, the participant was looking at the outside world in the beginning (index 5, samples 1 through 30, 0.5 seconds). After that period participant gazed at the PND's display (index 8, samples 30 through 40, 0.1667 seconds). When he was done with looking at the PND's display screen, he returned his gaze to the outside world (index 5, samples 40 through 60, 0.333 seconds).

Index	Object
1	Speedometer
2	Steering wheel
3	Front simulator screen
4	Right simulator screen
5	Left simulator screen
6	Dashboard
7	Left review mirror
8	PND's display screen

Table 4.2.1 Gaze object indexes

The red trapezoids in the upper portion of Figure 4.2.1 represent 100 ms windows where the TIPDT was calculated. They appear as index 9 in the figure, but this number was used just to represent how the windowing was done (index 9 doesn't exist).



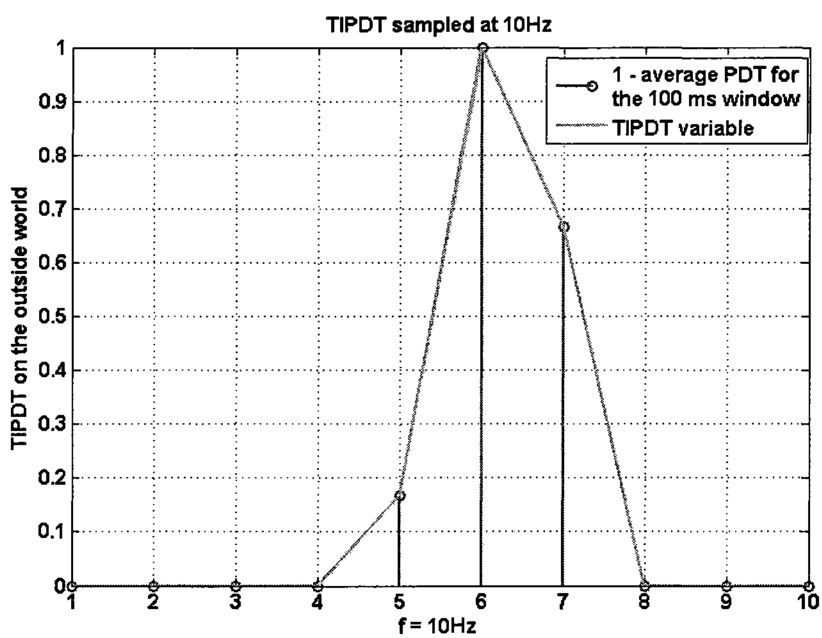


Figure 4.2.1 TIPDT transformation example

The TIPDT was calculated using the equation below

$$TIPDT_n = 1 - \frac{N}{W}, n = 1,2, \ldots S$$

Equation 4.2.1 TIPDT

where N is the number of samples for not looking at the outside world (number of intersection indexes 1, 2, 6, 7, and 8), W is the length of 100ms window in samples (6), and S is the number of raw eye tracker samples for the analyzed segment divided by 6 (downsampling from 60Hz to 10Hz will reduce the total number of samples by the factor of 6).

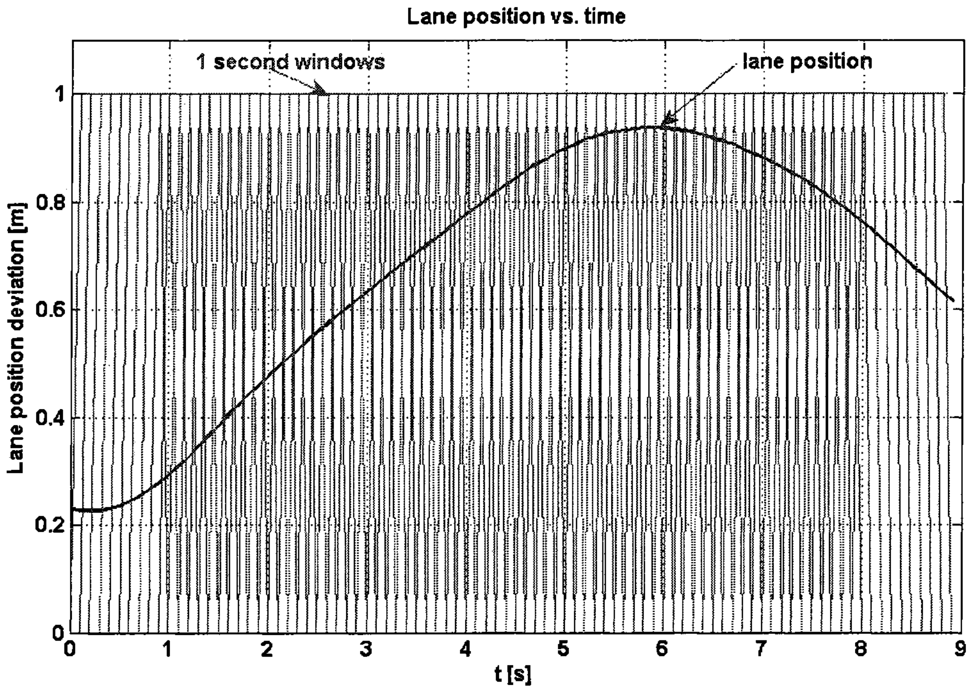
The peaks in the cross-correlation between TIPDT and driving performance measures, lane position and steering wheel, would indicate worse driving performance (larger variance values) correlated with reduced visual attention on the outside world (larger TIPDT values).

The short-term lane position and steering wheel angle variances were calculated at a 10 Hz rate for 1 second long windows (i.e., for 10 samples of the given driving performance measure at a time) as illustrated in Figure 4.2.2. The choice of 1 second for the window length reflects an expectation that on straight roads the corrections to lane position, accomplished by relatively large changes in the steering wheel angle, will take less than 1 second.

As mentioned previously, two cross-correlations were calculated. $\mathbf{Rlp}_{\mathbf{nav}}[lag]$ is the cross-correlation between lane position variance and the TIPDT on the outside world for navigation aid **nav**. $\mathbf{Rlp}_{\mathbf{nav}}$ was calculated as the average of cross-correlations for each of the 13 segments and each of the 8 participants. $\mathbf{Rstw}_{\mathbf{nav}}[lag]$ is the cross-correlation between the steering wheel angle variance and the TIPDT and it was calculated analogously to $\mathbf{Rlp}_{\mathbf{nav}}[lag]$. Both calculations were implemented using Matlab's xcorr function. As stated in Matlab's help file, the true cross-correlation sequence for two jointly stationary random processes, x_n and y_n, $-\infty<n<\infty$, is calculated as

$$R_{xy}(lag) = E\{x_{n+lag}y_n^*\} = E\{x_n y_{n-lag}^*\}$$

Equation 4.2.2 True cross-correlation sequence



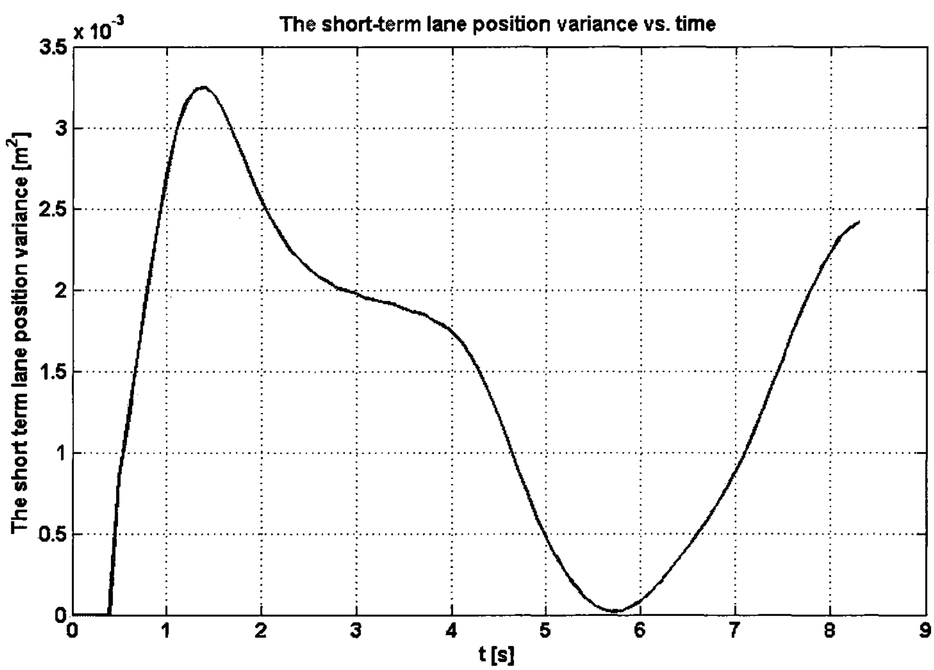


Figure 4.2.2 The short term lane position variance

where E{} is the expected value operator and * denotes the complex conjugate operator when complex-valued data are present. Matlab's xcorr function estimates this sequence according to the equation below.

$$\hat{R}_{xy}(lag) = \begin{cases} \sum_{n=0}^{N-lag-1} x_{n+lag} y_n^* & lag \geq 0 \\ \hat{R}_{yx(-lag)}^* & lag < 0 \end{cases}$$

Equation 4.2.3 Matlab's xcorr function

where N is the length of x and y sequences, and $\hat{R}$ denotes estimated cross-correlation sequence with 2*N-1 length.

The **lag** variable indicates the number of samples by which the variance measure lags behind the PDT measure. Thus, for positive values of lag, a peak in the cross-correlation indicates that there is an increase in the variance following an increase in the time the participant spent not looking at the outside world.

4.3 Experiment results

The primary goal of this thesis is to find out how visual attention to the two PNDs influences driving performance. Therefore, results of driving performance, visual attention, and cross-correlations between the two will enlighten this subject.

4.3.1 Driving performance

A one-way ANOVA for each of the driving performance measures with **nav** as the independent variable was performed. There were no significant effects for any of the three variances of driving performance measures or for average velocity as can be seen in figures 4.3.1 through 4.3.4 and tables 4.3.1 through 4.3.4. This result mirrors findings from the preliminary study [27]. There were no collisions in any of the experiments. Hence, participants were able to pay sufficient attention to the road to avoid contact with other objects or pedestrians.

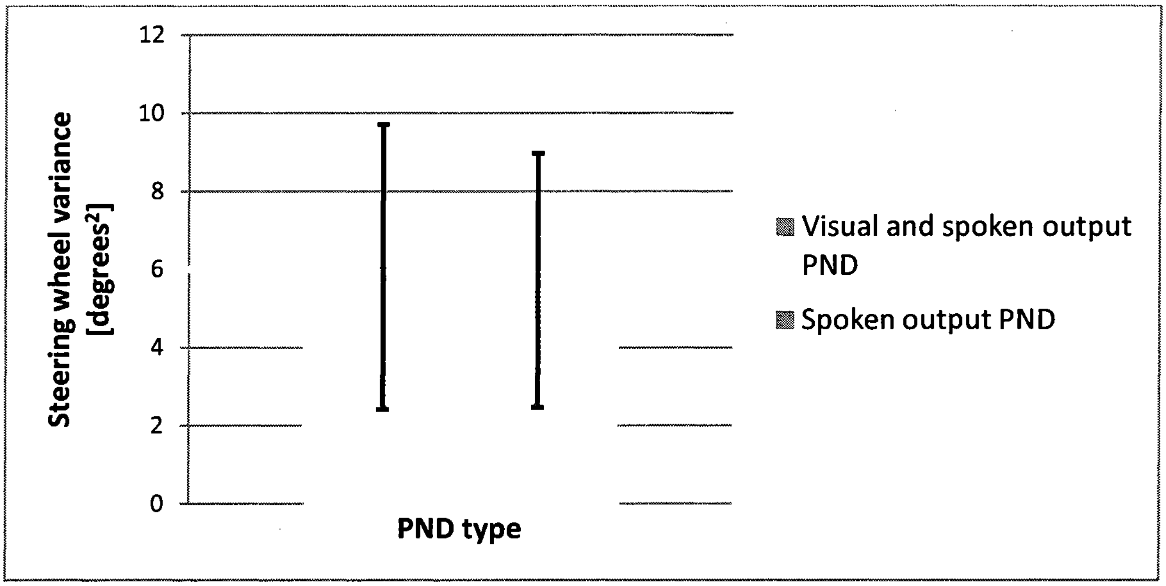


Figure 4.3.1 Steering wheel angle variance with standard deviation for the two PNDs

	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
ANOVA	1	0.47733	0.4733	0.0399	0.8445

Table 4.3.1 ANOVA results for steering wheel angle variance for the two PNDs

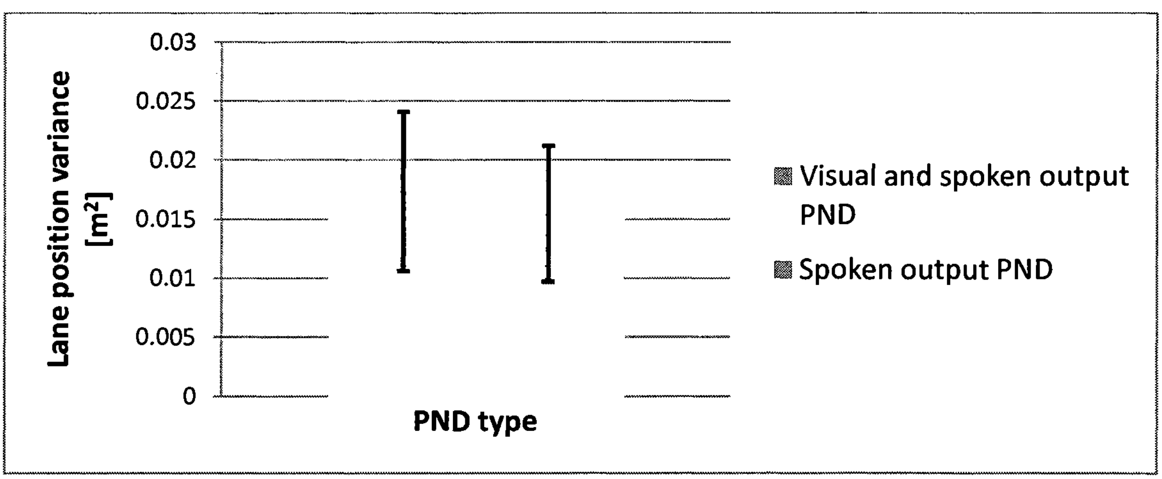


Figure 4.3.2 Lane position variance with standard deviation for the two PNDs

	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
ANOVA	1	0.00001429	0.000014	0.3642	0.5558

Table 4.3.2 ANOVA results for lane position variance for the two PNDs

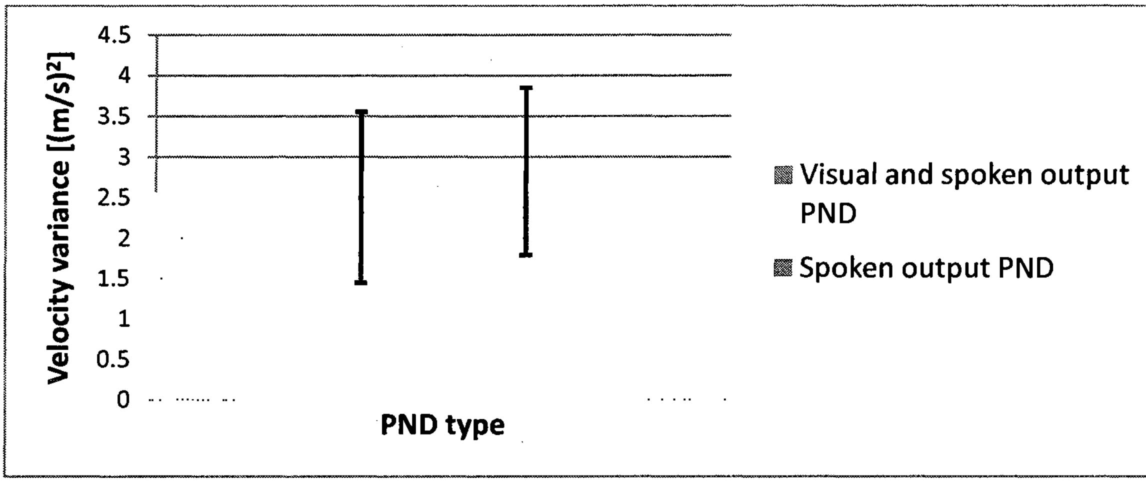


Figure 4.3.3 Velocity variance with standard deviation for the two PNDs

	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
ANOVA	1	0.410698	0.41070	0.3792	0.5479

Table 4.3.3 ANOVA results for velocity variance for the two PNDs

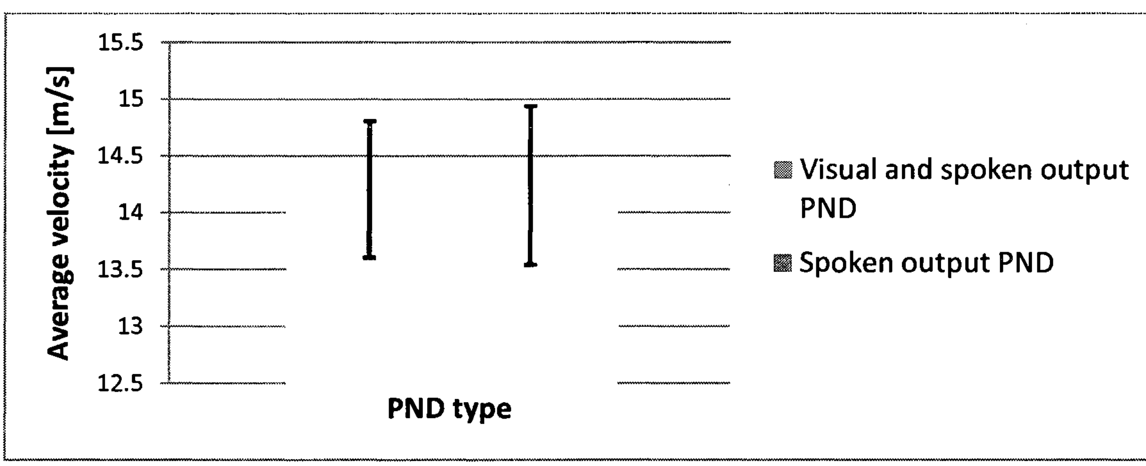


Figure 4.3.4 Average velocity with standard deviation for the two PNDs

	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
ANOVA	1	0.0048418	0.004842	0.0114	0.9165

Table 4.3.4 ANOVA results for average velocity for the two PNDs

4.3.2 Visual attention

A one-way ANOVA using PDT as the dependent variable was performed with the aim to evaluate the effect of different navigation aids on visual attention. As expected, the time spent looking at the outside world was significantly higher when using spoken directions as compared to the standard PND directions, $p<.01$. Specifically, for spoken directions only, the average PDT was 96.9%, while it was 90.4% for the standard PND.

A one-way ANOVA for each of the navigation aids using PDT as the dependent variable was performed in order to assess the effect of distance from the previous intersection on PDT on the outside world for the two navigation aids. For the standard PND, results showed a significant main effect, $p<.01$, while the effect was less significant for the PND with spoken output only, $p<.05$. Figure 4.3.5 shows the differences in PDT on the outside world.

The question of how the PDT on the PND screen changes with the distance from the previous intersection was also addressed in the analysis. Another significant effect was found using a one-way ANOVA. Figure 4.3.6 shows the differences in PDT on the LCD screen for the standard PND. These results indicate that on short road segments, when drivers are expecting to possibly turn at the upcoming intersection, they are likely to look at the display of a standard PND. However, they are less likely to do so as they approach the next intersection.

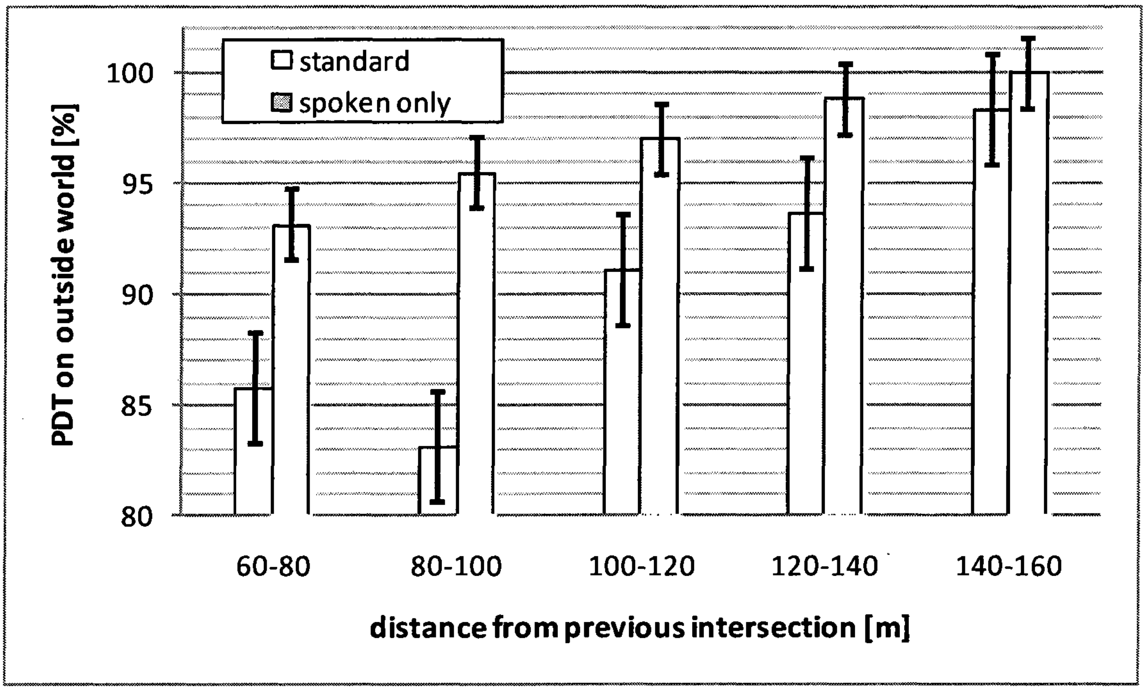


Figure 4.3.5 PDT on the outside world (with standard error), changing as vehicles travel between intersections

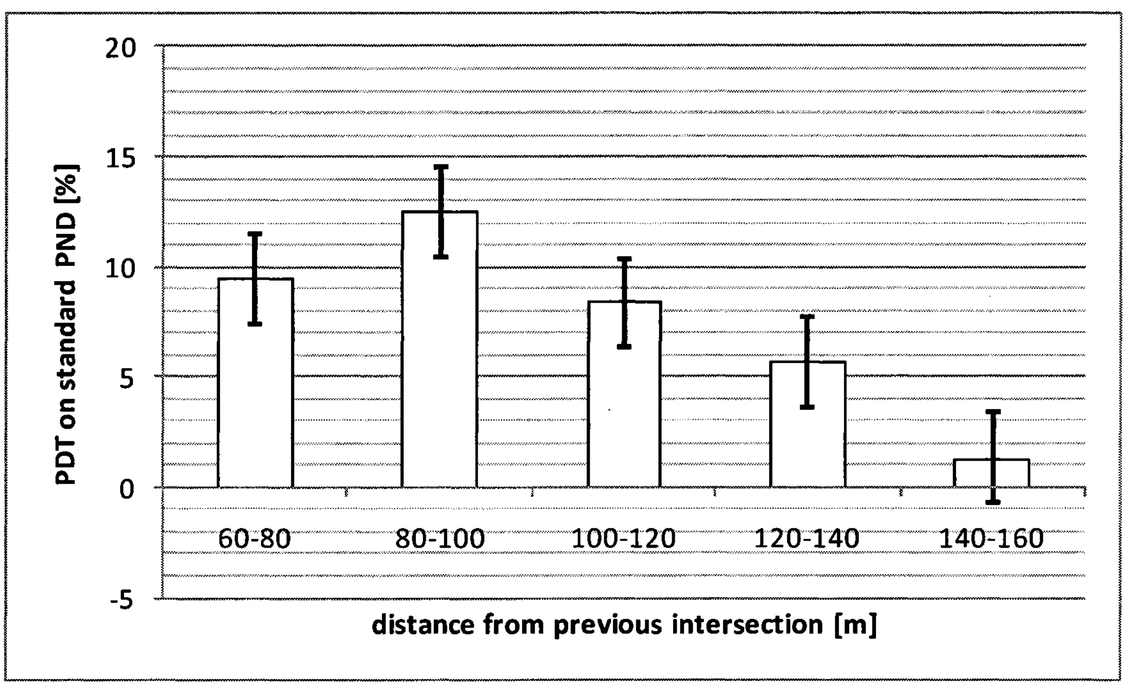


Figure 4.3.6 PDT on LCD screen of the standard PND (with standard error), changing as vehicles travel between intersections

4.3.3 Cross-correlation

The cross-correlation analysis indicates that there is a relationship between the IPDT on the outside world and the two short-term variances. This relationship is evident from peaks in the two cross-correlation functions, $\mathbf{Rlp_{nav}[lag]}$ and $\mathbf{Rstw_{nav}[lag]}$, shown in Figure 4.3.7. In order to evaluate whether the peaks arose due to chance, a randomization test in a manner similar to the one used by Velt et al. [31] was cionducted. Specifically, while pairs of sequences of TIPDT and variance values from the same segment were used in cross-correlation calculations (section 4.2.3), in the randomization test the cross-correlation between the TIPDT from one segment and variances from a different segment was calculated. The total number of 1000 random arrangements of TIPDT values with respect to the variances was created. In other words, each value of **lag** had 1000 cross-correlation results. The bottom $(1\text{-}p)\cdot 1000$ cross-correlation values were found for each value of **lag**. The statistical significance was estimated by comparing cross-correlation values for the original data with these values. If the cross-correlation for the original data was larger, then the result was considered statistically significant with probability less than p, e.g. to estimate the $p<.05$ significance level, the bottom 1000 - 50 = 950 cross-correlation values for each value of lag were found. If, for a given value of lag, the cross-correlation value from the original data was larger than these values, the result was statistically significant with $p<.05$.

The cross-correlation results are shown in Figure 4.3.7. As the graph in the top part of Figure 4.3.7 indicates, for the standard PND, the cross-correlation between instantaneous PDT on the outside world and short-term lane position variance, $\mathbf{R_{lp,standard}}$, has several statistically significant peaks. For the most prominent of these peaks, the lag

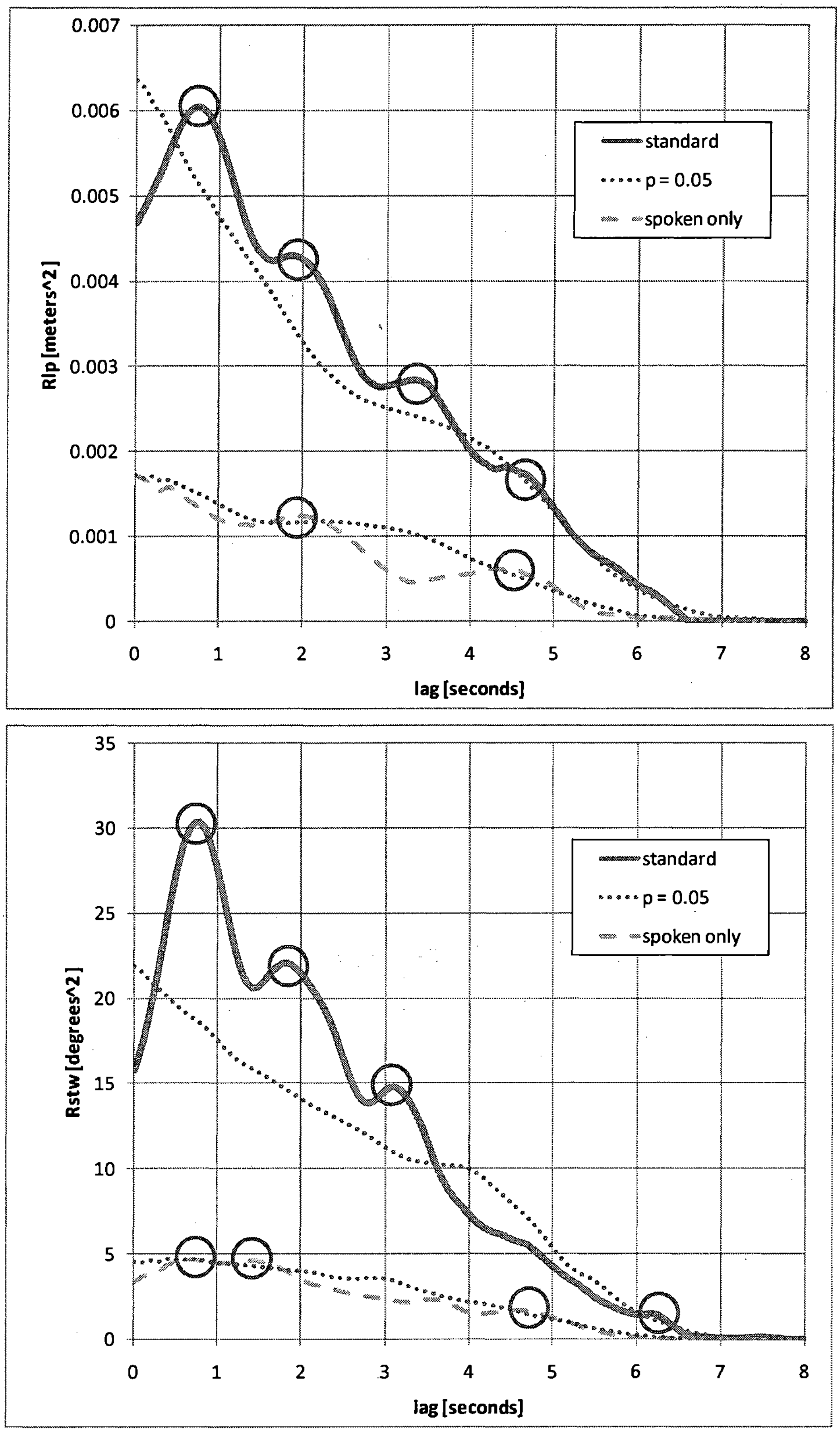
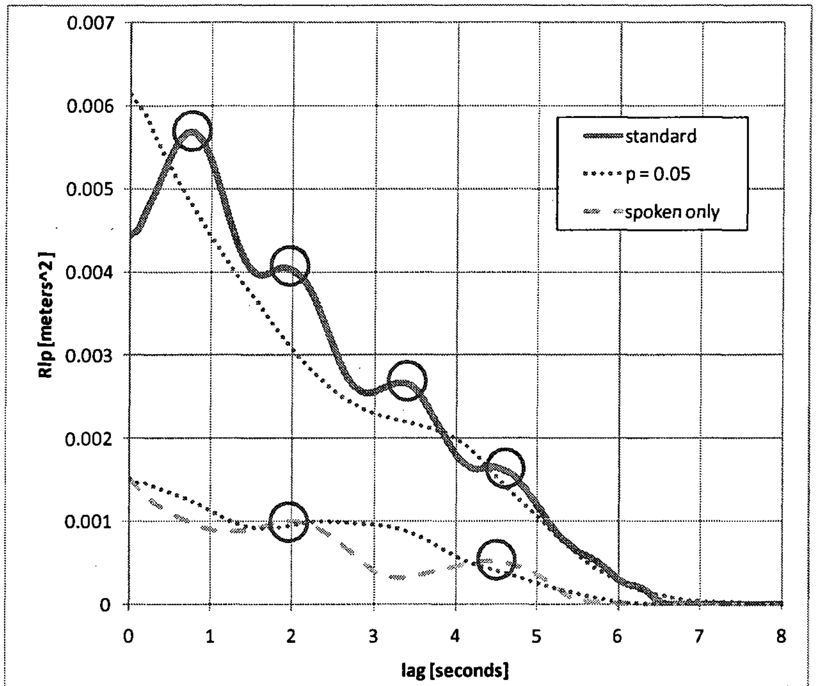


Figure 4.3.7 Cross-correlation between TIPDT on the outside world and lane position variance (top) and steering wheel variance (bottom). Circled peaks indicate statistically significant increases in variance occurring after increases in the TIPDT, with the delay indicated by the value of lag

is about 0.8 seconds, indicating that an increase in the lane position variance follows reduced attention to the outside world. The graph at the bottom of Figure 4.3.7 indicates that similar peaks exist for the steering wheel angle variance ($\mathbf{R}_{\mathbf{stw,standard}}$). The two graphs also show that statistically significant peaks exist for PND with spoken directions as well. In tracing the source of the peaks, we found that when drivers were not looking at the roadway, they were looking either at the speedometer, dashboard, or steering wheel. This is to be expected. However, the peaks for the spoken directions are about six times smaller than for the standard PND.

Why is there such a difference in the magnitude of the effects? The data indicates that the answer is in the length of gazes drivers use to view the standard PND. Figure 4.3.8 again shows cross-correlation values for the two navigation aids. However in this case the cross-correlations were calculated using gazes away from the outside world that are 200 ms or more in length. Clearly, there is a striking resemblance between the graphs in Figure 4.3.7 and Figure 4.3.8, respectively: peaks are located in practically the same locations and the magnitudes are almost the same. We can conclude that gazes away from the outside world lasting 200 ms or longer are the major contributors to peaks in the cross-correlations. As Figure 4.3.9 shows, about 60% of all fixations (gazes at the same location lasting at least 100 ms) at the standard PND are in fact at least 200 ms long.

In summary, whenever drivers look away from the road in such a way that it causes higher variance in lane position or steering wheel angle, it is because they are spending at least 200 ms doing so. When a visual display is present, the magnitude of the effect on driving performance is about six times greater. This is probably due to the fact



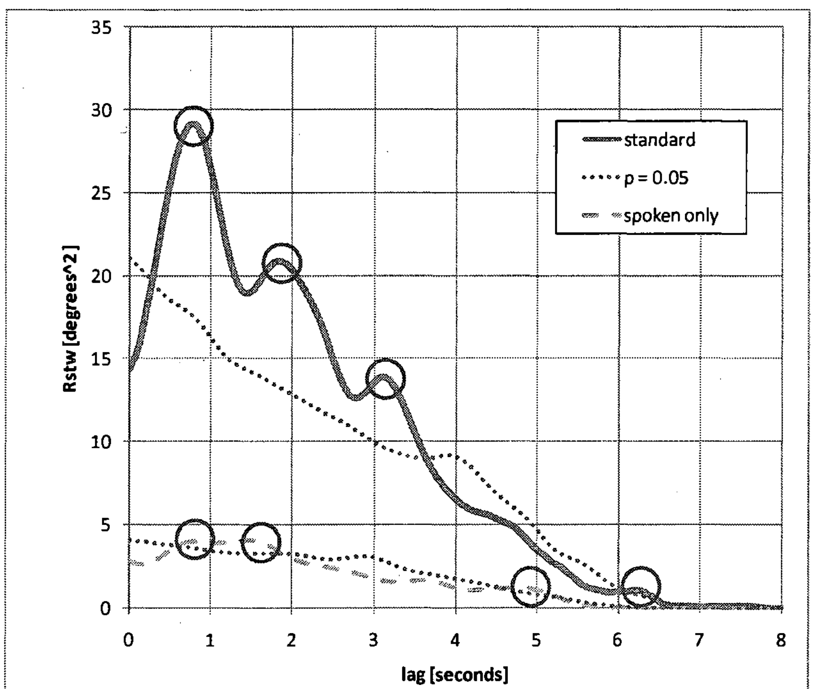


Figure 4.3.8 Cross-correlation between TIPDT on the outside world and lane position variance (top) and steering wheel variance (bottom). Cross-correlation calculated only using gazes away from the outside world of 200 ms or longer. Circled peaks indicate statistically significant increases in variance occurring after increases in the TIPDT, with the delay indicated by the value of lag

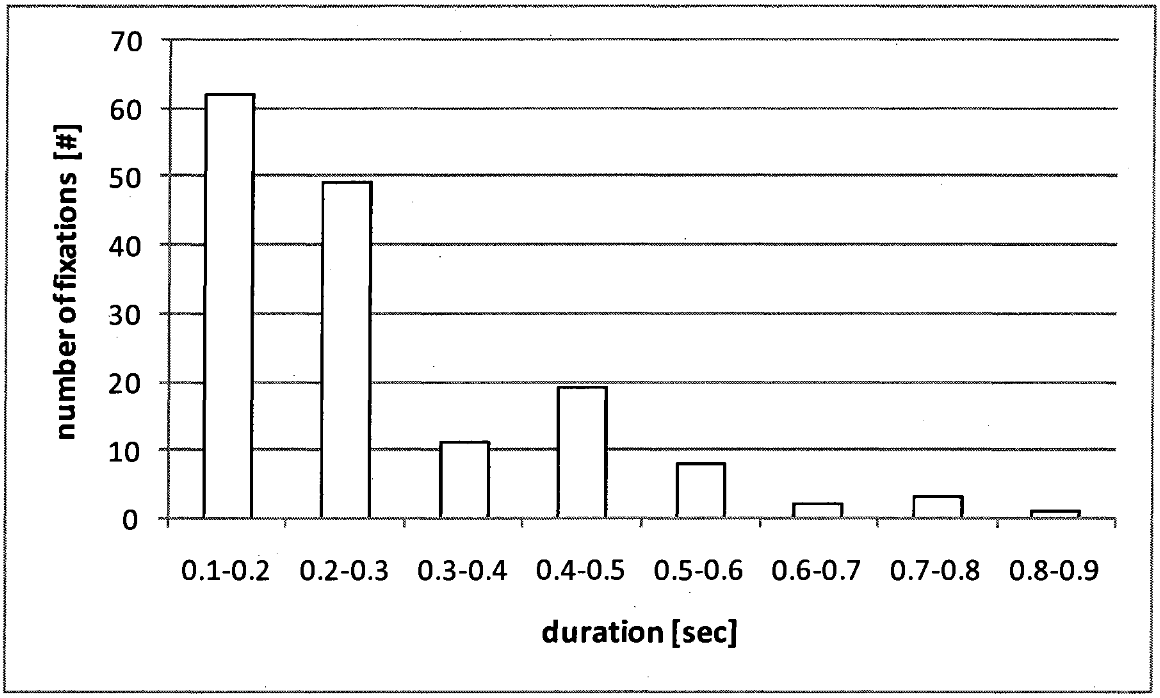


Figure 4.3.9 Distribution of fixations at the standard PND screen by duration

that unlike looking at the dashboard, looking at a map that is changing in real-time requires a fair amount of cognitive effort. Drivers need to mentally parse the information in the display, and that is more distracting.

4.4 Post experiment questionnaires

At the end of the experiment, participants filled in the experiment questionnaire in order to determine their general views on their performance and preference for the two PNDs. The experiment questionnaire had three sections with the total of 31 questions:

1. general questions about the experiment,
2. questions about visual and spoken output PND,
3. and questions about spoken output only PND

All questions, except two for the general questions about the experiment (how many times have participants participated in the driving simulator experiment, ranking on a scale from 1-10 how sick they felt while driving in a simulator), were designed using a Likert scale, and included 5 possible answers: strongly agree, agree, undecided, disagree, and strongly disagree. Methods from quantitative statistics cannot be used for the analysis of these questionnaires. Descriptive statistics are used instead: median, mode, and interquartile range are used rather than mean, standard deviation, or variance [32]. Median is the middle value in the ordered set of values or the average of the middle two values if the set has an even number of elements. Mode is the value that most frequently occurs in the set. Interquartile range is the difference between the upper and lower quartiles, where the lower quartile is the value which is higher than 25% and lower than 75% of the values in the set, and the upper quartile is the opposite (higher than 75% and lower than 25% of the values in the set). The interquartile range indicates the dispersion of the data and spans 50% of the values in the set, removing the highest and lowest values.

Another method for analyzing the Likert scale results is visualizing them with bar charts. These two methods (descriptive statistics and bar chart) are used for the questionnaire analysis. Only answers regarding the preference between the two PNDs will be analyzed while answers for spoken prompts will be summarized.

4.4.1 Visual and spoken output PND

This part of the questionnaire had 12 questions, 7 about spoken prompts and 5 about preferences and opinions about visual display. Only questions concerning the visual display are analyzed here. Each question and the descriptive statistics for the answers are summarized in tables, while bar charts visualize the answers.

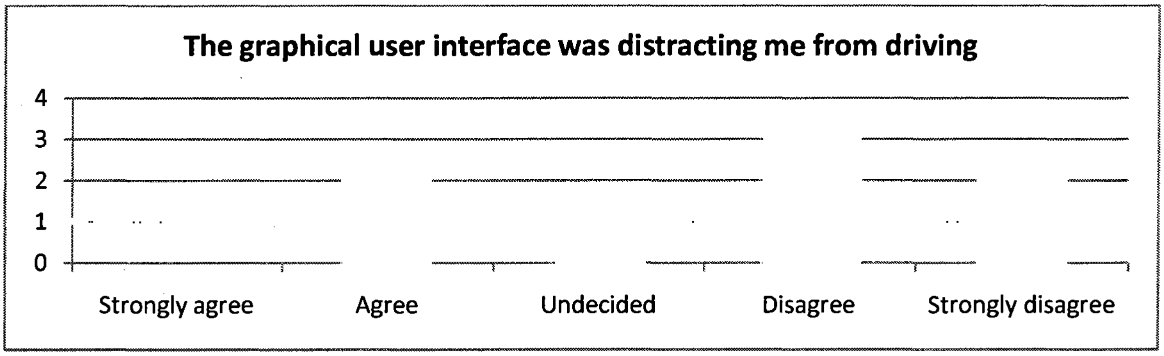


Figure 4.4.1 Bar chart for the answers on question "The graphical user interface was distracting me from driving"

The graphical user interface was distracting me from driving					
Median	Disagree	Mode	Disagree	Interquartile range	2 units

Table 4.4.1 Descriptive statistics for the answers on question "The graphical user interface was distracting me from driving"

Most participants thought that PND's visual display wasn't distracting them from driving (5/8). Both median and mode are at the same level "Disagree". Interquartile range is spanning 2 answer levels.

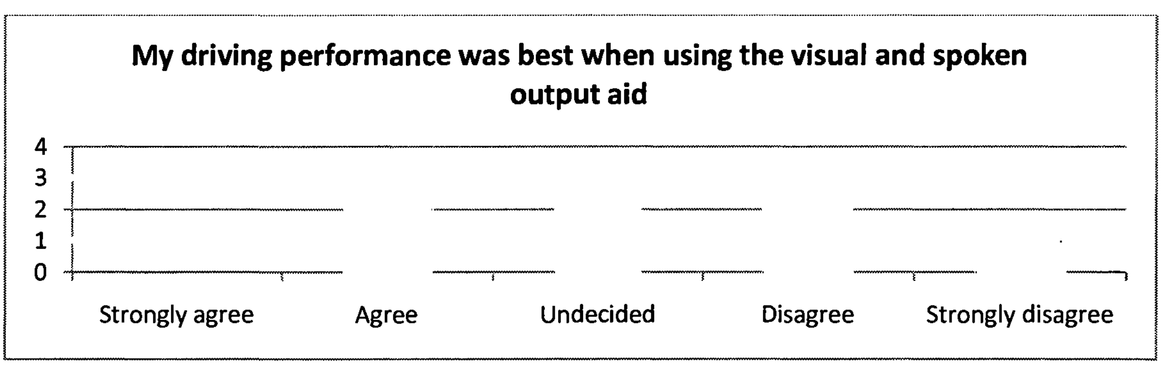


Figure 4.4.2 Bar chart for the answers on question "My driving performance was best when using the visual and spoken output aid"

My driving performance was best when using the visual and spoken output aid					
Median	Undecided	Mode	Undecided	Interquartile range	1.5 units

Table 4.4.2 Descriptive statistics for the answers on question "My driving performance was best when using the visual and spoken output aid"

Participants were undecided if their driving performance was best when navigating with visual and spoken output PND. Median and mode are both "Undecided", with less variance because interquartile range is 1.5 units.

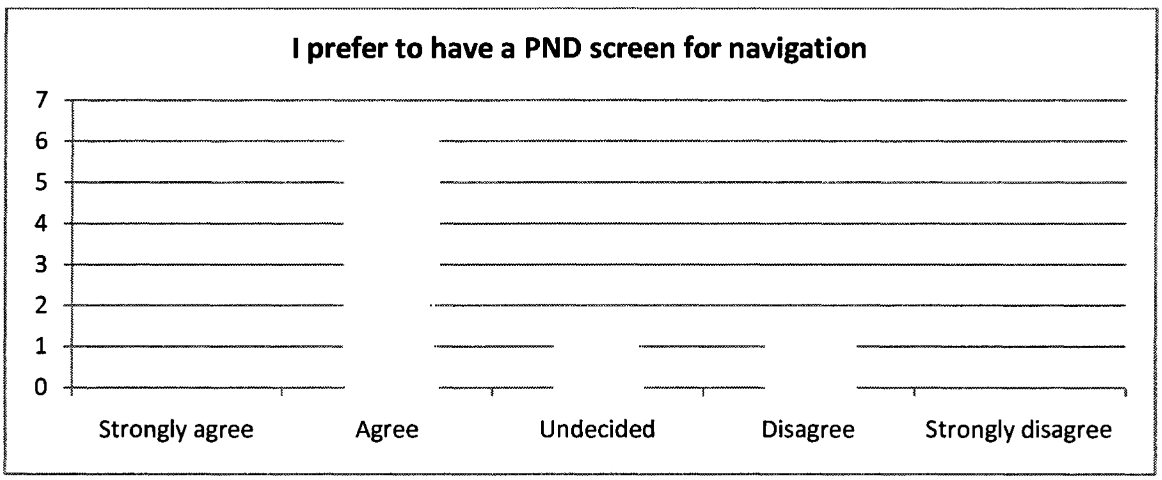


Figure 4.4.3 Bar chart for the answers on question "I prefer to have a PND screen for navigation"

I prefer to have a PND screen for navigation					
Median	Agree	Mode	Agree	Interquartile range	0.5 units

Table 4.4.3 Descriptive statistics for the answers on question "I prefer to have a PND screen for navigation"

Descriptive statistics show that participants have strong preference toward use of the PND's display screen when navigating. Median and mode are both Agree with interquartile range of only 9.5 units, which shows that there is little variance in their answers.

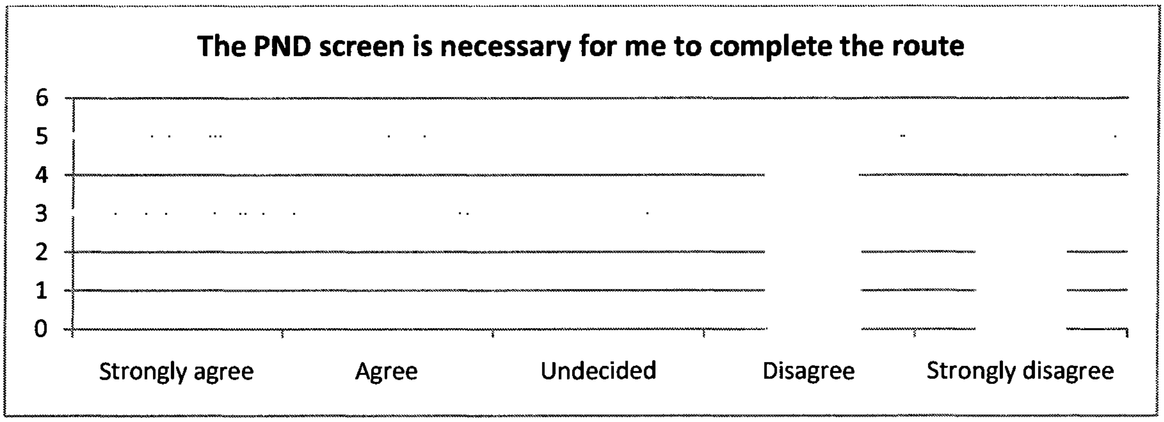


Figure 4.4.4 Bar chart for the answers on question "The PND screen is necessary for me to complete the route"

The PND screen is necessary for me to complete the route					
Median	Disagree	Mode	Disagree	Interquartile range	1 unit

Table 4.4.4 Descriptive statistics for the answers on question "The PND screen is necessary for me to complete the route"

Participants found that they don't necessarily need the PND's visual display to complete the route. Median and mode are "Disagree" and interquartile range is again low, only 1 unit.

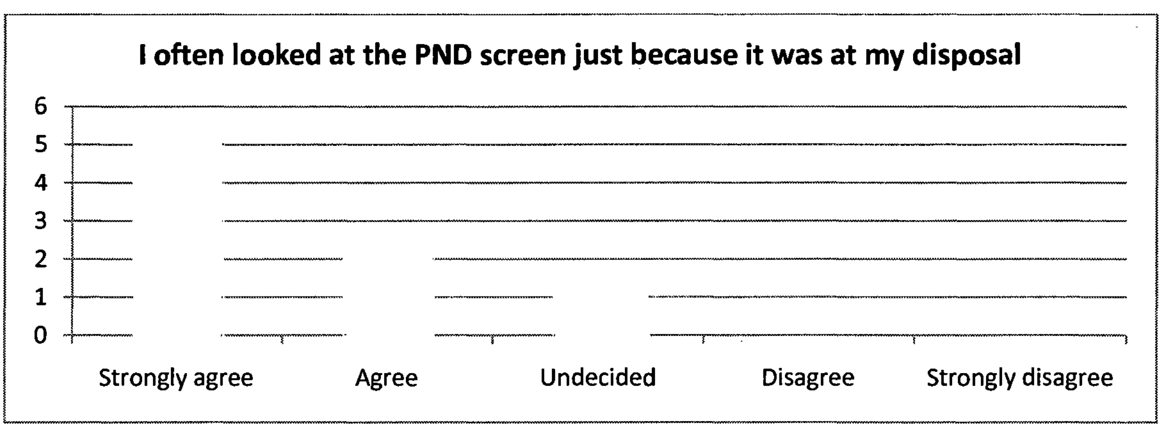


Figure 4.4.5 Bar chart for the answers on question "I often looked at the PND screen just because it was at my disposal"

I often looked at the PND screen just because it was at my disposal					
Median	Strongly disagree	Mode	Strongly disagree	Interquartile range	1 unit

Table 4.4.5 Descriptive statistics for the answers on question "I often looked at the PND screen just because it was at my disposal"

Participants strongly agreed that they looked at the PND's display screen just because it was at their disposal. This is shown with median and mode being on the level of "Strongly agree" and interquartile range of 1 unit.

4.4.2 Spoken output only PND

This part of the questionnaire had 10 questions, 6 about spoken prompts, and 4 about preferences and opinions about spoken output only PND. The question "The voice prompts were distracting me from driving" was repeated in both sections (sections about combined output PND and spoken output only PND), but wasn't analyzed in section 4.4.1. The answers for both sections will be analyzed here.

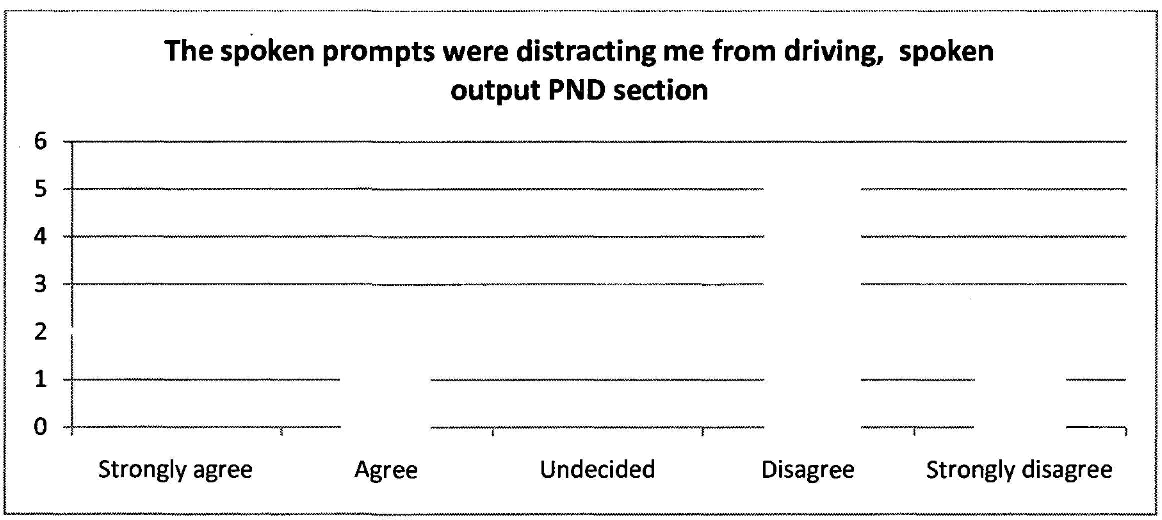


Figure 4.4.6 Bar chart for the answers on question "The spoken prompts were distracting me from driving" for the spoken output PND section

The spoken prompts were distracting me from driving					
Median	Disagree	Mode	Disagree	Interquartile range	0.5 units

Table 4.4.6 Descriptive statistics for the answers on question "My driving performance was best when using the speech only system" for the spoken output PND section

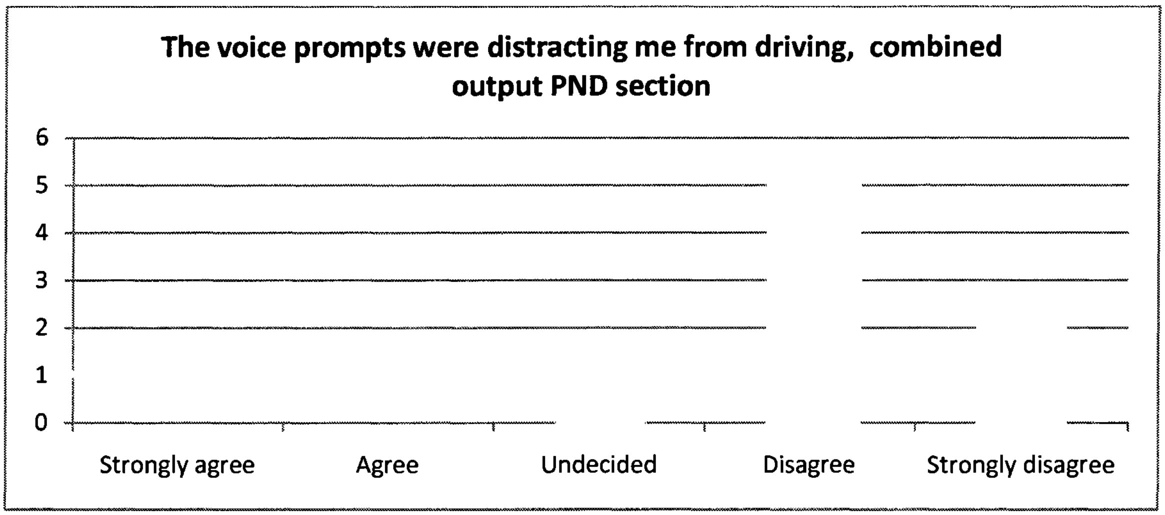


Figure 4.4.7 Bar chart for the answers on question "The voice prompts were distracting me from driving" for the combined output PND section

The spoken prompts were distracting me from driving					
Median	Disagree	Mode	Disagree	Interquartile range	0.5 units

Table 4.4.7 Descriptive statistics for the answers on question "The spoken prompts were distracting me from driving" for the combined output PND section

As it can be concluded from the figures 4.4.6 and 4.4.7 (as well as from tables 4.4.6 and 4.4.7) participants found that spoken prompts didn't distract them from driving. The same median, mode, and interquartile range appear twice ("Disagree", "Disagree", 0.5 units).

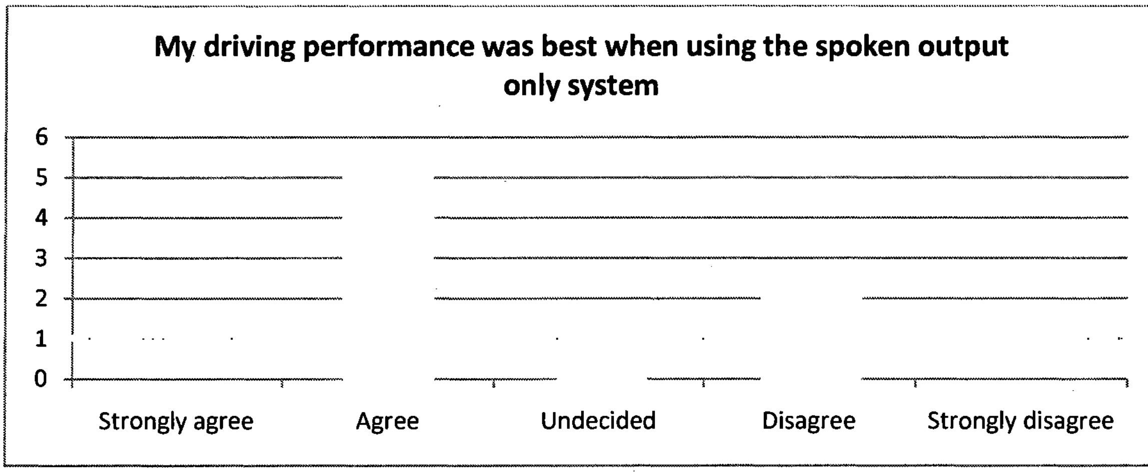


Figure 4.4.8 Bar chart for the answers on question "My driving performance was best when using the spoken output only system"

My driving performance was best when using the spoken output only system					
Median	Agree	Mode	Agree	Interquartile range	1.5 units

Table 4.4.8 Descriptive statistics for the answers on question "My driving performance was best when using the spoken output only system"

Participants believed that their performance was best when using the spoken output only PND. This is shown with mode and median being on the same level, "Agree", and interquartile range being 1.5 units.

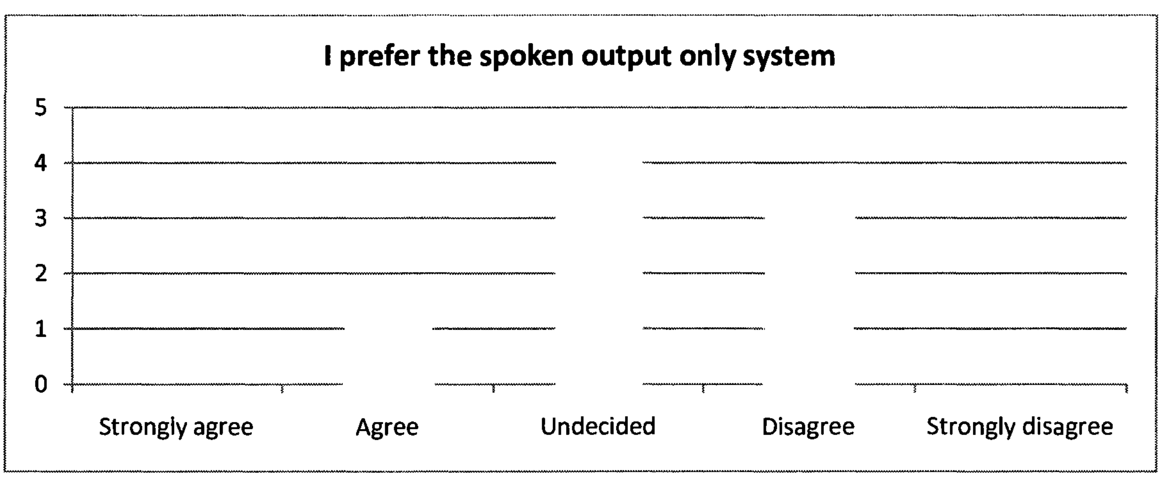


Figure 4.4.9 Bar chart for the answers on question "I prefer the spoken output only system"

I prefer the spoken output only system					
Median	Undecided	Mode	Undecided	Interquartile range	1 unit

Table 4.4.9 Descriptive statistics for the answers on question "I prefer the spoken output only system"

Participants were undecided about their preference towards spoken output only PND. This is shown with mode and median being on the same level, "Undecided", and interquartile range being 1 unit.

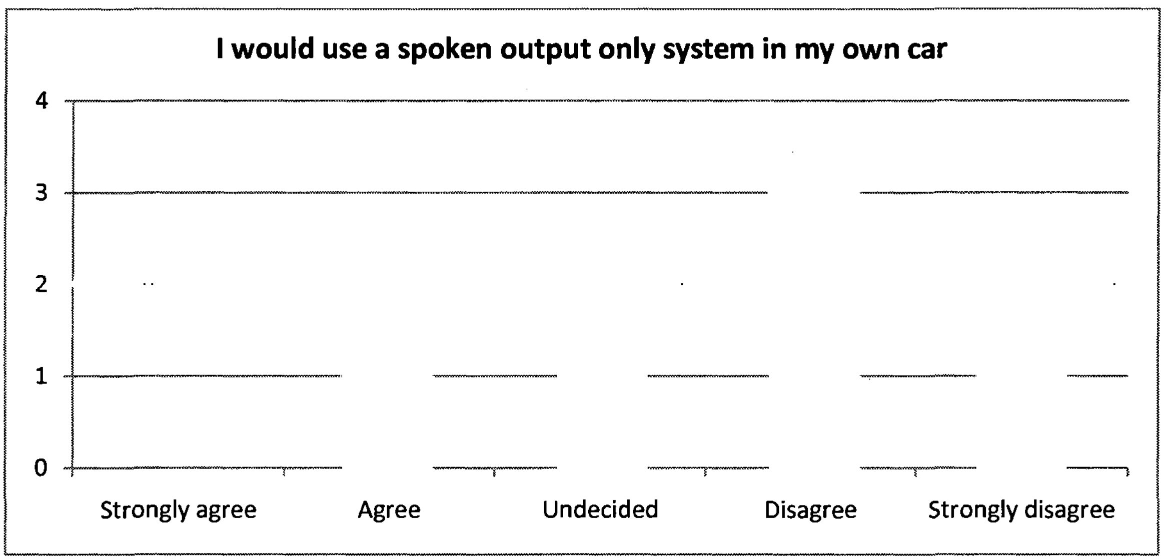


Figure 4.4.10 Bar chart for the answers on question "I would use a spoken output only system in my own car"

I would use a spoken output only system in my own car					
Median	Disagree	Mode	Disagree	Interquartile range	1.5 units

Table 4.4.10 Descriptive statistics for the answers on question "I would use a spoken output only system in my own car"

Participants showed that they would not use the spoken output only PND in their car. This is shown with median and mode being at the "Disagree" level and with range of 1.5 units.

4.4.3 Spoken prompts

As stated in section 3.3, both PNDs used the same spoken prompts. Participants found that they weren't frustrating and weren't difficult to understand. Spoken prompts didn't give too much information and their timing was perfect (they weren't too early or too late). One participant didn't have the questionnaire with questions regarding spoken prompts, so answers from 7 participants are summarized in Table 4.4.11.

Question	Combined output PND	Spoken prompts only PND
The navigation device's spoken prompts were frustrating	4 disagree, 3 strongly disagree	5 disagree, 4 strongly disagree
The navigation device's spoken prompts were difficult to understand	1 disagree, 6 strongly disagree	3 disagree, 4 strongly disagree
The navigation device's spoken prompts gave too much information	3 disagree, 4 strongly disagree	3 disagree, 4 strongly disagree
The spoken prompts were given too early	4 disagree, 3 strongly disagree	6 disagree, 1 strongly disagree
The spoken prompts were given too late	5 disagree, 2 strongly disagree	5 disagree, 2 strongly disagree
The timing of the spoken prompts was perfect	2 strongly agree, 4 agrees, 1 undecided	3 strongly agree, 3 agrees, 1 undecided

Table 4.4.11 Summarized answers for spoken prompts

4.5 Discussion

With respect to designing in-car navigation aids, our results seem to suggest that if users can trust a PND enough to follow whatever spoken directions they are given, even when they are lost, a navigation system with no visual display may be the most favorable option since visual attention and consequently driving performance will likely be improved. This finding is important for two reasons. First, any sophisticated GUI that could hold a driver's attention even more than the simple 2D view we presented, such as 3D terrain maps [33;34], is likely to affect driving performance in an even worse way. Second, small PND devices that rely primarily on speech present viable alternatives to the typical GPS form factor. For example, Verizon VZ Navigator [35] provides spoken turn-by-turn directions along with a map, but on some phones (e.g., flip phones), the map and text are too small to read. Our research suggests that, if the map is intentionally turned off, using these devices may not result in worse driving performance than using PNDs with larger displays, and may even result in better visual attention and consequently better driving performance.

The key to a successful PND interface may be to earn the trust of the users. At the end of our experiment, we asked participants to rate their experiences with the three navigational aids. Five of the eight participants strongly agreed or agreed with the following statement: "I prefer to have a GPS screen for navigation." We hypothesize that this sentiment will be especially strong on roads where users may seek reassurance that they are on the right path. For example, on long road segments, drivers may get anxious that they have missed a turn and may want to get feedback from the navigation aid. These may be times when drivers cast a glance at the visual output of a navigation aid.

CHAPTER 5

CONCLUSION

In-vehicle PNDs enhance the driving experience while navigating from start to end destination by providing a vehicle's real-time location on an electronic map accompanied with spoken prompt instructions. Although this may seem convenient, there are certain problems caused by these devices. Drivers shift their attention from the road ahead to the PND's display to check their location on the map or to see where the next turn is going to be. This shift of attention could come in a dangerous moment, particularly in urban city environments where certain unexpected events are most likely to happen, e.g. pedestrian trying to cross the street outside the crosswalk area or vehicle parked on the street pulling out. In other words, the main **problem** with PNDs is that they distract drivers from keeping their eyes on the road ahead because they require the driver's visual attention. Alternatively, drivers could receive only spoken prompt instructions which would most likely keep the driver's attention on the road ahead, i.e. it would reduce the distraction caused by PNDs.

The problem stated in the above paragraph motivated the research conducted for this thesis. The **primary goal** of this thesis was to investigate the influence of two PNDs on driving: the influence of a standard PND, with both navigational map and spoken prompt instructions, and the influence of a PND with spoken prompts only. This goal was split up into two sub goals. The **first goal** was to discover if a standard PND causes drivers to spend less time looking on the road ahead than a PND with spoken output only. The **second goal** was to inspect the effects of glancing at the PND's visual display on driving performance.

There were two hypotheses regarding the stated goals. The **major hypothesis** was related to the **first goal** of the thesis, and it stated that a standard PND, with visual and spoken outputs, would influence the PDT on the outside world negatively when compared to the PND with spoken output only. Drivers are visually distracted by the map displayed on the PND when they are navigating with the standard PND and consequently they will spend less time looking at the road ahead. On the contrary, a PND with spoken output only doesn't have the visual display and thus nothing that will visually distract the drivers. The **secondary hypothesis** was related to the **second goal** of this thesis, and it declared that glancing at the PND's visual display will reflect negatively on the driving performance. More accurately, an increase in the steering wheel and lane position variances were expected to happen whenever drivers look away from the road. This would be more notable in the cross-correlation between the PDT not looking at the road ahead and the lane position variance for the standard PND than for the PND with spoken output only. This result was expected because drivers would be more visually distracted by the standard PND. The same expectations apply for the correlation between PDT not looking at the road ahead and steering wheel angle variance.

A between-participants experiment was designed in our high-fidelity driving simulator as part of the **approach** used to investigate the hypotheses. An urban city like scenario was created with four unexpected events:

- pedestrian suddenly crossing the street,

- vehicle pulling out,
- vehicle in front braking,
- and vehicle speeding into the intersection

The reason why an urban environment was chosen is because typically driving in this environment involves making more turns than, for example, driving in a rural environment, and participants are more likely to glance at the PND when they need to make a turn. The route in the driving scenario was 10 km long, with seventeen 200 meter segments, six 400 meters segments, one 600 meter segment, two 800 meters segment, and two 1600 meters segments. It had two directions, up-down (or North-South) and down-up (or South-North) with three unexpected events happening in each direction.

Four types of research devices were used in the experiment:

- DriveSafety DS-600c driving simulator which provided driving performance measures, i.e. lane position, steering wheel angle and velocity,
- SeeingMachine's faceLAB 4.6 eye tracker which provided information about participant's gazes
- Lilliput 7" VGA 619GL-70NP monitor for simulating PND's visual display
- Sony HDR-HC3 HDV 1080i, Panasonic PV-GS65, and Sony DCR-HC28 camera that were used for manual data transcription

Twenty nine participants were recruited through flyers and promotional emails. Eleven participants did not complete the experiment, while ten were classified as outliers. They were paid with $15 BestBuy gift cards for participating in the experiment. They interacted with two PNDs on the same route, but they traversed the route in different directions for each PND. This approach was used to prevent participants from learning the route over the course of the experiment and to keep the driving task complexity equal across routes. The order of interactions between the PNDs and traversed routes were counterbalanced.

To prove our **major hypothesis,** a one-way ANOVA using PDT as the dependent variable was performed. The results confirmed that participants did spend more time looking at the outside world when using spoken directions as compared to the standard PND directions, with significance $p<.01$. Specifically, for spoken directions only, the average PDT was 96.9%, while it was 90.4% for the standard PND. Glancing at the visual display was not necessary to complete the navigation task. In fact, there were no cases of missed directions for any of the navigation aids. For the city route and traffic conditions utilized, spoken directions provided sufficient information without introducing a visual distraction.

To test our **secondary hypothesis,** we performed cross-correlation analysis between PDT not looking at the road ahead and driving performance measures, short-term steering wheel angle and lane position variance. We found statistically significant peaks that indicate that there may be a causal relationship between looking away from the outside world, e.g. to look at the LCD screen, and an increase in the variance of lane position and steering wheel angle. We also found that the cross-correlation peaks are larger for gazes away from the outside world lasting 200 ms or longer. This is important since, for the case of the standard PND, about 60% of all fixations at the LCD screen were at least 200 ms long. In other words, the way in which users interact with standard PNDs very often results in looking away from the outside world for more than 200ms at a time. This in turn is correlated with increased short-term lane position and steering wheel variances. Although any increase in the risk of accidents due to these increased variances still needs to be quantified, our results provide designers of in-car navigation aids with reason for caution and a framework for assessing any negative impact on driving due to visual displays.

CHAPTER 6

FUTURE WORK

The research carried out in this thesis showed that glancing at the PND's display screen negatively influences driving performance. Drivers spend less time looking at the outside world and increase in the short-term lane position and steering wheel angle variance appears every time they look away from the road ahead. To further investigate the influence of a PND's visual display on driving performance, certain steps for future work are suggested. Participants in the experiment were all male students and it would be beneficial to expand this group with females and elder drivers. Besides a 2D map that was used in the study, PNDs are also displaying egocentric maps and it would be interesting to see how this type of map would influence PDT and driving performance. Predictive models of when the drivers are likely to look at the PND display for reassurance could be used to assist the development of spoken only navigation aids that deliver prompts reassuring drivers that they are on the right track. Driving scenario could be improved to resemble an urban city environment even more.

6.1 Expand participant group

All participants in the experiments were young male drivers. Tsimhoni et al. report on differences in glance duration, number of glances, and task completion time when reading electronic maps between different gender and age groups [36]. It would be gainful for future work to include young male and female, and older male and female participants. The results from this improved study could bring new insight into the correlation between PDT and driving performance as well as new PND design guidelines.

6.2 Explore more maps

A 2D map was used in the experiments. However PNDs also offer egocentric maps. It has been shown that this type of map can improve user performance on a navigation task [37]. Following the industry trends, the effect of displaying a 3D map on the PND's display screen on PDT and driving performance could be explored. To go even a step further, futuristic augmented reality windshield displays could be investigated. PDT and driving performance could then be compared for different types of maps to show which one is the safest for use.

6.3 Investigate predictive models

Prediction models of driver's glances at the PND for reassurance could be made. These models could then be used to assist in the development of spoken output only PNDs by telling us in what situations and when drivers need reassurance. Spoken output PNDs would know then when they need to confirm that drivers made a correct turn. It would be interesting to see if this would make a difference in users' preference between the two PNDs.

6.4 Driving scenario

All intersections used in the driving scenario are four way 90° intersections, but more complex intersections can be found in any larger city and thus should be added to the scenario. It would also be interesting to see how these new intersections would reflect on PDT and driving performance. If any kind of more complex intersection is to be added to the scenario, it would have to be manually created because HyperDrive Authoring Suite ™ offers only T and four way intersections. Ambient traffic could be generated based on numbers of vehicles per hour in urban cities, e.g. New York or Boston, which could be gained from the literature. Pedestrians in the scenario could be seen walking only on the sidewalk. To simulate a real world urban city environment, pedestrians who are crossing the street should be added.

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APPENDIX A: Personal information questionnaire

Subject ID: ______________ Date: __________ Time: __________

1. Gender

   Female ___ Male ___

2. Age: ___

3. Do you wear (indicate yes or no):

   Glasses? ___ Contact lenses? ___

4. Are you a student?

   No ___ Undergraduate ___ Graduate ___

5. Are you a US citizen or US resident?

   No ___ Yes___

6. Do you have a social security number?

   No ___ Yes ___

7. If not a student, what is your highest education level?

   High school ___ College ___ Graduate ___

8. Is English your native language?

   Yes ___ No ___ but I've been speaking English for ___ years.

9. Are you left-handed or right-handed?

   Left-handed ___ Right-handed ___

10. If you have a valid driver's license, what year did you get it?

    Exactly in ______ Approximately in ______

    I do not remember ______ No driver's license ______

11. Approximately how often do you drive?

Never ___ A few times a month ___ A few times a week ___ Daily ___

12. Approximately how many miles do you drive annually?

___________ miles

13. Have you been in a driving simulator before? Check (or fill in) all that apply.

Never ___ Once or twice ___ Many times ___ At UNH ___ At _____________

14. If you have been in a driving simulator before please provide details below (e.g. dates, studies).

____

____

____

15. Do you own an in-car GPS system?

Yes ___ No ___

16. Do you own other GPS enabled devices?

No ___ Yes I own (please list all):

____

17. Approximately how often do you use GPS-enabled devices for car navigation?

In-car GPS system (make/model: ____________________________________):

Never or very rarely ___ Once a month ___ Once a week ___ Daily ___

Phone (make/model/navigation software: ______________________________):

Never or very rarely ___ Once a month ___ Once a week ___ Daily ___

Laptop (make/model/navigation software: _____________________________):

Never or very rarely ___ Once a month ___ Once a week ___ Daily ___

______ (make/model/navigation software: _____________________________):

Never or very rarely ___ Once a month ___Once a week ___ Daily ___

______ (make/model/navigation software: ________________________________):

Never or very rarely ___ Once a month ___Once a week ___ Daily ___

---

18. Do you find GPS-enabled devices convenient for car navigation?

In-car GPS system:

Very inconvenient ___ Inconvenient ___ Convenient ___ Very convenient ___

Phone:

Very inconvenient ___ Inconvenient ___ Convenient ___ Very convenient ___

Laptop:

Very inconvenient ___ Inconvenient ___ Convenient ___ Very convenient ___

______:

Very inconvenient ___ Inconvenient ___ Convenient ___ Very convenient ___

______:

Very inconvenient ___ Inconvenient ___ Convenient ___ Very convenient ___

---

19. Approximately how often do you print driving directions?

Never or very rarely ___ Once a month ___ Once a week ___ Daily ___

---

20. Do you find printed directions convenient?

Very inconvenient ___ Inconvenient ___ Convenient ___ Very convenient ___

---

21. Approximately how often do you play video games?

Never or very rarely ___ Once a month ___ Once a week ___ Daily ___

---

22. Approximately how often do you play sports?

Never or very rarely ___ Once a month ___ Once a week ___ Daily ___

---

23. How often do you get motion sickness as a passenger in a car?

Never___ Most of the time ___ Occasionally ___ Always___

---

24. How often do you get motion sickness while on a boat?

Never___ Most of the time ___ Occasionally ___ Always___

---

25. How often do you get motion sickness while on a roller coaster?

Never___ Most of the time ___ Occasionally ___ Always___

APPENDIX B: Experiment questionnaire

Subject ID: ______________ Date: __________ Time: __________

Please indicate the level of agreement with each of the 29 statements below (3 pages).

1. The instructions at the beginning of the experiment were clear.

   Strongly Agree ___Agree ___Undecided ___Disagree ___ Strongly Disagree ___

2. I understood what I had to do in the navigation task.

   Strongly Agree ___Agree ___Undecided ___ Disagree ___ Strongly Disagree ___

3. Training was sufficient.

   Strongly Agree ___ Agree ___Undecided ___ Disagree ___Strongly Disagree ___

4. The experiment was interesting.

   Strongly Agree ___ Agree ___ Undecided ___Disagree ___Strongly Disagree ___

5. The routes were very short.

   Strongly Agree ___Agree ___Undecided ___ Disagree ___ Strongly Disagree ___

6. The routes were very long.

   Strongly Agree ___Agree ___ Undecided ___ Disagree ___Strongly Disagree ___

7. Remembering turns from the first route helped me navigate the second route.

   Strongly Agree ___Agree ___Undecided ___ Disagree ___Strongly Disagree ___

8. On a scale 1-10 (1 = normal, 10 very sick) how did you feel while driving the simulator?

   ______

9. Before today, how many times have you participated in driving simulator experiments? If more than 0 times, please give details.

Visual and Speech Aid

10. The navigation device's voice prompts were frustrating.

    Strongly Agree ___Agree ___Undecided ___ Disagree ___ Strongly Disagree ___

11. The navigation device's voice prompts were difficult to understand.

    Strongly Agree ___Agree ___Undecided ___Disagree ___Strongly Disagree ___

12. The navigation device's voice prompts gave too much information.

    Strongly Agree ___Agree ___Undecided ___ Disagree ___ Strongly Disagree ___

13. The voice prompts were given to early.

    Strongly Agree ___Agree ___Undecided ___Disagree ___Strongly Disagree ___

14. The voice prompts were given to late.

    Strongly Agree ___Agree ___Undecided ___Disagree ___Strongly Disagree ___

15. The timing of the voice prompts was perfect.

    Strongly Agree ___Agree ___Undecided ___Disagree ___Strongly Disagree ___

16. The voice prompts were distracting me from driving.

    Strongly Agree ___Agree ___Undecided ___Disagree ___Strongly Disagree ___

17. The graphical user interface was distracting me from driving.

    Strongly Agree ___Agree ___Undecided ___Disagree ___Strongly Disagree ___

18. My driving performance was best when using the visual and speech aids.

    Strongly Agree ___Agree ___Undecided ___Disagree ___ Strongly Disagree ___

19. I prefer to have a GPS screen for navigation.

    Strongly Agree ___Agree ___Undecided ___Disagree ___Strongly Disagree ___

20. The GPS screen is necessary for me to complete the route.

Strongly Agree ___Agree ___Undecided ___Disagree ___ Strongly Disagree ___

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21. I often looked at the GPS screen just because it was at my disposal

    Strongly Agree ___Agree ___Undecided ___ Disagree ___ Strongly Disagree ___

Speech Only Aid

22. My driving performance was best when using the speech only system

Strongly Agree ___Agree ___Undecided ___Disagree ___ Strongly Disagree ___

23. I prefer the speech only system.

Strongly Agree ___Agree ___Undecided ___Disagree ___Strongly Disagree ___

24. I would use a speech only system in my own car.

Strongly Agree ___Agree ___Undecided ___Disagree ___Strongly Disagree ___

25. The navigation device's voice prompts were frustrating.

Strongly Agree ___Agree ___Undecided ___Disagree ___ Strongly Disagree ___

26. The navigation device's voice prompts were difficult to understand.

Strongly Agree ___Agree ___Undecided ___Disagree ___Strongly Disagree ___

27. The navigation device's voice prompts gave too much information.

Strongly Agree ___Agree ___Undecided ___ Disagree ___Strongly Disagree ___

28. The voice prompts were given to early.

Strongly Agree ___Agree ___Undecided ___Disagree ___Strongly Disagree ___

29. The voice prompts were given to late.

Strongly Agree ___Agree ___Undecided ___Disagree ___Strongly Disagree ___

30. The timing of the voice prompts was perfect.

Strongly Agree ___Agree ___Undecided ___Disagree ___Strongly Disagree ___

31. The voice prompts were distracting me from driving.

Strongly Agree ___Agree ___ Undecided ___Disagree ___ Strongly Disagree ___

Please use the space below to provide comments and suggestions about the study.

APPENDIX C: Institutional Review Board Approval

University of New Hampshire

Research Conduct and Compliance Services, Office of Sponsored Research
Service Building, 51 College Road, Durham, NH 03824-3585
Fax: 603-862-3564

19-Jun-2008

Kun, Andrew
Electrical & Computer Eng Dept
Kingsbury Hall
Durham, NH 03824

IRB #: 2980
Study: Speech Sample Collection for Speech Recognition Engine Comparison and Development
Review Level: Expedited
Approval Expiration Date: 24-Jun-2009

The Institutional Review Board for the Protection of Human Subjects in Research (IRB) has reviewed and approved your request for time extension for this study. Approval for this study expires on the date indicated above. At the end of the approval period you will be asked to submit a report with regard to the involvement of human subjects. If your study is still active, you may apply for extension of IRB approval through this office.

Researchers who conduct studies involving human subjects have responsibilities as outlined in the document, *Responsibilities of Directors of Research Studies Involving Human Subjects.* This document is available at http://www.unh.edu/osr/compliance/irb.html or from me.

If you have questions or concerns about your study or this approval, please feel free to contact me at 603-862-2003 or Julie.simpson@unh.edu. Please refer to the IRB # above in all correspondence related to this study. The IRB wishes you success with your research.

For the IRB,

Julie Simpson

Julie F. Simpson
Manager

cc: File