An analysis of driver's visual attention when exposed to roadside drone operations

by
Alden Sova

A THESIS

submitted to

Oregon State University

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(Honors Associate)

Presented April 15, 2019
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Drones are being used increasingly in the transportation sector for roadside applications such as surveying, structural inspection, and traffic monitoring, which raises distraction concerns for drivers. This study examines the visual attention of a group of Oregon drivers to determine drones' potential as distracting roadside elements. Eye tracking data was collected from 30 subjects during a driving simulator experiment featuring roadside drone operations. The independent variables manipulated were drone proximity to roadway, flight path, and roadside land use. Comparisons were made between visual attention during drone event exposure and baseline visual attention and between visual attention during drone exposure while facing different types of surrounding land use (urban vs rural). Results showed that roadside drone operations had a statistically significant effect on drivers' visual attention, and that this effect was present both in rural and urban scenarios.

Key Words: visual attention, distraction, drones, driving simulator

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Honors Baccalaureate of Science in Industrial Engineering project of Alden Sova presented on April 15, 2019.

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I understand that my project will become part of the permanent collection of Oregon State University, Honors College. My signature below authorizes release of my project to any reader upon request.

Alden Sova, Author

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1 INTRODUCTION

Unmanned Aerial Vehicles (UAVs) or drones are unmanned aircraft. They were originally designed for military use and were developed and used in this capacity throughout the 20th century (O, 2017). However, they have now become ubiquitous in both commercial and recreational capacities. Commercial uses range across many sectors, from agricultural inspection and crop dusting to law enforcement and search & rescue (Mallela, 2017). One tentative application is by state departments of transportation (DOTs) for mapping and surveying infrastructure. Using drones is cheaper, safer, and more efficient for such tasks. Many DOTs have already implemented drones in their work, and several more are currently researching the possibility. With the possibilities, however, come the risks of operating aircraft in necessarily close proximity to roadways, including among them potential driver distraction.

This thesis is based upon data acquired during a study by Hurwitz et al. investigating driver distraction, funded by the Oregon Department of Transportation (ODOT) (Hurwitz et al., 2018). The ODOT study similarly examined the potential for driver distraction when exposed to roadside drone operations (in both urban and rural environments), as well as effects on driving performance. Visual fixation durations and dwell durations, vehicle velocity, and vehicle lateral position were analyzed during drone encounters.

This thesis further examines the driver visual gaze data from drone exposures by extracting new visual attention performance measures and analyzing that data. Experimental eye gaze data is compared to baseline fixation behavior as established for each individual participant. Drone-inspired gaze patterns-previously referring only to those directly focused on the drone operations-are expanded to include all off-road fixations.

2 LITERATURE REVIEW

This literature review explores research and policy in two distinct categories relating to drone use in close proximity to roadways. The first section focuses on the concept and theories of visual attention and its role in driver behavior. The second delineates the history and evolution of drone technology and use, as well as policy and legislation surrounding it. The review concludes with a summary of previous simulator studies analyzing external distraction.

2.1 VISUAL ATTENTION

2.1.1 What is visual attention?

Humans are constantly bombarded by a surfeit of visual information, and are tasked with triaging and filtering this information into what is processed and in which order. Visual perception refers to the act of raw visual information retrieval (roughly 30 to 40 fragments of information- such as smells, sounds, visual and tactile data- per second), but visual attention focuses on the information that is selected from this larger array (Grissinger, 2012). The selection process is divided into overt and covert selections. Overt selections are based on eye movements, wherein our eyes will migrate to locations of interest and acquire information. Covert selections are achieved via visual attention. With our eyes focused on a single location, our attention can shift to various characteristics of this location such as the shape and color (Chen and Choi 2008).

2.1.2 Factors influencing attention

In the words of Michael Posner, "the basic function or purpose of attentional mechanisms is to protect the brain's limited capacity system (or systems) from informational overload" (Posner, 1989). There are a number of these mechanisms and heuristics in place to minimize mental overexertion.

VISUAL ATTENTIVENESS

Visual attentiveness, the information that captures our attention is influenced by four main factors (Grissinger, 2012).

Goals and Tasks

One factor that manipulates attentional fixation patterns is goals/tasks. In a typical urban environment, someone tasked with finding an airplane would look skyward, whereas looking for a pedestrian would bring their gaze to the sidewalks and streets (Itti, 2001). "Abrupt visual onsets" can also capture one's attention, often powerfully enough to overcome alternate instruction or at the expense of one's performance (Yantis, 1990).

Mental Workload and Task Disruption

Inattentional blindness (or change blindness) is a phenomenon whereby even a large change in the visual environment goes unnoticed. The predominant explanation for this effect is that visual attention is necessary to see change. Normally, the motion indication implicit in a change would attract attention, allowing it be seen. But if this indication is lost or masked in some way, the viewer's attention would not be attracted to the change. Instead, the viewer must direct their attention around the scene, object by object, until the change is observed. Until this point, they will not be able to notice the change (Taya and Mogi 2010).

Inattentional blindness is most common when we are simultaneously performing two tasks, such as speaking on the phone while filling out paperwork. Despite widespread championing of multitasking, complicated tasks require our undivided attention. When we work with simpler or highly practiced tasks, it is easy to become bored and expend less mental attention on them. So ingrained is routine in our daily life, that we spend the majority of each day in a state equivalent to auto pilot, occasionally focusing to ensure tasks are being managed smoothly. This state makes us extremely susceptible to inattentional blindness. Ultimate reliance on cell phones has further dulled us in our ability to observe deviations from the normal routine (Grissinger, 2012).

Conspicuity

Conspicuity is defined as the likeliness of a piece of information or an object to capture one's attention. It is broken into sensory conspicuity and cognitive conspicuity. *Sensory Conspicuity* refers to the physical characteristics of the information. Properties such as luminosity and contrast work to make one feature more important than its surroundings. Interestingly, factors like bright colors and flickering are less successful in defining conspicuity than are those processed in our sensory memory without conscious thought, dubbed “preattentive properties”. Examples of preattentive properties include color and shape.

Cognitive Conspicuity is the perceived significance of the collected information. A well known example of this is the “cocktail party effect”. In a situation with overlapping conversations, one can tune into a single person’s voice, or will have their attention diverted by a conversation in which they hear their name (a significant sound to them). Meaningful information can jump out at us in a variety of settings. When scanning a newspaper, headlines that contain terms or concepts relevant to us may catch our attention.

Expectations

Expectations play an important role in how we attend to and process new information. With expectations of how something should appear, based on past experience, we often fall victim to the *confirmation bias*, which signifies the interpretation or filtering of information to support pre-existing beliefs or understandings (Nickerson, 1198). Errors arise when we are faced with new or unusual conditions diverging from familiar experiences. The aforementioned autopilot utilized to conserve mental processing can shield or divert attention from information that evidences a deviation from our expectations while focusing on information that endorses them.

2.1.3 Bottom up and top down processing

Information is typically processed according to one of two paths: bottom-up or top-down processing. Bottom up (or “exogenous) processing refers to a rapid, automatic, data-driven, stimulus influenced approach. By observing and piecing together discrete parts of a system, a larger emergent system can be visualized and understood.

A top-down (or “endogenous”) approach relies on one’s background knowledge, experiences, and expectations to influence perception. Those utilizing this slower, voluntary approach look for big-picture patterns rather than looking through minute details individually, although these details are mentally grouped in the process. For example, when a driver sees a crosswalk, they know that this means there is a high chance of people walking or running into the street. This conclusion is not evidenced by the white stripes on the asphalt, but by their experience and past knowledge that these white stripes signify a location where people will be crossing a street (Katsuki, 2014).

2.1.4 Attention and eye glances

There are two main movement-based functions of the eye. Fixation refers to maximizing an object's focus exposure by positioning it in the center of the fovea. Tracking is our ability to fixate on moving objects, a quintessential evolutionary survival technique. Rapid movements of the eye are called saccades (Chen and Choi 2008).

A number of studies contend that there is a direct correlation between visual attention and eye movement. Thus, most researchers agree that the most accurate way to measure visual attention is by tracking eye locations and movements (Velichkovsky et al., 2003; Itti and Koch, 2001; Irwin, 2004).

Visual information processing is divided into a two-stage model of pre-attentive and attentive processing. Pre-attentive processing is the general visual localizing of objects in the visual field. At the second level, attentive processing, these objects (mostly shapes) are focused upon and identified, leading to an inevitable informational bottleneck. This is why drivers attend to only a small subspace of the available roadway environment information, mostly ignoring the rest. An experiment run by Velichovsky et al. (2003) tested the presentation of attentive and pre-attentive processing. Participants in a driving simulator were exposed to two types of roadway hazards: pedestrians and red traffic lights. Researchers found that eye tracking indicated direction of attention. They further discovered that attentive processing leads to longer fixations and that hazards increased fixation durations by 100% or more. Interestingly, this response remained constant over time, even as the subjects gained familiarity to the hazards. Han et al. (2014) performed a simulator study, wherein salient and dynamic elements were tested against actual fixation heat maps, which showed similarities between the two.

However, a number of studies purport that eye movements do not capture all cognitively processed elements (Mack and Rock, 1998; Posner, 1980). Via covert attention, visual attention can be distributed without eye movement. However, this "does not nullify the use of fixation location/duration to measure processing location/duration, but hints that the metric may not be completely accurate or precise" (Irwin, 2004). For the purposes of this thesis, we assume an ideal correlation between visual attention and eye movements.

2.1.5 Role of visual attention in driving

One of the predominant attentional theories in application to driving is inattentional blindness, aka “looking without seeing”. In this case, the masking element is typically either blinking or saccadic suppression (the brain selectively preventing visual processing during saccades). In a study by Galpin et al. (2009), participants were exposed to complicated driving scenarios, with screen flashes (representing *periodic blanking*) once every second. During the flashes, one object in the scene changed. Participants were able to identify relevant changes (i.e. those related to potential hazards) with greater success than seemingly inconsequential changes (i.e. background scenery). Despite this, inattentional blindness is a significant contributor to driving accidents.

A driver’s working memory load or cognitive load can have a significant impact on their reactions and capabilities. As the environment becomes more complex, there are more factors and objects vying for the driver’s attention, increasing their visual processing capacity and cognitive load. When driving in increasingly complex or demanding environments, fixation durations decrease, speed increases, brake reaction time decreases, steering deviation increases, and following distance decreases, all consequently escalating driver risk (Underwood et al., 2003; Ericson et al., 2017).

A study by Johan Engström (2011) found that braking reaction time decreased with increased working memory capacity, but this was dependent on the nature of the roadway complication. The risk is only elevated with regard to cued events, such as a car braking unexpectedly, an ordinary driving occurrence. When exposed to un-cued events, like a suddenly turning oncoming car, cognitive load did not have an effect on reaction.

Working memory load also hinders logical interpretation of information. In a separate study, participants were instructed to change to specified lanes by pop-up roadside signs, facing varying levels of cognitive loading. Engström found that with high cognitive loads, there was a significant increase in flawed lane selections. These consisted primarily of failure to change lanes, but occasionally of switching to an incorrect lane.

TYPES OF DISTRACTIONS

Distracted driving accounts for roughly 25% of all motor vehicle accidents, and more than double this percentage in young drivers (“100 Distracted”, 2018). In relation to driving, there are three main categories of distraction: visual, manual, and cognitive (“Three Types”).

Visual distractions are those that divert our visual attention, causing us to take our eyes off the roadway. Examples include looking at billboards, GPS maps, or what song is playing on the radio. Even at small durations, visual distractions can be extremely hazardous. According to a study from Virginia Tech, glances totaling more than 2 seconds “increase near-crash/crash risk by at least two times” (Klauer, 2006).

Manual distractions refer to those wherein one or both hands leave the steering wheel of the car. These can be something like eating or smoking while driving. In the event of a roadway hazard, near-instantaneous wheel manipulation may be necessary, and the time required to bring both hands back to the wheel is critical.

Cognitive distraction is when one’s mind is no longer focused on the driving task, and is instead focused on a distractor, like a phone call or daydreaming. This can lead to engaging in “looking without seeing”, whereby one will be watching the road, but not actively attending to it.

Each of these types increases risk, but activities that fall into multiple categories simultaneously are even more dangerous, which is why texting and driving is the most dangerous form of distracted driving, 6 times more dangerous than driving under the influence of alcohol and increasing crash risk by at least 8 times, according to the National Safety Council (“Cell Phones”, 2015; “100 Distracted”, 2018).

EXTERNAL DISTRACTIONS

Driving distractors can be dichotomized as external or internal. External distractors are those existing outside the vehicle (billboards, other cars, etc.), whereas internal distractors refer to those within the vehicle (passengers, objects brought into the vehicle, etc.). Internal distractions can cause manual, cognitive, and visual distractions. External distractions are typically only cognitive or visual, as objects outside the vehicle are generally out of reach. Drones and drone operations can be classified as external, cognitive, visual distractions (“Distractions”, 2011).

Within the external classification, the major distractions are the behavior of other vehicles/drivers, animals, pedestrians, and sunlight, the most significant being other vehicles (38% of external distraction driving events). External distraction accounts for approximately a third of all distracted driving events, and were marked as a contributing factor in 29.4% of all crashes between 1995 and 1999 (“External”, 2003; Stutts, 2001). Despite this, the majority of research on this issue has focused on internal distractions (phones, GPSs, etc.), rather than effects of external distractions on driver behavior (Divekar et al., 2012)

The key in comparing internal and external distractions is the conflicting effects on driver behavior. For internal distractions, experienced drivers are reluctant to glance away from the road for long durations. However, in the case of external distractions, no such prudence is exhibited. In fact, they glance for long durations, just like their novice driver counterparts (Chan et al., 2010).

DISTRACTED DRIVING SIMULATOR STUDIES

Driving simulators are devices that enable operators to realistically reproduce driving scenarios. These simulators are used in research to observe driver behavior, especially to study behavior in conditions that would be illegal/unethical to subject participants to (for the safety of participants or those in other vehicles).

As previously noted by Divekar et al. (2012), the majority of driver distraction studies focus on internal distractors, but there are still a number of simulator studies focused on external distractors. Chan (2008) found that the percentage of especially long duration glances off the road was twice as large when faced with external distractors compared with internal distractors. Divekar et al. (2012) established that, in the presence of an external distraction, both novice and experienced drivers took equally long glances off the roadway, and that these glances adversely influence their hazard anticipation by about 4.5 times, and in the case of novice drivers, led to a 26% increase in lane boundary exception. The issue is that both novice and experienced drivers are unable to distribute their glances between the roadway and the external distraction (Chan et al., 2010). Two well known simulator studies from Milloy and Caird (2011) observed driver behavior when passing roadway-adjacent digital and video billboards and wind farms. These studies found that such external distractions negatively affect drivers’ ability to maintain lane position, speed, following distance, and reaction times. They further established that more crashes occurred when passing billboards and windmills than when driving controlled highways. Dexterity deficits and increased crash/near-crash risk were further corroborated by Klauer and Guo (2014) and the Federal Motor Carrier Safety Administration ("Using Driver", 2015).

2.2 DRONES

2.2.1 Unmanned Aerial Vehicles

Unmanned aerial vehicles, or drones, refer to any unpiloted aircraft or spacecraft (this thesis considers the former). They are typically manufactured from light, composite materials so as to increase maneuverability and decrease weight. Drones have two distinct parts: the drone vehicle and the ground control system. The drone is comprised of the propulsion system keeping it in the air and the central system, which contains a power source, transmitter and receiver, and any additional non-essential components (sensors, navigational instruments, cameras, etc.). The ground control system, controlled by the operator, manipulates all drone movement and activity (Howell, 2018).

2.2.2 Types of drones

There are three predominant categories of drones: fixed wing, single rotor helicopter, and multi rotor, as displayed in Figure 1 below. Each has advantages and disadvantages and serves particular uses more effectively. Selection depends on desired task as well as operator skill level.

Figure 1.1: Common drone types (“Common”, 2010)

Fixed Wing

Fixed wing drones use wings like an ordinary airplane to generate lift. Thus, they only need to generate thrust in the forward direction, making them the most efficient UAV class. This efficiency allows them to stay airborne for much greater durations. They can also be run on gasoline-powered engines, whose energy-dense fuel allows them to remain aloft for 20 hours or more.

The main drawback to fixed wing drones is that they are unable to hover in a single location, which is necessary for certain applications, especially aerial photography. It also makes landing and launching quite challenging, as they often need a catapult launcher or runway for launch, and a parachute or runway to ensure safe landing. Other disadvantages include cost and difficulty of use. Fixed wing UAVs are typically utilized by government or large scale operators, and cost thousands of dollars. Furthermore, the runway launching/landing and lack of stationary hovering make for a much steeper learning curve.

Multi Rotor

Multi rotor UAVs use a symmetrical frame of evenly distributed vertical propellers to keep itself aloft, the most common model being a “quadcopter” (four propellers). Multi rotors are much cheaper than their fixed wing competitors, often costing less than $100. These drones are also much more maneuverable, able to hover in one place, and can take off and land vertically and accurately, requiring nothing more than a small horizontal surface.

Due to their design, multi-rotor drones are inherently inefficient, as substantial energy is required to keep the drone in the air. This limits their flights times, distances, and cargo capacity significantly. Heavy duty versions can carry more massive loads, but at the further expense of flight duration.

Single Rotor (Helicopter)

The third design, single rotor, has a single vertical propeller, as well as a tail rotor for steering. Its large single rotor design and gas-power capability makes this type much more efficient than multi rotors. The propeller allows it to hover in a single location, while the high energy-density fuel increases endurance and payload capacity.

Single rotor drones require a lot of maintenance, due to their complex design. Maintenance fees, in addition to initial acquisition cost limits common use of single rotors. Lacking the stability of a multi rotor UAV, these drones can exhibit minor vibration, restricting their use in aerial photography/videography (Chapman, 2016).

2.2.3 Uses for drones

Commercial Drones

Non-military drone use falls into one of two categories: commercial or recreational/hobby. Commercial drone use, that under commercial, public, or governmental entities is divided into six main categories (Mallela, 2017):

1. Emergency services: firefighting, rescue, coastguard
2. Government: law enforcement, research, border patrol, infrastructure surveying
3. Agriculture/Forestry: crop dusting, monitoring environments
4. Global inspection: collect data and imagery, monitor wildlife populations, natural disaster observation, weather monitoring
5. Telecommunications: tower inspections, radio planning, temporary satellite substitution
6. Energy: monitoring oil/gas distribution infrastructure, electricity grids and distribution system

There are numerous other commercial drone uses, and as the vehicles become more ubiquitous, the list will only get longer and the applications broader.

Hobby/Recreation Drones

Hobby/Recreation drones are small unmanned aerial systems (sUAS) flown for personal interests (Cordinal, 2016). There are fewer regulations under the Federal Aviation Administration (FAA) targeting hobby drone operation compared with their commercial competitors. There are several national and worldwide recreational drone organizations, including:

World Drone Organization-promotes recreational operator advocacy, offers drone license certification, digital flight logbook, and drone insurance
(https://worlddroneorganization.com/)

MultiGP-professional drone racing league, local chapters, hosts races, events, and competitions
(https://www.multigp.com/)

2.2.4 History/prevalence of drones

The timeline of non-military drone use began in earnest in 2006, when the FAA authorized the use of commercial drones in civilian airspace for the first time. Drones began to be used sparsely in agriculture and infrastructure sectors. In 2013, two things happened that changed the course of drone usage history. Amazon announced its intentions to deliver packages via drones and DJI-a drone industry leader-released the first of its popular *phantom* drone series, a series that still holds roughly 70% of all commercial drone registrations (O, 2017; Valentak, 2017). Drone registrations and fabrications then began by the thousands, and both hobby and commercial drones exploded globally. Drone sales reached 2.2 million in 2016, and this number is expected to reach 3.55 million by 2021 ("Drone Sales", 2018).

2.2.5 Issues/dangers/concerns with drone use

We are still too close to the advent of mainstream drone use for research or statistics on the dangers of drones, but there is inherent risk in the enterprise. As drone use becomes more and more prominent, so too will its hazards and casualties. Drone accidents are already reported almost daily, falling into several main trends: emergency response interference, airspace encroachment, and civilian area crashes ("World Wide", 2019).

2.2.6 Use in transportation

Federal and state departments of transportation are beginning to use drones in their work. Compared with a traditional surveying/inspecting crew, a drone is cheaper, safer, more time efficient, decreases traffic congestion, and is capable of reaching difficult locations (AASHTO, 2016). Drones are being utilized in the following applications: accident clearance, surveying/identifying, monitoring natural disaster risks and identifying potential natural disaster risks, structural inspections, crash mapping and reconstruction, topographic mapping, and traffic and road condition monitoring (Mallela, 2017).

In March 2018, the American Association of State Highway and Transportation Officials (AASHTO) found that 35 of 44 responding state DOTs confirmed use of drones for a broad range of applications. Their survey established that 20 state DOTs-Alaska, Utah, Maine, Delaware, Oklahoma, Colorado, Oregon, Mississippi, Ohio, Nebraska, West Virginia, New Jersey, North Carolina, Montana, Georgia, Iowa, Pennsylvania, Tennessee, Arizona, and Nevada-are using drones in daily tasks. Fifteen more are currently researching drone utilization prior to implementing them (Dorsey, 2018).

As of May 2018, 10 states have been selected for the United States DOT (USDOT)'s Unmanned Aircraft Systems Integration Pilot Program. The states, and their selected commercial subsidiaries, are researching, evaluating, and testing drone application concepts (under relaxed FAA regulation) to help the USDOT and FAA in constructing future legislation. Tested concepts include: flights over people, package delivery, night operations, and flights beyond a pilot's line of sight (Stevens, 2018; "UAS Integration", 2018).

2.2.7 Future uses of drones

To avoid aerial collisions, the FAA has taken a restrictive approach to drones thus far. Though it prioritizes safety, the agency wants the drone industry to thrive, which was a factor in deploying the aforementioned Integration program, which is allowing limited regulatory leniency with authorized commercial institutions. However, some companies are simply opting to operate outside the United States, Alphabet (Google's parent company) has been testing drone backyard delivery in Australia, while Zipline has been examining delivering blood to hospitals in Africa (French, 2018). The UAS Integration program hints that package delivery, the widely and eagerly anticipated drone application that has already been implemented in several nations worldwide, is on the US' horizon (Jones, 2017).

2.2.8 Legislation surrounding drones

The FAA was born under the Federal Aviation Act of 1958, which permanently placed American airspace under FAA purview, which includes all drone operations. As drone applications continue to expand, legislation will be written to regulate them, to preserve safety and privacy ("A Brief History", 2017). Legislation will not necessarily become increasingly restrictive, and may in fact become more lenient as the drone landscape evolves. For example, the FAA is allowing specific waiver leniency in their exploration of non-line-of-sight drone flights for delivery systems (UAS Integration, 2018).

FEDERAL LEGISLATION

The FAA is the entity responsible for writing, instituting, and enforcing legislation pertinent to drone operations ("A Brief History", 2017). As the world of drones evolves, new regulations are written in place of outdated ones. The timeline of the FAA’s regulation over drone operations has been shaped by three pieces of legislation:

The FAA Advisory Circular 91-57, established in 1981, entitled “Model Aircraft Operating Standards”, enacted a short list of requirements targeted toward drone operations (“*Advisory Circular*”, 1981).

Requirements:

- Operate sufficiently far from populated and noise sensitive areas
- Do not operate around spectators until aircraft has been sufficiently tested
- Do not fly higher than 400 ft
- When flying within 3 miles of airport, notify airport officials
- Give right of way to and avoid flying near full-scale aircraft

Section 333 of the FAA Modernization and Reform Act (FMRA), released in 2012, outlined requirements for public drone operation (“FAA Modernization”, 2012).

Requirements:

- Certificate of waiver, certificate of authorization, or airworthiness certification
- Certificate outlines case-by-case flight specifications and instructions.
- Grant of exemption required for all non-hobby purposes

Part 107 of FAA Regulations, entitled ”Small Unmanned Aircraft Regulations”, was enacted in 2016 as an updated overarching policy on drone operation, summarized in table 1.1 (“SUMMARY”, 2016).

Table 1.1: Summary of Part 107 of FAA Regulations, ”Small Unmanned Aircraft Regulations”

Operational Requirements	-Drone must weigh <55 lbs -Line of sight (LOS) operation -May not operate over non participating or underneath covered structures -Only operate during daylight hours -Yield to other aircraft

	-Maximum speed: 100 mph, maximum altitude: 400 ft -An individual may not operate multiple drones at one time
Remote Pilot Certifications and Responsibilities	-Operator must hold or be under direct of supervision of a holder of a remote pilot airman certificate -Must be at least 16 years old -Report any serious injury or property damage >$500 to FAA
Aircraft Requirements	-Remote pilot must administer pre-flight check of drone to confirm it is in safe condition for use
Model Aircraft	-Part 107 does not apply to model aircraft

Advisory Circular 91-57 and Section 333 are no longer considered the active regulatory standards for drone operation in the United States. As of 2016, Part 107 is the current active regulatory standard for commercial drone use. Commercial operators may apply to the FAA for waivers allowing leniency of specific elements of the regulation (FAA, 2018). Section 336 of the FMRA currently applies to hobby drone users, requiring that models be properly registered and labeled, registrants must be at least 13 years old and permanent US citizens, and all flights must be within the operator's line of sight and no higher than 400 feet ("Register", 2018).

STATE LEGISLATION

Although the focus of existing drone regulation is at the federal level, state governments have begun developing and implementing legislation at the individual state level. Table 1.2 summarizes the legislation surrounding drone use in Oregon (www.oregonlegislature.gov).

Table 1.2: Summary of Oregon's legislation regarding drone use

Regulation	Year	Summary
HB 2710	2013	-Any drone operated by public body must be registered with Oregon Department of Aviation (DOA) -Prohibits public use of drone with weapon capability

		-Law enforcement agencies may utilize drones under the following conditions: -With a warrant authorizing use -With written consent from the individual -With probable cause of a committed crime -For emergency purposes, such as an imminent threat to the safety or life of an individual -For law enforcement training purpose
HB 2534	2015	-Requiring the State Fish and Wildlife Commission to develop a regulatory framework relating to drone use in the pursuit of wildlife (hunting, trapping, angling)
HB 5702	2016	-Specifies fees for public drone registration
HB 4066	2016	-Designates public drone weaponization as a class A misdemeanor -Prohibits drone operation near "critical infrastructure" -Regulates drone data collection by public bodies
HB 3047	2017	-Allows law enforcement to utilize drones for recreation/investigation of crime scenes -Designates firing a projectile from a drone a class C felony -Prohibits flying drones over private property in a way that harasses or bothers occupants/owners
HB 3048	2017	-Prohibits pilot from operating a drone such that the drone comes within 50 ft of a person without individual's consent

3 METHODOLOGY

This Chapter describes the central research questions of this thesis and the methods utilized to answer them. Also included is a description of the unique contribution of this thesis, a requirement of the Honors College.

3.1 Research questions

As described in the literature review, drones are being used in more and more sectors and applications. Some of these applications bring drones in close proximity to roadway infrastructure, such as transportation management or agricultural monitoring. Given this, driver distraction is a potential risk associated with increased drone use, which is the basis of this thesis and the following research questions:

- Do drivers glance away from the forward roadway for longer durations when exposed to a roadside drone operation?
- How does the land use surrounding a roadside drone operation affect driver visual attention?

3.2 Equipment

The research equipment used in this experiment was the OSU Driving Simulator and the Applied Science Laboratories (ASL) eye-tracking system, both of which are described in subsequent sections.

DRIVING SIMULATOR

Although drones are currently being used by DOTs across the country, it would be dangerous to run field studies wherein a driver was intentionally distracted in an active roadway scenario. A driving simulator experiment was designed instead.

The OSU Driving Simulator is a high-fidelity simulator made up of a full-size 2009 Ford Fusion cab mounted on an electric pitch motion system, which allows for realistic representation of acceleration/deceleration.

The driving environment is projected onto screens surrounding the vehicle, as shown in Figure 2.1. Three screens in front of the cab produce a front 180-degree view, while a fourth projector behind the cab simulates the back view, as visible through the rear windshield and rear-view mirror. The two side mirrors are LCD screens that display rear side views. While participants are being tested, the lights in the simulation room are turned off. Ambient sounds are presented by a surround sound system outside of the vehicle.

Figure 2.1: Driving simulator cab with projected simulation

The simulator is controlled from a computer workstation in an adjacent room (Figure 2.2), which prevents visual or auditory distraction to the driver, and allows complete immersion in the simulator task.

Figure 2.2: Operator workstation displaying in-vehicle camera feeds (left), simulated environment (middle), and vehicle dashboard (right)

The computer system consists of a quad-core host running Realtime Technologies' software, "SimCreator", with a 60 Hz graphics output rate. The simulator captures and outputs accurate performance measures, such as position, braking, acceleration, and speed. The virtual environments used were designed and developed with Internet Scene Assembler (ISA), SimCreator, and Blender. JavaScript-based sensors were implemented which based the motion of the simulated drone operations on the subject vehicle's location.

The following parameters were recorded at approximately 60 Hz per second throughout the experiment:

- Time - To allow mapping changes in speed and position of subject relative to drone location
- Instantaneous subject vehicle speed - To identify changes in subject's speed in response to drone operation
- Instantaneous subject vehicle position - Track lane position of subject vehicle when passing drone operation
- Behavioral (visual) data - The driving simulator is equipped with 5 cameras at various subject viewing angles, which live feed to a monitor in the simulator workstation via

SimObserver software to allow observation of participant actions and behavior when approaching the simulated drone operation (Figure 2.2).

EYE TRACKER

Eye-tracking data was collected via the ASL Mobile Eye XG system, shown in figure 2.3. The system consists of a pair of glasses with a mounted camera that allow unrestricted movement of the head while tracking the pupil location with a sampling rate of 30 Hz. *Fixations* are recorded when the subject's eyes pause in a single location for more than 100 milliseconds. *Total dwell times* are recorded as the total duration of fixations and saccades consecutively within a single area of interest (AOI).

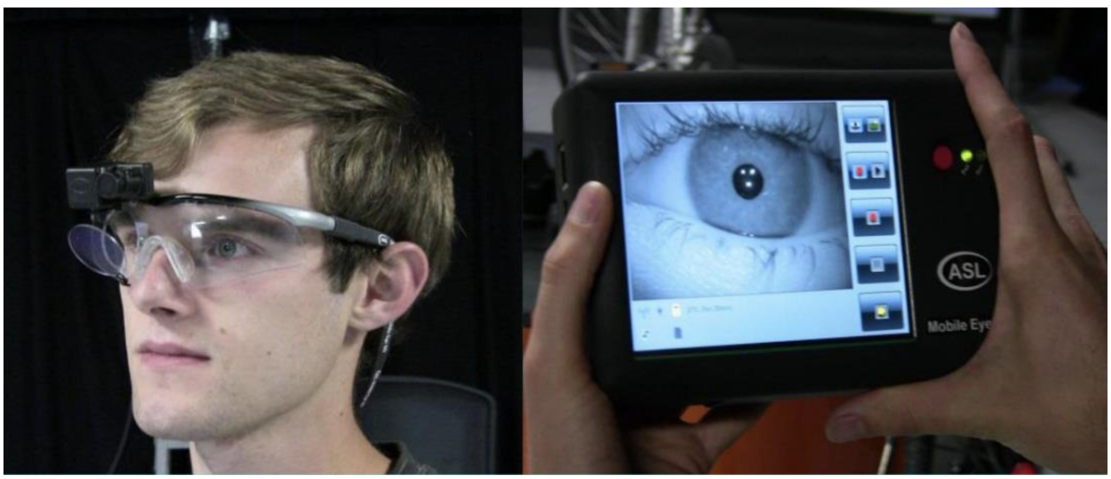

Figure 2.3: ASL Mobile Eye XG system fitted to a researcher (left) and system control unit (right)

3.3 Experimental design

An experiment was designed with the potential implementation of roadside drone use in mind (Note: Oregon State University IRB approved, study #7547). According to current FAA regulations, drone operators must remain within line of sight of their drone. It is common for the operator to work with a spotter to ensure that this requirement is met. Furthermore, when drone pilots are utilizing First Person View technology (virtual reality), a spotter is required ("SUMMARY", 2016).

The term “drone operation” in this experiment refers to two figures standing side by side with a quadcopter drone, measuring approximately one meter by one meter above them. Figure 2.4 shows an example drone operation composition as seen by a participant in the simulator.

Figure 2.4: Example roadside drone operation displayed in simulator

INDEPENDENT VARIABLES

The driving environments were designed and developed with SimCreator software, and the movements of the drones was coded with Javascript. The environments featured three independent variables: land use, lateral offset, and flight pattern,

Land Use

The land use surrounding the roadway fell into two categories: rural and urban. The rural environments (Figure 2.5) featured periodic fencing and basic agricultural/rural infrastructure. The road type was single-lane and two-way, with a constant dashed yellow line. Participants faced light ambient traffic and occasional traffic signals.

Figure 2.5: Example simulated rural environment displayed in experiment

The urban environments (Figure 2.6) presented a typical urban/suburban environment, with sidewalks, buildings and parking lots lining the roadway. The two-way road had four lanes with no median and light ambient traffic in both directions. Both land use types had posted speed limits of 35 mph.

Figure 2.6: Example simulated urban environment displayed in experiment

Lateral Offset

Lateral offset referred to the proximity of the center of the drone operation to the roadway, either 0 ft, 25 ft or 50 ft away. In accordance with FAA policy, the drones never flew over the roadway (illegal to fly over drivers) (SUMMARY, 2016).

Flight Pattern

The third independent variable, flight pattern, had three levels: takeoff, scanning, and racing. These three categories were chosen to most closely replicate common drone operation patterns, based on information gathered from the literature review. Takeoff patterns refer to the initial, strictly-vertical ascension of the drone. Scanning drones follow smooth, predictable patterns parallel to the roadway. Racing drones had a quicker, more erratic flight path.

3.4 Factorial design

A within-group, counterbalanced and partially randomized factorial experimental design was implemented to allow analysis of each individual independent variable. The eight independent variable levels are summarized in table 2.1

Table 2.1: Description of experimental dependent variables and their levels

Dependent Variable	Level	Level Description
Lateral Offset	0	0 ft
	1	25 ft
	2	50 ft
Flight Path	0	Rural
	1	Urban
Land Use	0	Takeoff
	1	Scanning
	2	Racing

As each participant would be driving multiple environments, the order of the scenarios was counterbalanced to counteract “practice effects”. Four different track layouts were designed and presented to participants in random order. Each track had either 4 or 5 drone operations, and 1 option was randomly assigned from each of the independent variable categories. Figures 2.7-2.9 show examples of various combination scenarios.


Figure 2.7: Example experimental scenario (0 ft offset, rural land use, takeoff flight path)


Figure 2.8: Example experimental scenario (25 ft offset, rural land use, scanning flight path)

Figure 2.9: Example experimental scenario (50 ft offset, urban land use, racing flight path)

3.5 Simulator sickness

Simulator sickness is a phenomenon similar to motion sickness that is common in driving simulator participants. It can lead to a variety of symptoms, including nausea, vomiting, dizziness, headaches, and sweating. The OSU driving simulator is equipped with an “emergency stop” button on the center console, allowing participants to immediately stop the current experiment if they begin to feel sick.

3.6 Subject demographics

Participants were recruited from the area surrounding Corvallis area by use of flyers posted throughout the community and emails sent to various campus organizations’ email lists. The requirements for participation were the following: must have a valid driver’s license, at least 1 year of driving experience, must not wear glasses, must be between the ages of 18-75, and must give written consent. A total of 54 individuals participated in the study. Thirteen (24%) of the participants experienced simulator sickness and could not complete the experiment. Problems with equipment resulted in the loss of data of 11 (20%)

participants. Overall, 30 complete datasets were collected. Sixteen (53%) of these participants were male and 14 (47%) were female, and they ranged in age from 18-70 years.

3.7 Experimental procedure

INTRODUCTION AND DOCUMENTATION

When participants arrived at the laboratory, they were given an informed consent document, describing the reasoning behind the study and the risks and benefits of their participation. The researcher discussed the document and informed the individual that they could stop the experiment at any time at no detriment to their compensation ($20 cash) and be free to leave.

Next, participants were asked to complete an online survey with questions in the following areas: demographics, highest level of education, prior experience with driving simulators, vision, history of simulator sickness, history of motion sickness (if participants had issues relating to the last three topics, they were encouraged not to participate in the experiment.

CALIBRATION

After completing the survey and consent document, participants were brought into the simulator, asked to adjust the mirrors and seat to their comfort, then to complete a 5 minute calibration drive. The purpose of the drive was to screen them for potential simulator sickness. They were instructed to drive normally, following traffic and traffic laws. Large yellow billboards with arrows were placed at intersections when a turn was intended, pointing the desired direction.

If participants exhibited no signs of simulator sickness, they were fitted and calibrated with the ASL glasses. Participants were instructed to direct their gaze to various points on the projected calibration image (Figure 2.7) ensuring that the eye tracker was accurately collecting the subject's visual attention data.

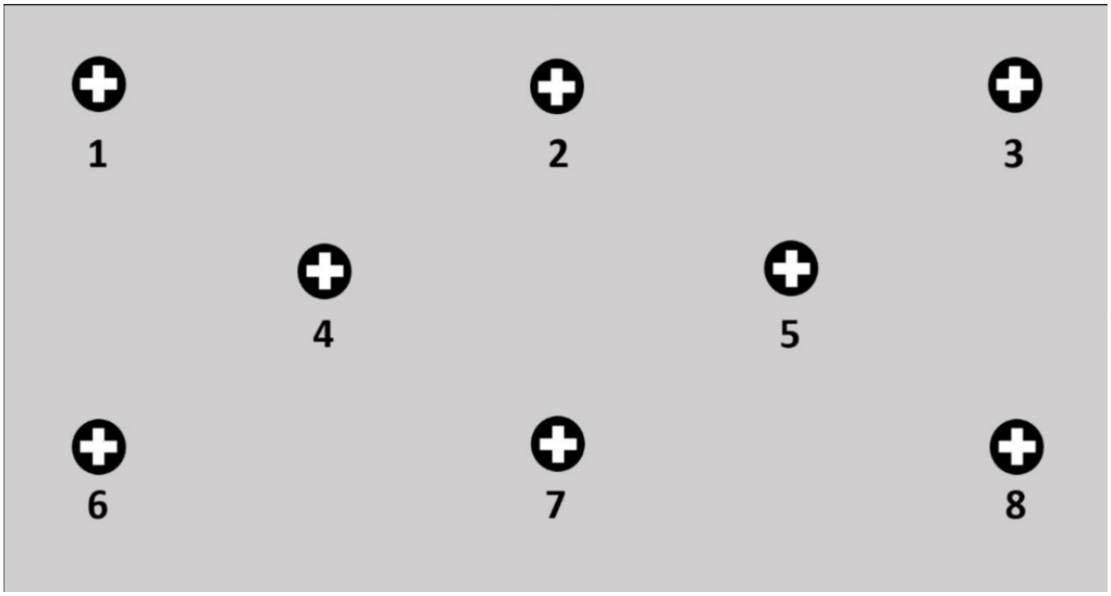

Figure 2.10: Eye tracking calibration screen

EXPERIMENTAL DRIVES

After their glasses were calibrated, the participants were given instructions for the 4 experimental drives. After each drive, the participant was instructed to stop the vehicle, and the researcher determined whether they were experiencing simulator sickness. The four track experiment was intended to be completed in 30-40 minutes.

POST-DRIVE SURVEY

After completing the experimental drives, subjects were asked to complete an online post-drive survey. The survey featured questions about simulator sickness experience during the experiment, previous experience with drones, and position on future drone operations in developed areas and near roadways, as was presented in the experiment. The entire experiment, including both the pre- and post-surveys, informed consent document, calibration drive, eye tracker calibration, and the four experimental drives took participants approximately 1 hour.

3.8 Data reduction

After all participant data was collected, fixation and dwell data from the ASL Eye Tracker was analyzed using *ET Analysis* software. Researchers viewed each subject’s video files and cropped them to the length of time the drone operations were visible (4-11 seconds, depending on driver speed). Next, polygons were drawn around AOIs on individual video frames every 5 frames, shown in Figure 2.8. One AOI, “operation”, was drawn around just the drone operation, and another, “roadside”, around the entirety of the right-side off-road scene (where the drone was located). This ensured capture of all off-road glances toward the drone operations, even those not directly focused on them. Once the AOIs were assigned for each video file, spreadsheets containing fixation and dwell data were exported to be analyzed further in *Microsoft Excel* and *Statistical Package for the Social Sciences (SPSS)*.

Figure 2.11: “roadside” (left) and “operation” (right) Areas of Interest (AOIs) drawn over video file in *ET Analysis* software

3.9 Control

Control segments were created to establish a baseline of participant visual attention data without influence from the drone operation. For each participant, two control segments were generated: one for the rural scenarios and one for the urban scenarios. The location of the control segment was the same for all participants, and the length was determined based on the average length of the drone operation segments previously defined for the rural and urban events. As with the experimental segments, AOIs were drawn surrounding the entire visual field to the right of the roadway for the entirety of both the urban and rural segments.

3.10 UHC thesis unique contribution

The data used in this thesis was originally collected for a simulator study by Hurwitz et al. (2018) The study examined the effects of roadside drone operations on several aspects of driver performance, while this thesis focused on visual attention data.

There were two unique contributions of this thesis. First, control segments were created for each participant to improve and expand the statistical conclusions. Also, a second area of interest (AOI) was added to the segment files, allowing measurement of all off-road fixations, rather than those limited to the drone operation itself. This thesis serves as an extension of the study by Hurwitz et al. (2018), corroborating and adding to its results by use of different methods and statistical analyses.

4 RESULTS/ANALYSIS

This Chapter outlines the results of the study. The first sections attend to the participant demographics and survey data, and later sections report the visual attention data of the experiment.

4.1 Participation statistics

Fifty-four total individuals (30 men and 24 women) participated in this simulator experiment. Approximately 24% (6 men and 7 women) experienced symptoms of simulator sickness, and did not complete the experiment. Inaccurately calibrated equipment or other equipment error led to the loss of eleven (20%) additional data sets (both men). These results are summarized in Table 3.1.

Table 3.1: Summary of participation statistics

Population	Total Participants	Simulator Sickness	Calibration Issues	Analyzed Participation
Total	54 (100%)	13 (24%)	2 (4%)	30 (56%)
Men	30 (56%)	6 (46%)	2 (100%)	22 (54%)
Women	24 (44%)	7 (54%)	0 (0%)	17 (46%)

The 30 analyzed participants were those who completed the simulator experiment and had complete and accurate eye-tracking data sets. The participants ranged in age from 18 to 70 years (mean age: 28.7 years).

4.2 Pre-drive survey demographic data

Table 3.2 displays the demographic data collected from the participant surveys. All responses recorded from participants who exhibited simulator sickness were excluded from the analyzed dataset. All participants resided in Oregon, although were not necessarily licensed in Oregon.

Table 3.2: Summary of pre-drive survey results

Question	Available Responses	Number of Participants	Participant Percentage
How many years have you been licensed?	1-5 years	11	37%
	6-10 years	9	30%
	11-15 years	0	0%
	16-20 years	4	13%
	More than 20 years	6	20%
How often do you drive in a week?	1 time per week	3	10%
	2-4 times per week	5	17%
	5-10 times per week	10	33%
	More than 10 times per week	12	40%
How many miles did you drive last year?	0-5,000 miles	6	20%
	5,000-10,000 miles	11	37%
	10,000-15,000 miles	9	30%
	15,000-20,000 miles	3	10%
	More than 20,000 miles	1	3%

4.3 Post-drive survey results

Table 3.3 summarizes responses to the survey participants were asked to complete following the simulator experiment.

Table 3.3: Summary of post-drive survey results

Question	Available Responses	Number of Participants	Participant Percentage
Before this experiment, had you ever seen a drone while driving?	Yes	8	27%
	No	22	73%
Do you think advanced warning signs would be helpful to you as a driver?	Yes	24	80%
	No	6	20%

4.4 Comparing visual attendance between land types

For each drone operation encounter, the length of participant fixations was recorded. Total fixation duration (TFD) was calculated by summing the durations of all fixations on the smaller "operation" AOI during a drone encounter. Higher TFDs signify a greater interest in the drone operation, suggesting a higher distraction potential. A zero TFD indicates the participant did not direct their gaze to the drone operation the entire time it was visible. TFDs are a useful metric for comparing distraction potential with different independent variable conditions. TFD is used in the following sections to compare distraction potential between rural and urban environments and between control and experimental drone encounters.

One important question in this study was whether participant visual attentional behavior in reaction to the roadside drone operations was different based on land-use type. To determine the significance of this variable, fixation percentages of rural and urban scenarios were compared. For every drone encounter, the percentage of each participant's "operation" TFD to the total time the drone was in their visual field was calculated. The percentage averages of all urban encounters and all rural encounters were calculated, then a t-test was used to determine if there was a significant difference between the two. The t-test showed no significant difference in the mean ratio for the urban scenarios ($M=0.120$, $SD=0.145$) or for the rural scenarios ($M=0.138$, $SD=0.148$); [$t(430)=1.31$, $p=0.190$].

4.5 Visual attendance in drone presentation

The second focus of this study was comparing subjects' off-road visual fixation durations between drone encounters and baseline driving. Control segments were created to measure participants' visual attention when not influenced by the presence of a drone operation. For each subject, a control segment was included for both the rural and urban environments, always in the same location. The lengths of these segments were based on each subject's average speed, so as to accurately compare the experimental and control segments for the drone operations. The aforementioned "roadside" AOIs (encompassing all glances to the right of the roadway) were utilized in measuring the baseline glances. The TFD from the control segments served as a representation of driver's off-road fixations during typical simulated driving. Figure 3.2 shows boxplots of the TFD of the rural and urban scenarios.

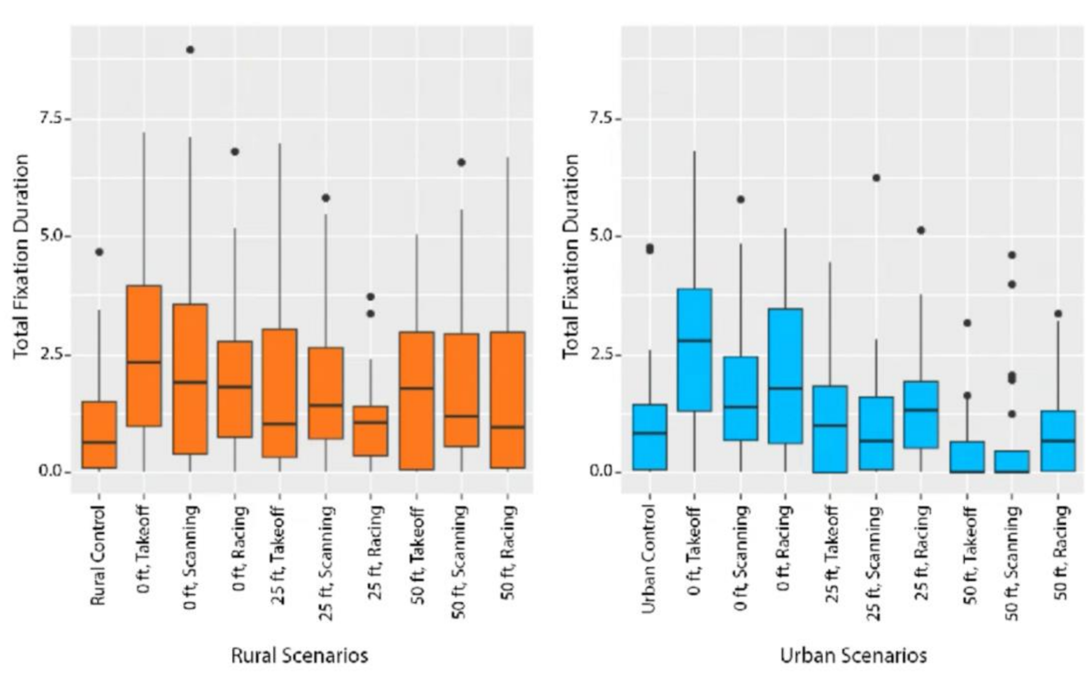

Figure 3.1: Boxplots of TFD of the nine experimental scenarios and the control segment in the rural and urban environments, respectively

Once the control segments were created, analysis of variance (ANOVA) tests were performed to establish if there were differences in any of the average TFDs in the urban and rural scenarios. Each analysis included the land type's eight experimental scenarios and its control segment. The ANOVA test showed that drone events had a significant (95% confidence level) effect on average TFD in both the rural and urban scenarios (Rural: $F(9, 290) = 2.653$, $p=0.006$, Urban: $F(9, 290) = 8.45$, $p= <0.0001$). Since the ANOVA tests presented significant results, a post-hoc Dunnett's test (Tables 3.5 & 3.6) was performed to determine which of the experimental scenarios resulted in significantly different TFD from the baseline driving performance. Dunnett's method is a post-hoc test used in the case of comparing multiple experimental groups to a single control group. The results of the Dunnett's test comparison are displayed in Table 3.4 and 3.5 below.

Table 3.4: Summarizes Dunnett's results for rural scenarios

Rural Comparison	Mean Difference	Standard Error	P value
0 ft, Takeoff, Control	1.788	0.444	<0.001**
0 ft, Scanning, Control	1.300	0.463	0.028**
0 ft, Racing, Control	1.054	0.365	0.118
25 ft, Takeoff, Control	0.881	0.417	0.267
25 ft, Scanning, Control	0.862	0.352	0.289
25 ft, Racing, Control	0.150	0.256	1.000
50 ft, Takeoff, Control	0.811	0.357	0.354
50 ft, Scanning, Control	1.039	0.404	0.128
50 ft, Racing, Control	0.739	0.403	0.459
**Indicates result significant at 95% confidence level			

Table 3.5: Summarizes Dunnett's results for urban scenarios.

Urban Comparison	Mean Difference	Standard Error	P value
0 ft, Takeoff, Control	1.667	0.414	<0.001**
0 ft, Scanning, Control	0.548	0.358	0.31
0 ft, Racing, Control	0.915	0.379	0.111

25 ft, Takeoff, Control	0.111	0.323	0.989
25 ft, Scanning, Control	-0.04	0.341	1
25 ft, Racing, Control	0.309	0.326	0.782
50 ft, Takeoff, Control	-0.68	0.27	0.074
50 ft, Scanning, Control	-0.524	0.321	0.685
50 ft, Racing, Control	-0.239	0.291	0.801
**Indicates result significant at 95% confidence level			

P values marked with ** were less than 0.05, deeming the results statistically significant at the 95% confidence level. The significant scenarios were at the 0 ft offset for both takeoff and scanning patterns in the rural scenarios, and the 0 ft takeoff pattern in the urban scenarios.

5 DISCUSSION/CONCLUSION

This Chapter reviews the research questions and summarizes the findings of this simulator experiment, then concludes with suggestions for future work in this area.

5.1 Research questions

The purpose of this study was to examine effects of drones operated in close proximity to roadways on drivers' attention and performance. Two main research questions steered the procedure of the experiment:

- Do drivers display longer than average off-road visual fixation durations when exposed to roadside drone operations?
- How does the surrounding environment affect visual attention in drivers exposed to drone operations?

To address these research questions, data from 30 subjects of a previous OSU driving simulator study was reduced and analyzed in SPSS software.

5.2 Research Findings

Drones, once a small and specific market, are becoming more and more common in the world today. As their applications grow across sectors, and between both commercial and recreational operations, so does their presence near infrastructure and roadways. Many of these applications bring drone operations in close proximity to roadways, where they have the potential to distract and degrade driver performance.

The data analyzed in this experiment was originally collected by Hurwitz et al. (2018) in a separate simulator study. The project, funded by the Oregon Department of Transportation (ODOT) was a preliminary evaluation of driver distraction due to near-roadway drone operations; ODOT, like many other state departments of transportation, is researching the use of drones in transportation related applications. The project explored three factors (distance from roadway, flight pattern, and physical environment) of a roadside drone operation event and their influence on several facets of driver performance. This thesis focuses only on effects on drivers' visual attention, evidenced by total fixation durations.

In establishing the overall effect of drone operations on driver visual attention, subjects' on-drone TFDs during drone exposure events were analyzed. Rather than comparing TFDs during drone operation exposure events to an assumed baseline off-road TFD of zero, accurate baselines were created for each subject. For every participant, a segment with length equal to an average drone event was fitted with the same “roadside” AOI (capturing all right-side off-road glances) as the drone events. This was done because drivers do not typically allocate 100% of their visual attention to the road itself; it is common to glance at off-road elements from time to time. Creating control segments from participants’ own experiment files is the most accurate baseline, rather than determining them from normal driving data or assuming off-road TFDs to be zero.

The results of the ANOVA test showed an effect on off-road TFD at the 95% confidence level for both rural and urban environments. In the rural category, the two significant scenarios were both of the 0 ft offset division, while the only significant urban scenario was the 0 ft offset with a takeoff flight pattern. These findings illustrate that roadside drone operations can be distracting to drivers, but primarily in minimal proximity to roadways (0ft).

Further questioning the differences between the effects in rural and urban environments, a T-test was implemented to examine average offroad glance percentages during drone events. The test found no significant difference between urban and rural environment percentages. Despite urban driving environments having more visual clutter around the drone operation.

5.3 Future work

The results of this thesis suggest that roadside drone operations are distracting to drivers. Potential future work could include:

- Evaluating various tools and methods for warning/preparing people for the exposures (thus minimizing distraction potential)
- Varying drone operation appearance (pilot/spotter out of sight, multiple drones simultaneously)
- Testing driver reaction to hazards requiring immediate attention (pedestrian crossings, forward car braking), and

- Analyzing driving experience as a variable in drone distraction (69% of participants in this study have been driving under 10 years, so it is difficult to make assumptions based on this data set alone).

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