HAZARD PERCEPTION TRAINING FOR ADOLESCENTS WITH AUTISM SPECTRUM DISORDER ON THE INTERACTIVE DRIVING SIMULATOR: USING EYE TRACKING TECHNOLOGY TO DETERMINE EFFECTIVENESS

By

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Rationale: Driving is an important developmental milestone for all adolescents as it increases their independence and ability to participate in vehicle-dependent activities. However, adolescents with high functioning autism spectrum disorder (HFASD) are less likely to obtain licenses and drive independently due to characteristics related to their diagnosis. Although current research exists exploring the efficacy of driving simulator training for adolescent drivers with HFASD and eye tracking, there is a gap in the literature related to training on the simulator and its effects on overall driving performance and hazard perception and response in this population. **Purpose:** This pilot study utilized a training protocol on the simulator that included hazard perception to determine its effect on overall driving performance. Eye tracking technology was used to determine if there was a change in hazard perception and response to non-social and social hazards after training. **Design:** This study was a one group, pretest-posttest intervention design. **Methods:** There were 17 participants between the ages of 15 and 22 with a self-reported diagnosis of ASD and a desire to learn to drive independently. Each participant completed a pre-test and post-test on the driving simulator while wearing eye tracking technology. Each participant completed a protocol of 30 learning modules with scenarios related to driving skills and hazard detection and response in one-to-one training. **Analysis:** Driving performance was measured by a quantitative score from a standardized observational tool for driving. Eye tracking measures including fixation duration, fixation count, and time to first fixation were analyzed using a Wilcoxon Signed Rank Test. **Results:** Participants significantly increased their overall driving performance scores pre-test to post-test. Results of hazard perception using eye tracking technology tended towards improvement overall, but specific hazard results were inconsistent and varied for both non-social and social hazards in terms of fixation duration, fixation count, and time to first fixation. **Discussion:** Findings from this study indicate driving simulator training related to hazard perception was effective in improving overall driving simulator performance in adolescents with HFASD. Additionally, findings indicate hazard perception and response differs for this population after hazard perception training, but specific eye tracking measures may increase or decrease, and results may not be specific to non-social or social hazards.

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Chapter 1: Introduction

Autism spectrum disorder (ASD) is a neurodevelopmental disability with social, communication, and behavioral challenges typically characterized by impaired social interaction, repetitive behavior, difficulty developing relationships, and difficulty communicating both verbally and non-verbally (American Psychiatric Association, 2013). The most recent Diagnostic and Statistical Manual of Mental Disorders (DSM) DSM-5 created an umbrella term autism spectrum disorder that offers in-depth descriptions of core features, with general examples to determine a child's need for clinical services (Lai et al., 2014).

As defined as a spectrum disorder, individuals with ASD have a wide range of symptoms with the severity of symptoms differing between individuals. The DSM-5 specifies three levels of severity for ASD, Level 3 "requiring very substantial support," Level 2 "requiring substantial support," and Level 1 "requiring support" (American Psychiatric Association, 2013). For example, those that experience significant deficits in social interaction and restricted, repeated behaviors that interfere with all functioning would be classified with severity level 3. However, individuals that have difficulty initiating social interactions or have restricted, repeated behaviors that interfere with functioning in specific contexts would be classified with severity level 1. Although, the term high functioning autism spectrum disorder (HFASD) is no longer used in the DSM-5, it can be used to identify individuals with ASD classified as severity level 1. Before the DSM-5 changed terminology, studies found those with HFASD typically present with little language difficulty, high cognitive skills, and often succeed in higher education, secure full-time work, developed relationships leading to marriage and families, and live independently (Cederlund et al., 2008; Howlin, 2000; Levy & Perry, 2011). However, even those with HFASD, or ASD classified as severity level 1, still need assistance with everyday living skills and thus, need occupational therapy evaluation and intervention (Monahan, 2012).

In the United States, the Centers for Disease Control and Prevention (CDC) estimate the number of children with ASD every two years, using the largest ASD tracking system, The Autism and Developmental Disabilities Monitoring Network (ADDM) (Maenner et al., 2020). Currently, the CDC reports the prevalence of ASD in the United States as 1 in 54, with an estimated 2 million people diagnosed with ASD, compared to 2002, when the prevalence was only 1 in 150 (Maenner et al., 2020). This indicates the rate of children diagnosed with ASD has almost tripled in the last 20 years and a half-million people with ASD will be of driving age in the coming decade (Lubin & Feeley, 2016).

In the *Occupational Therapy Practice Framework: Domain and Process* (2014), driving and community mobility is one of the identified instrumental activities of daily living (IADLs) in the domain of practice for occupational therapy practitioners (American Occupational Therapy Association, 2014 [AOTA]). Typically, IADLs require higher level thinking and organizational skills with driving being the most complex, largely due to the unpredictable and dynamic nature of the environment in which driving is performed. Thus, an emphasis needs to be placed on the importance of occupational therapy to address the needs of these individuals from a perspective of complex IADLs, including driving to live independently, especially as the prevalence of children with ASD has increased.

Research has shown driving is essential to helping those with ASD gain employment, participate in social activities, and attain a high quality of life (Curry et al., 2017; Huang et al., 2012; Lubin & Feeley, 2016). However, driver’s license rates in the adolescent population with ASD are lower than rates in the general population (Curry et al., 2017; Lubin & Feeley, 2016).

This is likely because characteristics of ASD (e.g., executive functioning issues, impaired motor coordination, problems with attention, rigidity in thinking, increased levels of anxiety, understanding non-verbal communication) are barriers to independent driving (Almberg et al., 2017; Classen, Monahan, & Wang, 2013; Daly et al., 2014; Reimer et al., 2013).

Obtaining a driver's license is an intricate process, where each new driver must acquire a set of new and complex skills. This process may be impossible for adolescents with ASD classified as level 2 and 3. It may also be more difficult for adolescents with HFASD or those with severity level 1, making them less likely to obtain a driver's license, despite its importance for working and/or living independently. Therefore, occupational therapy practitioners are in a unique position and have the requisite education and skill set to assist those with HFASD in driving skills to increase the likelihood they achieve their independent living goals (Monahan, 2012) as driving is within the occupational therapy practitioner's scope of practice (AOTA, 2014). In fact, occupational therapy practitioners have an ethical obligation to assist adolescents with HFASD with obtaining a license, and they should consider how to address the skills and abilities needed to increase safety and fitness to drive (Hunt & Slater, 2012; Monahan, 2012). Occupational therapy practitioners must develop and use evidence-based guidelines, resources, and studies which help support the opportunities to increase the likelihood those with HFASD will achieve goals of becoming independent and driving themselves.

One evidence-based method for increasing fitness to drive and safety for adolescents with HFASD is using interactive driving simulators. Driving simulators offer clinicians a safe, objective alternative to on-road driving (Classen, 2017; Mullen et al., 2011). Studies have shown that simulators can demonstrate the differences between driving skills in adolescents with HFASD and their typically developing peers, while others use simulators to attempt to train driving skills in adolescents with HFASD (Brooks et al., 2016; D. J. Cox et al., 2017; S. M. Cox et al., 2016). However, there are few evidence-based studies demonstrating successful intervention strategies or protocols. Therefore, studies designed to develop interactive driving simulator training protocols for adolescents with HFASD should continue to be investigated to determine the most effective methods of intervention.

Chapter 2: Literature Review

Model of Driving

Michon's (1985) *Hierarchy of Driving Behavior* categorizes driving into three levels of behavior: operational, tactical, and strategic (Michon, 1985). An updated description of Michon's levels of behavior can be used to more fully understand what these levels of driving behavior indicate and how they relate to the skills needed to learn to drive and continuously drive safely (Transportation Research Board [TRB], 2016).

- The Operational level: Controlling the motor vehicle through the physical actions of steering the wheel, moving or shifting gears, pressing the accelerator or brake, or using the turn signals. Draws upon skills that are overlearned and habitual so that performance of such actions is largely automatic.
- The Tactical level: Executing maneuver control over the vehicle to complete a goal directed trip in response to prevailing conditions; including behaviors that are typically learned and practiced such as maintaining lane position or speed, obstacle avoidance, gap acceptance, obeying traffic signals, turning, and passing other vehicles.
- The Strategic level: The general planning of a trip, including trip goals, route, and modal choice with the associated costs and risks involved; This also includes the ability to adapt plans when necessary such as changing a route due to a crash or construction, needing to make an unexpected stop (e.g., to use a bathroom), a change in a trip's goals, or seeking help if lost.

Learning to Drive

Driving is considered an integral part of development and maturation for teenagers because they gain the ability to transport themselves to vehicle-dependent activities independently when they acquire their license. The U.S Department of Transportation estimates 87% of those who are age-eligible to drive have a license (U.S. Department of Transportation: Federal Highway Administration, 2014) and a study by Huang et. al (2012) found teens with driver's licenses were more likely to hold a paid job, attend full-time regular education, and plan to go to college than teens who were age-eligible for a license but did not have one.

The process to obtain a license is different depending on where a person lives as state governments have jurisdiction over transportation laws. Most states in the U.S utilize a Graduated Driver Licensing (GDL) policy to provide adolescent novice drivers with a clear process to work towards obtaining a driver's license. GDL policies typically include driver's education and supervised driving requirements as well as restrictions about when and how adolescents can drive (Chen et al., 2006). Driver's education requirements vary from state to state, but in North Carolina, driver's education includes 30 hours of classroom instruction followed by six hours of behind the wheel instruction. However, in all states, driver's education includes the "rules of the road" and the basic driving skills of steering, using pedals, lane maintenance, turning, and speed maintenance.

As driving instructors typically teach driver's education classes to adolescents, it is important to understand a driving instructor's purpose and teaching role related to Michon's *Hierarchy of Driving Behavior*. Driving instructors focus on teaching adolescents how to handle and drive a motor vehicle (operational level skills) and knowledge about the rules of the road (tactical level skills) (Dickerson et al., 2018). They typically do not focus on teaching strategic skills, such as adapting to the environment or planning routes. Once a teenager completes driver's education, they obtain a driver's permit and can drive when accompanied by a licensed adult driver. Teenagers obtain the most practice driving with supervision and learn the most strategic skills when they have their driver's permit (Simons-Morton & Ouimet, 2006). After a specific amount of time with a driver's permit, a teenager takes a road test to gain a driver's license, which allows them to drive a vehicle without supervision.

Driving Simulator

Driving simulators are computer-controlled technology made to mimic driving in a virtual context, usually used for training or research. Driving simulators are typically divided into two groups, high fidelity research or clinical driving simulators (Classen, 2017). High fidelity research simulators are systems that include actual vehicles and extensive visualization needing technicians to program; typically, complex, expensive, and used for driving-related research in multiple fields. Clinical driving simulators are smaller systems with only the main controls of a vehicle and are designed for health professionals for rehabilitation or research. Clinical driving simulators, like high fidelity simulators, are also representative of driving on real roads with the software responding interactively with the "driver's" responses. Interactive driving simulators designed for clinical use typically have a driver cab, monitors to visualize the driving scenarios, and driver controls (e.g., steering wheel, gas/brake pedals, turn signals). Interactive driving simulators provide an impression of driving, are safe, use relatively less space, and are cost-effective. They allow practitioners and/or researchers to obtain objective data and create standardized evaluation or intervention protocols (Classen, 2017).

Many studies have reported driving simulation has moderate to high reliability and is appropriate for measuring driving performance (Classen & Akinwuntan, 2017). Driving simulation has also demonstrated concurrent validity (predicts similar outcomes) with driving on real roads (Shechtman et al., 2009). Additionally, several studies have found simulated driving behavior has relative validity (approximates driving behavior) with on-road driving behavior (Mullen et al., 2011; Bella, 2008; Lee et al., 2003).

Driving simulators have been used in research with multiple populations and diagnoses including, but not limited to developmental disabilities or intellectual disabilities (Brooks et al., 2014), veterans (George & de la Perrelle, 2017), older adults (Lee et al., 2003; Selander et al., 2013), Multiple Sclerosis (Harand et al., 2018), Parkinson's disease (Devos et al., 2016) stroke or brain injury (Blane et al., 2018), and ASD (Brooks et al., 2016; D. J. Cox et al., 2017; N. B. Cox et al, 2012; S. M. Cox et al., 2016).

HFASD and Driving

ASD, even for those that are classified with severity level 1, can affect an adolescent's ability to obtain a license. There is evidence that those with ASD obtain licenses less often than their typically developing peers. Lubin and Feeley (2016) found only 24% of adults with ASD report driving themselves, as most transportation needs are met by a family member or friend, and 75% of adults in the general population report driving themselves (Lubin & Feeley, 2016). This incongruity in driving rates between those with ASD and the typically developing population was supported by another study by Curry et al. (2017). Curry found 83.5% of eligible adolescents attain a driver's license, but only 33% of eligible adolescents with ASD attain a driver's license (Curry et al., 2017).

Most researchers agree the core characteristics or associated deficits of ASD, such as motor deficits (Brooks et al., 2016; Classen, Monahan, & Brown, 2014; Classen, Monahan, & Hernandez, 2013), visual-perceptual deficits (Bishop et al., 2017; Sheppard et al., 2010; Wang et al., 2015), cognitive deficits (S. M. Cox et al., 2016; Hill, 2004), non-verbal communication deficits (Almberg et al., 2017; Chee et al., 2017; Classen & Monahan, 2013; Daly et al., 2014), and a higher rate of anxiety (Chee et al., 2015; N. B. Cox et al., 2012; Reimer et al., 2013), present potential barriers to driving and could explain the discrepancy between driving rates of those with ASD and the general population.

Performance Skills for Driving

Performance skills are the skills required for a person to complete an activity (AOTA, 2014). Driving is a complex IADL which requires motor, process, and social communication skills. It also requires specific body functions, including but not limited to mental, sensory, and movement functions.

Motor/Physical Factors

Motor skills are necessary to plan out motor actions while operating the vehicle, such as pressing the gas or brake pedals, or steering (Dickerson & Niewoehner, 2012). A person has motor deficits when they have difficulty with certain motor skills. Motor deficits are decreased performances in gross motor or fine motor skills, sometimes manifested by increased clumsiness and instability or decreased coordination.

Individuals with HFASD may have motor deficits including reduced accuracy of hand movements, poor bilateral coordination of the hands, poor coordination of upper and lower limbs, and poor hand-eye coordination, as reported in the literature (Fournier et al., 2010). In fact, Fournier et al. (2010) conducted a meta-analysis of motor coordination in the ASD population. The results determined motor coordination deficits were prevalent across multiple studies and therefore should qualify as a core symptom of ASD. Fournier et al. (2010) concluded there was a consensus amongst the studies which indicated those diagnosed with ASD had deficits in balance, gait, motor planning, and upper and lower extremity function. These deficits are likely to affect a driver's ability to react to unexpected events in their environment, maneuver the car, and control the speed of the car using the gas or brake pedals.

In a study comparing the motor skills of adolescents with HFASD to neurotypical controls (Brooks et al., 2016), the participants with HFASD took significantly longer to complete motor-related tasks without errors on a driving simulator. Specifically, participants with HFASD took on average 30-35 minutes more to complete the motor-related tasks without errors (Brooks et al., 2016).

Similarly Classen, Monahan, and Hernandez (2013) found upper-motor deficits could have caused an increase in lane maintenance errors when driving on a simulator. In their study, drivers in the HFASD group made significantly more lane maintenance errors when compared to the control group. The researchers hypothesized decreased upper-extremity motor deficits and motor coordination created a slower motor response when making turns, causing the HFASD drivers to exit their lane more often than controls (Classen, Monahan, & Hernandez, 2013). When driving in a simulator, the researchers also found adolescent drivers with HFASD made significantly more speed regulation errors than drivers in the control group. They hypothesized motor deficits in the HFASD population provided an explanation for the statistically significant difference when driving (Classen et al., 2014).

These studies provide evidence that motor deficits will affect driving in those with HFASD. In relation to Michon's *Hierarchy*, motor deficits are going to affect a driver's operational level of skills. In interventions to assist drivers with HFASD, operational skills may need to be focused on first to ensure they are at an appropriate level for safe driving.

Sensory/Perceptual Factors

Sensory-perceptual skills are required to respond to external cues from the car or surrounding environment. One of the most important sensory-perceptual skills related to driving is visual-perceptual skill. Visual-perceptual skills are those needed to take visual information from the environment, analyze, and interpret it to produce a motor action (Classen, 2017). Deficits in visual-perceptual skills would affect a driver's ability to comprehend and react to visual information from the driving environment.

Individuals with HFASD are shown to be slower to visually perceive and react to hazards in the driving environment (Bishop et al., 2017; Sheppard et al., 2010). This could be due to adolescents with ASD having slower visual scanning velocities than their typically developing peers. In fact, Wang et al. (2015) compared 20 individuals with ASD and 19 control individuals to obtain detailed information about gaze differences. This research differed from other eye gaze studies by providing complex visual stimuli similar to what people see in the real world. The visual stimuli included multiple dominant objects with non-social and social objects to make the scenes as close to real life visual stimuli as possible. Individuals with ASD were significantly slower to visually fixate on faces or hand gestures when compared to controls. It was hypothesized this was due to slower scanning velocities and despite object distribution in a photo, adolescents with ASD tended to focus on the center of a picture. Specifically, adolescents with ASD looked at the center of an image two times as much as the typically developing controls. This tendency to look at the center of an image could adversely affect driving; important information comes from all areas around the car and drivers must scan in different directions. If their focus is in the center, drivers will miss information from the side view mirrors and left and right areas outside of the car (Wang et al., 2015).

Cognitive/Processing Factors

Cognitive skills involve planning or managing an activity, and can also involve quick decision making and judgments, which lead to specific actions (Dickerson & Niewoehner, 2012). The higher level cognitive-related skill of *executive functioning* includes planning, self-regulation, prioritizing, working memory, and problem-solving (Hill, 2004). These skills are essential for driving as they help a person make decisions and act when the driving environment changes, or they are required to complete a driving maneuver. For example, planning is essential for drivers to decide on their route, speed, and how they react to changes in the driving environment. The plan must be consistently revised based on information from traffic lights, road signs, and other drivers. Another aspect of executive functioning is mental flexibility or set-shifting, which refers to a person's ability to shift actions dependendent on changing circumstances (Hill, 2004). Mental flexibility is important for driving as conditions on the road are constantly changing. When weather, traffic, or traffic signals change, drivers are required to set shift to a different action and may need to change the route of the car.

Studies have linked difficulties with executive functioning to poorer driving performance in those with HFASD (S. M. Cox et al., 2016; Hill, 2004). Navigating, an executive function, is directly related to the strategic skill level in Michon's *Hierarchy*. It requires a driver to plan and follow a route to arrive at a destination. Adolescents with HFASD have demonstrated a deficit in general navigating when compared to their typically developing peers (Hill, 2004). A 2013 study by Reimer et al. found a shift in gaze when drivers with HFASD were required to drive and simultaneously complete a cell phone task, a higher cognitively demanding situation. During this high cognitively demanding task, drivers with HFASD shifted their attention from the roadway towards a less complex area, either to the sides of the road or the sky. This increased cognitive demand may have affected their ability to respond quickly to hazards or a change in the roadway environment (Reimer et al., 2013). In 2016, Cox et al. further studied the impact of executive functioning difficulties and their relationship to working memory (i.e., temporarily storing and managing information used to guide behavior and carry out specific actions) on tactical driving including lane positioning, speed, turning, and traffic signals using a simulator. The study found adolescents with HFASD had deficits in their working memory, tested by their ability to remember road signs while performing a task which required accurate steering and braking performance. Using working memory had a negative effect on steering and braking performance in adolescents with HFASD (S. M. Cox et al., 2016). This may indicate interventions to assist drivers with HFASD should decrease focus on executive functioning skills (i.e., strategic level), until motor skills (i.e., operational level) are sufficiently practiced and the driver is competent.

Social Interaction factors

Social interaction factors are those that can "be observed during the ongoing stream of a social exchange" (Fisher & Griswold, 2014, p. 1241). During a social exchange, communication typically occurs to increase understanding. Communication is the words, behaviors, and signals we use to convey, and exchange information or feelings. Verbal communication specifically includes the words we speak and the sounds we use when speaking. Non-verbal communication is separate from the verbal words people use and can include body language, eye contact, facial expressions, gestures, pitch, and tone of voice (Craighead & Nemeroff, 2004). Difficulties with non-verbal communication can affect a driver's ability to communicate with other drivers and understand the non-verbal information they convey.

Adolescents with HFASD demonstrate difficulty anticipating the intentions or actions of other drivers and may misinterpret non-verbal cues when driving (Almberg et al., 2017; Chee et al., 2017; Classen & Monahan, 2013; Daly et al., 2014). This can be especially difficult when the rules of the road are ambiguous (e.g., parking lots, exiting driveway, arrival at a four way stop simultaneously) or when other drivers do not adhere strictly to rules of the road (e.g., neglecting to use a turn signal, running a yellow light) (Monahan, 2012). Classen and Monahan (2013) found adolescents with HFASD had increased signaling errors in a simulator when compared to their typically developing peers. The researchers believed this was due to the participants' deficit in non-verbal communication, resulting in their decreased understanding of the importance of signaling (Classen & Monahan, 2013). In another study, Almberg et al. (2017) had 12 adolescents with HFASD complete a questionnaire resulting in reported problems interacting with other road users. The participants reported issues interpreting traffic situations and anticipating what other road users would do in different driving situations (Almberg et al., 2017). Another study reported deficits in non-verbal communication caused adolescents with HFASD to have a decreased ability to predict movements or objectives of other drivers or pedestrians on the road, which could potentially lead to more accidents (Daly et al., 2014).

Anxiety. Anxiety is a feeling of worry, unease, or fear, typically related to an impending event (American Psychological Association, 2020) and symptoms can include panic, shortness of breath, sweating, nausea, and higher blood pressure or heart rate. In a study on driving behavior, adolescents with HFASD were more likely to have higher heart rates when driving, which could be an indicator of higher anxiety (Reimer et al., 2013). This phenomenon is supported by the self-reported increased anxiety rates of those with HFASD (Cox et al., 2012). Additionally, in a study using Q-methodology (an inductive and deductive approach to understanding viewpoints) young adults with HFASD defined the viewpoint "I am anxious when I drive and will only drive when I need to'' as accurate (Chee et al., 2015). Anxiety may make driving a stressful and mentally demanding experience, especially with difficult driving maneuvers which can contribute to errors that may lead to crashes. Alternatively, higher anxiety rates could be one reason adolescents with HFASD have lower rates of licensure; increased anxiety while driving could contribute to the decision to not drive. **Driving Simulation**

Evaluation

Driving simulators allow for the assessment of adolescent drivers with HFASD in more challenging, but less dangerous environments, as scenarios can include environments that may not be immediately available to drivers (e.g., urban environment for those living in rural areas) or hazards that are not realistic for driver training (e.g., pedestrian running in front of car). Researchers have found adolescents with HFASD have difficulty with speed, lane maintenance, signaling, car maneuvering, steering, and multi-tasking while driving (Brooks et al., 2016; Classen, Monahan, & Wang, 2013; D. J. Cox et al., 2017; S. M. Cox et al., 2016; Reimer et al., 2013; Ross et al., 2017). A study by S.M. Cox et. al (2016) found adolescents with HFASD had significantly slower reaction times when steering in a driving simulator, which could affect their ability to avoid crashes and drive safely. A 2013 study by Classen et. al found adolescents with HFASD were more likely to make more types and a larger number of driving errors in a simulator than their typically developing peers, especially related to visual acuity, visual-motor integration, and motor skills (Classen, Monahan, Brown, & Hernandez, 2013). Additionally, a 2017 study by D.J. Cox et al., also found adolescents with HFASD were more likely to make driving errors than their neurotypical peers, as demonstrated by their overall tactical driving composite score. The study found adolescents with HFASD performed worse on multiple tactical driving variables, including crashing, swerving, lane maintenance, and tailgating (D. J. Cox et al., 2017).

Training

Driving simulators have given reliable and detailed information about the characteristics of those with HFASD due to their safe use compared to on road driving (Classen, Monahan, & Hernandez, 2013; S. M. Cox et al., 2016; Reimer et al., 2013). It is possible driving simulators can also be appropriate and functional tools to improve driving skills in the HFASD population with an appropriate trainer. Although there are currently no best practice protocols for simulator training, the following studies investigated the efficacy of driving simulation for training drivers with HFASD.

A simulator was used to compare motor driving performance of adolescents with HFASD and their neurotypical peers and improve motor driving performance through simulated driving tasks (Brooks et al., 2016). There were 31 neurotypical control participants and 10 participants with HFASD in the study. Participants completed a total of 18 simulated driving tasks relating to steering and using the car's pedals. The tasks increased in difficulty and each participant had a maximum of five attempts to complete a task. The results of the study showed the number of trials to achieve error free performance on the more difficult tasks were not significantly different between the HFASD group and the control group. These interactive exercises were appropriate at balancing any existing differences in motor skills related to driving between the two groups (Brooks et al., 2016). This finding indicates the simulator training was effective at addressing motor skills for driving in the adolescent population with HFASD.

The researchers in the Brooks et al. 2016, study found simulator training to be effective for those with HFASD, but does it compare to on road driving for this specific population? A study explored this question by comparing *Virtual Reality Driving Simulator Training* (VRDST) to routine training on the road in adolescents with HFASD. Routine training consisted of instructing participants to follow the DMV training manual and having them document on road driving experiences. The VRDST consisted of between eight and 12 one-hour training sessions on a driving simulator. There were 51 participants with HFASD, and they completed pre-assessments and post-assessments on the simulator. Virtual reality driving simulation training resulted in significantly better overall performance post-assessment on driving. The specific variables effected were steering and speed control, meaning the VRDST participants demonstrated fewer instances of crossing the midline, swerving, tailgating, and speeding than the routine training participants (D. J. Cox et al., 2017).

Another study by Meeks (2017) included 15 adolescents with HFASD between the ages of 14 and 23 to determine the efficacy of a driving simulator as a training tool. Each participant moved through a standardized protocol of scenarios one-on-one with an instructor. The scenarios each participant practiced were related to 10 critical events including turn signals, stop signs, traffic lights, speed and lane maintenance, hazard identification and avoidance, right/left turns, lane changes, and navigation. The training was individualized so that each participant moved through training at their own pace, beginning a new skill once they received an 80% on two consecutive drives related to the skill. The researcher used a standardized driving evaluation, the *Performance Analysis of Driving Ability (P-Drive)* (Patomella, 2014), to compare pre-test and post-test scores of three drives and found significant results, indicating the participants improved their driving performance. This study suggests that using the driving simulator is a potentially effective tool to improve driving skills in those with HFASD.

Hazard Perception, Recognition and Response

One of the important aspects of driving critical to avoiding collisions is visually scanning the environment and perceiving hazards to respond appropriately to visual stimuli in the driving environment. A study by Underwood (2007) found visual scanning and attention was a differentiating factor between novice and experienced drivers and that decreased visual scanning was a risk factor for motor vehicle collisions. While all teens need to learn when to scan the environment and react to hazards, studies have found eye gaze, visual attention, visual scanning, and hazard perception differences between adolescents with HFASD and their typically developing peers (Bishop et al., 2017; Classen, Monahan, & Wang, 2013; Grynszpan & Nadel, 2015; Guillon et al., 2014; Reimer et al., 2013; Sheppard et al., 2010; Wang et al., 2015). This suggests that an important skill for driving may be affected in adolescents with ASD, making licenses more difficult to attain, collisions more common, and specific driving instruction related to visual scanning and hazard perception more essential to safe and independent driving for this population.

Reimer et al.'s (2013) study found statistically significant gaze differences by determining the exact gaze positions of adolescents with HFASD while in a car, compared to controls. The study reported the gaze of drivers with HFASD was 44% higher than typically developing controls (Reimer et al. 2013) when looking out the windshield area of the car. Drivers with HFASD were looking at the horizon more often than they were looking at objects lower in the visual field, such as oncoming vehicles or the dashboard. This visual gaze preference could cause them to miss pertinent information in the most active portions of the roadway (Reimer et al., 2013).

Adolescents with HFASD also tend to shift their visual attention to social and non-social stimuli in different ways than their typically developing peers (Guillon et al., 2014; Sheppard et al., 2010). Social stimuli are used to describe faces and people, while non-social stimuli are unrelated to people such as shapes, objects, or locations. For example, Guillon et al. (2014)

reviewed multiple eye tracking studies and found those with HFASD exhibit decreased visual attention to social stimuli, such as faces and people, when compared to typically developing individuals. They found the visual attention of the participants in situations with multiple people or complex social situations, and in situations comparing naturalistic and acting behavior, was significantly different for those with HFASD. This suggests visual attention was context-specific, and if contexts changed so would visual attention (Guillon et al., 2014).

Commonly on the road, the context changes when a driver perceives a hazard and must take some action to address it. Sheppard et al.'s (2010) study explored drivers' ability to recognize and respond to hazard scenarios. They used 10 videos of driving scenarios, each containing a hazardous situation to determine hazard responses in 23 participants with HFASD and 21 control participants. They defined a driving hazard to the participants as "an event that occurs on the road whilst you are driving along that would make you have to consider taking some kind of action to avoid an accident" (Sheppard et al., 2010, p. 506). Participants were required to hit a button as soon as they noticed a hazard in the video and then were required to identify the hazardous situation for a researcher. Results determined participants with HFASD identified fewer socially relevant hazards, such as pedestrians or cyclists, yet identified non-social hazards (e.g., car, bus) the same as control participants. Also, the participants with HFASD were significantly slower at responding to all hazards. Two explanations for this result were proposed: the participants may have become aware of the hazard later than the controls, or they perceived the hazards at the same time as controls, but motor deficits caused them to respond more slowly (Sheppard et al., 2010).

Another study by Sheppard et al. (2017) explored these proposed explanations by combining hazard videos with eye tracking technology (Sheppard et al., 2017) . A total of 15 participants with HFASD and 16 control participants watched driving scenario videos containing hazardous situations and were asked to press a key when a hazard occurred. The results of this study determined the control participants were significantly faster at fixating (or looking) at a hazard when compared to the HFASD group. However, once participants with HFASD fixated on a hazard their response-time to key-press was not significantly different than the control group, suggesting a motor response occurred just as quickly in the HFASD group as it did in the control group once fixation occurred. Interestingly, this study also found no statistically significant differences between groups in accuracy or response time to social and non-social hazards, unlike similar studies. However, researchers did report reaction time to hazards approached significance for participants in the HFASD group reacting slower than participants in the control group (Sheppard et al., 2017).

These results were similar to Bishop et al.'s (2017) work in which 16 drivers with HFASD and 16 control drivers drove a simulator scenario with multiple hazard situations. Data from the simulator showed the HFASD group had no significant differences in their reaction times to social and non-social hazards. However, when drivers with HFASD were compared to the typically developing controls, the control group had significantly faster reaction times to social hazards, increasing the likelihood of avoiding a motor vehicle accident with cyclists or pedestrians (Bishop et al., 2017).

Building on previous work with adolescent drivers with HFASD and their identification and driving response to hazards, studies have attempted to mitigate the visual scanning and gaze differences in adolescents with HFASD by combining eye tracking and driving simulators (D. J. Cox et al., 2017; Wade et al., 2017; Zhang et al., 2017). A novel virtual reality driving simulator, *The Virtual Reality Adaptive Driving Intervention Architecture* (VADIA), was created to be used with eye tracking. The VADIA combines a virtual driving environment with sensory peripherals to create a simulated, on the road, driving experience. The simulated on-road driving experience is meant to as closely match reality as possible; physical and sensory elements of driving on a real road are presented by the simulator system (Evans & Lavallière, 2017). Wade et al. (2017) tested two modes using the VADIA, performance-based and gaze-contingent, to train adolescents with HFASD and improve overall driving skills. Participants in the performance-based group completed tasks using the non-adaptive (i.e. without gaze-sensitivity) version of VADIA. They were permitted a maximum of three trial errors per driving assignment and a fourth trial error resulted in failure of the assignment which could not be re-attempted. Participants in the gaze-contingent group used an adaptive version of VADIA where trial errors were classified as either performance errors or gaze errors, and drivers had to follow the rules of the performance-based system, while also paying attention to salient aspects of the driving environment. Drivers who failed to look at any one of these important objects during trials (e.g., oncoming vehicles, traffic lights, etc.) received a gaze error. A maximum of three gaze errors and/or three performance errors were permitted in the gaze-contingent system, but a fourth error in either category resulted in an assignment failure. Researchers in this study found both the performance-based and gaze-contingent modalities significantly reduced driving trial errors in the VADIA after training (Wade et al., 2017).

However, there were some limitations to the scope of the VADIA study (Wade et al., 2017). First, the VADIA used eye tracking technology to determine whether each participant failed or passed an assignment. There was no specific training given to the participants to target improvements in their eye tracking and hazard perception skills. A more specific training protocol using a simulator and cues from a researcher could be used in other experiments to specifically affect scanning, hazard detection, and other driving skills needed on the road. Also, the VADIA was specifically created and structured by the researchers for these experiments and is not commercially available. It would be difficult for other researchers to repeat this experiment without access to the VADIA itself (Wade et al., 2017). However, other researchers have emphasized the importance of using driving simulators in combination with eye tracking technology and hazard training to further explore its efficacy in this population.

In fact, Sheppard et al. concluded that specific training programs that use eye tracking or facilitate hazard perception and focus on visual scanning will be beneficial to those with HFASD (Sheppard et al., 2010). Similar to the VRDST (D. J. Cox et al., 2017) and motor performance training (Brooks et al., 2016) studies, this study will use a driving simulator to train driving skills in adolescents with HFASD. This study will also be using performance-based errors to determine competence before moving further in the simulator protocol similar to the VADIA study (Wade et al., 2017). However, unlike the VADIA study, this study will use a commercially available driving simulator (STISIM OT Drive) and a specific simulation protocol focused on both general driving skills and gaze, visual scanning, and hazard perception/response skills to train adolescent drivers with HFASD (Wade et al., 2017). Also, participants in this study will have unlimited attempts to practice driving learning modules until competence is achieved and will not fail assignments. Lastly, this study will use eye tracking in the pre-test and the post-test to determine if hazard perception and response changed for the adolescent drivers with HFASD after training.

Summary

Driving is an important developmental milestone for all adolescents, as it increases their independence and their likelihood to hold a full-time job, receive an education, and attend college. However, obtaining a license is typically more difficult for adolescents with HFASD due to characteristics and symptoms related to their diagnosis. Occupational therapy practitioners have an ethical obligation to address difficulties with driving as driving and community mobility is within their scope of practice and they have the knowledge and skills to support adolescents with HFASD in learning to drive. Adolescents with HFASD typically have high cognitive skills and little language difficulty, but they may also have specific characteristics and symptoms that make driving a challenging, but obtainable goal.

Therefore, occupational therapy practitioners and researchers need to create a clearer picture and more evidence-based options to assess and increase fitness to drive for adolescents with HFASD. Clearly, the evidence supports that driving simulators can be used to train and evaluate driving skills in adolescents with HFASD (Brooks et al., 2016; Classen, Monahan, & Hernandez, 2013; D. J. Cox et al., 2017; S. M. Cox et al., 2016) and are a safe, low-cost, objective method (Classen, 2017; Bella, 2008; Lee et al., 2003). Also, studies have shown visual scanning of the environment and hazard perception and response are essential factors to drive safely and avoid collisions (Underwood, 2007). However, studies have shown adolescents with HFASD exhibit differences in eye gaze, visual attention, visual scanning, and hazard perception/response when compared to their typically developing peers. (Bishop et al., 2017; Reimer et al., 2013; Sheppard et al., 2010). Studies have used using eye tracking technology to further explore these differences as it adds the ability to understand in real-time when and where drivers with HFASD are looking, especially related to their response to social and non-social hazards (D. J. Cox et al., 2017; Sheppard et al., 2017; Zhang et al., 2017). The VADIA study by Wade et al. (2017) found a performance-based non-gaze contingent training protocol and an eye tracking gaze-contingent training protocol increased driving skills in those with HFASD (Wade et al., 2017). Although these studies have explored eye tracking and training on the simulator for adolescents with HFASD, there are still gaps in the literature. Studies have not yet explored whether a training protocol focusing on hazard perception and response can improve driving skills in adolescents with ASD or used eye tracking technology to determine if hazard perception and response to social and non-social hazards changes after driving simulator training. Thus, the purpose of this study will be to determine if training on an interactive driving simulator will improve the social and non-social hazard perception and driving performance of adolescents with HFASD.

Specifically, the research questions are: 1) is there a significant difference between pre- and post-training in overall driving performance scores as measured by a standardized observational tool designed to measure fitness to drive and 2) is there a significant difference between the pre- and post- time a person spends looking at a hazard (i.e., fixation duration), how many times a person looks at a specific hazard (i.e., fixation count), and how long it takes to look at a hazard once it is visible (i.e., time to first fixation)?

Chapter 3: Methods

Design

The design is a one group, pretest-posttest intervention design using outcome measures from eye tracking technology and outcome measures from observation of driving performance on an interactive driving simulator using a standardized observation tool. The intervention is the completion of structured learning modules with scenarios on an interactive driving simulator to improve hazard perception and response.

Participants

The target population was adolescents with HFASD who were not driving independently. A total of 17 participants were recruited through convenience/volunteer sampling by contacting the Autism Society of North Carolina, organizations that work with the population with ASD, personal contacts, through email and posted advertisements. Inclusion criteria was adolescents age between the ages of 15 and 22 years, self-reported diagnosis of ASD, and had a desire to learn to drive. Participants were excluded from the study if they had known motion sickness, had extreme behavioral issues or other significant neurological conditions that would affect driving behaviors. The inclusion criteria were chosen because 15 is the legal driving age in North Carolina. Participant demographics were obtained and are described in Table 1. Participants' mean age was 17.18, standard deviation (SD]=1.81. There were 14 males and 3 females with a variety of driving experience. A large group of participants (6) had no driving experience at all and two participants had participated in other training on the driving simulator. Approval from the Institutional Review Board of East Carolina University was obtained (see Appendix A) and informed assent from the children and informed consent from the children's parent or guardian was obtained before collecting any data.

Table 1. Participant Demographics

N	**Age M(SD)**	**Males /Females**	**Driving Experience Level**			
17	17.18 (1.81)	14/3	None	Simulator	Driver's Ed	Learner's Permit
			6	2	5	4

Equipment

Tobii Pro Glasses 2.

The study used the Tobii Pro Glasses 2 to collect eye-tracking data from the participants. The Tobii Pro Glasses 2 is a light-weight wearable eye tracker (see Appendix B) which takes gaze sampling frequencies at 50 or 100 Hz. It utilizes corneal reflection and dark pupil tracking to track eye movements and visual gazes. The head unit includes four eye cameras, gyroscope and accelerometer sensors, a 90-degree field of view in the scene camera, and a sound recording microphone. The head unit connects to a recording unit which allows for 120 minutes of recording time and downloads gaze data to an SD card (Tobii Pro, 2018a). The Tobii Pro Glasses 2 also come with a controller unit, which provides the researcher with a real-time video feed of where the participant is looking. The Tobii Pro Glasses 2 were found to have high accuracy and precision of gaze data in multiple lighting conditions, distances from targets, and gaze angles (Tobii Pro, 2017). Tobii Pro Lab was launched at the end of 2016 and reliability and validity of the system have not been established yet. However, the creators of the Tobii Pro Glasses 2 also created the Tobii Pro Lab to seamlessly work together to observe and analyze gaze recordings downloaded from the SD card in the recording unit. These systems were specifically made to use in combination to produce the most accurate eye tracking data.

WT-960 TRAN-SIT Car Transfer Simulator and STISIM OT DRIVE Simulator System.

This study also used the STISIM Driving Simulator System (Systems Technology Inc., Hawthorne, CA, USA) with STISIM OT Drive simulation software (Systems Technology Inc., 2013) to complete the pre-test and post-test. This clinical driving simulator has been used nationally and internationally in multiple studies and settings. The car “buck” or mock-up of a vehicle is the WT-960 TRAN-SIT (Advanced Therapy Products), a 48 in W and 60 in L mock-up car with functional doors, handles, and locks as well as a tilt steering wheel, gas, and brake pedals (Advanced Therapy Products, 2014). This mock-up car was fitted with three LCD screens which portray two side mirrors, a review mirror, and the animated driving environment of the STISIM. During the pre-test and post-test sessions, participants completed at least two orientation drives to learn or reorient themselves to how the simulator works.

DriveSafety RS 200.

This study used the DriveSafety RS 200 driving simulator with SimClinic Software (DriveSafety, Murray, UT, USA) to complete all hazard detection training sessions. During the simulator training sessions, participants completed a variety of driving simulator learning modules which included multiple scenarios available from the SimClinic software (Drive Safety Incorporated & Clemson University (2019). The scenarios ranged from easy to medium to hard and included hazards such as pedestrians, stop lights, bikers, dogs, and parked/moving vehicles.

Instrumentation and Outcome Measures

Tobii Pro Lab Analyzer Software

The Tobii Pro Lab Analyzer Software (Tobii, 2018b) was used to generate the eye tracking outcome measures. Each of these measures was related to areas of interest (AOIs), which in this case, were specific hazards in the driving simulator scenario. The first measure is *fixation duration* on AOIs. Fixation duration on AOIs is a measurement of the amount of time in seconds a participant spends looking at an AOI (hazard). The second measure is *time to first fixation* on AOIs which is a measurement of how long it takes a participant to look at an AOI once it is visible on the simulation screen. Finally, fixation *count* on AOIs was used. This is how many times a participant looks at a specific AOI while it is visible on the simulation screen.

The Tobii Pro Lab Analyzer software allows the replay and analysis of the recorded gaze data from each participant. The tools used included: manually mapped gaze points, areas of interest through excel files, and visual heat maps to analyze the data (see Appendix C). A diagram of the driving scene was created with the AOIs listed on the diagram. The diagram with each hazard encountered during the drive, was used to manually map each gaze point for each hazard in a scene (see Appendix D). Then, the software completed fixation-related metric analysis for each AOI. These numbers were then exported as an Excel spreadsheet to analyze.

P-Drive

The *Performance Analysis of Driving Ability* (P-Drive) (Patomella, 2014) is a standardized observational assessment tool developed by Ann-Helen Patomella. It is designed to evaluate driving performance on road and in a driving simulator. The *P-Drive* has scores for the following four areas: maneuvers, orientate, follow regulations, and attending/responding and a total score (Patomella, 2014). The *maneuvers* category includes items related to physically handling the car including steering, using the pedals, controlling the car's speed, and using the turn signals. The *orientate* category includes items related to listening, cognition, and positioning including planning, listening to instructions, keeping distance, and positioning on road. The *follows regulations* category includes items related to the "rules" of the road including yielding, obeying stops, and following speed regulations. The *attending/responding* category included items related to higher level cognition such as reacting, focusing, and problem solving. This category also included items related to awareness and response to various stimuli in the driving environment such as awareness to all directions outside the car, awareness of the mirrors, and response to regulatory signs, advisory signs, and fellow road users.

The manual has detailed descriptions/examples of how each item is scored (see Appendix E). Three items, 2 (changing gears), 7 (reversing), and 9 (wayfinding) were eliminated as they cannot be scored due to the nature of the driving simulator. Only behaviors that are directly observed are recorded and the areas include 25 actions or behaviors that could be observed while someone is driving. Each item on the score sheet is scored on a 4-point scale and each point correlates to a specific type of performance (4= competent performance, 3= hesitant performance, 2= ineffective performance, or 1= incompetent performance) (Patomella, 2014) (see Appendix F). Two trained raters scored each pre-test and post-test while the participant was on the simulator. After separately scoring, the raters then discussed the scores they gave for each item to ensure similar scores were obtained. If necessary, scores were adjusted during discussion by the two raters until there was less than a three-point difference between raters' total scores.

A study determined the *P-Drive* was a valid and reliable tool for measuring driving ability (Patomella et al., 2010). The *P-Drive* has acceptable person response validity, as 95% of drivers in the study demonstrated goodness-of-fit to the model (Patomella et al., 2010). Also, the

P-Drive had high correlation between raw scores and the interval score measures, indicating the raw scores for each item can be summed and used as a valid outcome measure (Patomella & Bundy, 2015). Additionally, the *P-Drive* was determined to have high predictive validity, as the positive predictive value= .95 and the negative predictive value= .90. This indicates the *P-Drive* was successful at predicting a passing or failing driving decision similar to the passing or failing driving decision determined by an occupational therapist using an on-road test, cognitive tests, and clinical characteristics of the participant (Patomella & Bundy, 2015). These high psychometric properties provide evidence that the *P-Drive* is an appropriate and informational driving performance outcome measure.

Procedure

After approval from East Carolina University's Institutional Review Board, potential participants were contacted. After initial contact, the participant (and parent if appropriate) read and signed assent and consent forms and completed a pre-testing session. The pretest session took approximately 75 minutes.

During the pretest session, the participant was fitted with the Tobii Pro Glasses 2. Once the glasses were calibrated, the participant was introduced to the STISIM simulator and completed two accommodation drives. When the accommodation drives were completed, and the participant felt comfortable with the simulator, Road Test Version 1 or Road Test Version 2 was randomly assigned. At post-test, the participant was tested on the other version. Although these two versions have virtually identical hazards, the events are in different orders and slightly adjusted as to prevent learning by the participant. For example, urban driving was either first or last and a pedestrian walking across the street came from another direction or some feet later down the street (see Appendix G). Using two versions of the same elements of the scenario Road

Test for pre-test and post-test mitigated any learning that could occur and ensured data received was accurate and objective. The hazards in both scenarios included pedestrians walking out onto the roadway, traffic lights, and parked/moving vehicles. Driving environments within the scenarios included metropolitan, school zone, rural, and residential environments.

All training sessions occurred within 12 weeks to ensure learning was reinforced. Each participant completed 30 learning modules to gradually build awareness and strategies to avoid hazards. Learning modules included one to four scenarios related to the specific modules' learning objectives. Learning modules were selected in sequence because the skills required built on each other and were necessary for subsequent learning modules and scenarios (see Appendix H). The first training sessions featured learning modules with scenarios focused on basic driving skills, such as speed and lane maintenance, using the pedals, and steering. The next training sessions featured learning modules with scenarios focused on visual scanning, identifying distractors, and detecting hazards while driving in the simulator. These learning modules ranged from easy to medium to hard and included social (pedestrians, bicyclists) and non-social (construction, parked cars) hazards. Each participant moved through the process in an individualized manner, as expected in occupational therapy interventions. If there was a skill or learning module that was difficult, the participant was given multiple opportunities to succeed. Thus, participants differed in the amount of training sessions they required to complete all 30 learning modules. Each training session's main objective was moving through the learning modules at the participant's unique pace ensuring competence before moving forward. Allowing the participant to repeat learning modules and scenarios with skills they found difficult ensured the participant was learning and could continue to efficiently move through the scenarios.

Once all training sessions were completed, the final testing session occurred which involved the participant completing the scenario not viewed at pretest on the STISIM simulator while wearing the Tobii Pro 2 glasses. The eye tracking data from those test drives was uploaded to the Tobii Pro Analyzer software for further analysis.

Data Analysis

Descriptive statistics were used to describe the demographics of the group, including gender, age, and driving experience. The outcome measures of *P-Drive* data and eye tracking data were analyzed, and both were not normally distributed. A Wilcoxon Signed Rank Test was used to determine if there were significant differences in pre-and post-scores for the eye tracking and *P-Drive* data. The eye tracking data was separated into non-social and social hazard categories for analysis. Significant differences in these outcome measures determined whether the specific hazard perception simulator training is effective in increasing hazard perception in adolescents with HFASD. The significance level for statistical testing was set at 0.05.

Specifically, the research questions are: 1) is there a significant difference between pre- and post-training in overall driving performance scores as measured by a standardized observational tool designed to measure fitness to drive and 2) is there a significant difference between the pre- and post- time a person spends looking at a hazard (i.e., fixation duration), how many times a person looks at a specific hazard (i.e., fixation count), and how long it takes to look at a hazard once it is visible (i.e., time to first fixation)?

Chapter 4: Results

Change in Driving Performance

Wilcoxon signed rank test showed significant differences for the total *P-Drive* scores with post-test scores significantly higher than pre-test ($Z = -3.259$, $p = 0.001$). It also showed significant higher scores for post-test for the categories of maneuvers ($Z = -3.267$, $p = 0.001$), follows regulations ($Z = -3.083$, $p = 0.002$), and attending/responding ($Z = -3.069$, $p = 0.002$). The only category that did not show a statistically significant difference between pre-test and post-test scores was orientate ($Z = -1.515$, $p = 0.130$). Table 2 displays the Z scores and P-values of the total *P-Drive* scores and for the four individual categories.

Table 2. Wilcoxon Signed Rank Test Comparing P-Drive Scores.

P-Drive	**Pre-test Statistics**			**Post-test Statistics**			**Test Statistics**	
	Median	**Mean**	**Std. Deviation**	**Median**	**Mean**	**Std. Deviation**	**Z Statistic**	**P-Value**
Total	47.00	48.84	10.63	61.75	61.75	12.83	-3.259[a]	0.001*
Maneuvers	10.00	11.09	2.80	15.00	14.72	2.97	-3.267[a]	0.001*
Orientate	9.00	8.94	2.19	9.50	9.91	2.38	-1.515[a]	0.130
Follow Regulations	8.00	7.63	1.74	10.50	9.97	1.83	-3.083[a]	.002*
Attending and Responding	21.00	21.25	6.01	25.75	27.19	6.79	-3.069[a]	.002*

All differences are defined as post-test—pre-test
p<=0.05
*indicates statistically significant change
[a] Based on negative ranks
[b] Based on positive ranks

Change in Hazard Perception

Non-Social Hazards

Head-On Collision. The *head-on collision hazard* is on a highway (70-mph zone) when a vehicle passes a truck and heads for the participant's vehicle, requiring the participant to move off the right side of the road to avoid a collision. Wilcoxon signed rank test showed no significant differences for head-on collision fixation count (Z = -1.725, p = 0.084) or total fixation duration (Z = -0.094, p = 0.925) between pre-test and post-test. Wilcoxon signed rank test did show a significant difference for time to first fixation for head-on collision (Z = -1.961, p = 0.050), with post-test significantly faster than pre-test. On average, participants looked at the head-on collision 2.68 seconds faster in the post-test than they did in the pre-test. Table 3 provides Z scores and P values for each eye tracking metric for the head on collision hazard.

Table 3. Wilcoxon Signed Rank Test Comparing Eye Tracking Metrics for Head-on Collision

Eye Tracking Measure	**Pre-test Statistics**			**Post-test Statistics**			**Test Statistics**	
	Median	**Mean**	**Std. Deviation**	**edian**	**Mean**	**Std. Deviation**	**Z Statistic**	**P-Value**
Fixation Duration	3.88	3.93	2.12	2.62	3.26	3.40	-0.094[a]	0.925
Fixation Count	2.00	1.64	.924	1.00	.91	.831	-1.725[b]	0.084
Time to First Fixation	4.25	4.38	2.39	2.06	3.10	2.91	-1.961[b]	0.050*

All differences are defined as post-test—pre-test
p<=0.05
*indicates statistically significant change
[a] Based on negative ranks
[b] Based on positive ranks

Hidden Stop. The *hidden stop hazard* consists of a stop sign hidden behind parked trucks in a 35-mph zone. The hidden stop sign and the parked trucks were analyzed as hazards. The Wilcoxon signed rank test showed no significant differences for the hidden stop sign for fixation count (Z = -0.707, p = 0.480), total fixation duration (Z = -0.840, p = 0.401), or time to first fixation (Z = -0.447, p = 0.655) between pre-test and post-test. Interestingly, the eye tracking data showed only 3 participants in the pre-test, and 4 participants in the post-test fixated on the stop sign hazard, instead they may have been fixating on the trucks hiding the stop sign. It also showed no significant differences between pre-test and post-test for fixation count (Z = -0.581, p =0.561) or time to first fixation (Z = -0.169, p = 0.886) for the parked trucks. Wilcoxon signed rank test did show significantly longer time in the pre-test vs post-test for total fixation duration for parked trucks (Z = -2.040, p = 0.041). Participants in the pre-test looked at the trucks for a longer amount of time than participants in the post-test, with an average of 3.66 seconds in the pre-test and 2.66 seconds in the post-test. Table 4 provides Z scores and P values for each eye tracking metric for the hidden stop hazard. Table 5 provides Z scores and P values for the trucks.

Table 4. Wilcoxon Signed Rank Test Comparing Eye Tracking Metrics for Hidden Stop Sign.

Eye Tracking Measure	Pre-test Statistics			Post-test Statistics			Test Statistics	
	Median	Mean	Std. Deviation	Median	Mean	Std. Deviation	Z Statistic	P-Value
Fixation Duration	0.00	0.24	0.47	2.62	3.26	3.40	-0.840[b]	0.401
Fixation Count	0.00	0.55	.934	0.00	0.36	.505	-0.707[b]	0.480
Time to First Fixation	18.89	16.75	8.04	11.32	12.71	4.24	-0.477[b]	0.655

All differences are defined as post-test—pre-test
p<=0.05
*indicates statistically significant change
[a] Based on negative ranks
[b] Based on positive ranks

Table 5. Wilcoxon Signed Rank Test Comparing Eye Tracking Metrics for Trucks on Right.

Eye Tracking Measure	Pre-test Statistics			Post-test Statistics			Test Statistics	
	Median	Mean	Std. Deviation	Median	Mean	Std. Deviation	Z Statistic	P-Value
Fixation Duration	2.81	3.66	3.28	2.40	2.66	2.72	-2.040[b]	0.041*
Fixation Count	3.00	3.73	2.97	2.00	3.27	3.80	-0.581[b]	0.561
Time to First Fixation	3.67	4.17	3.53	3.96	4.78	4.19	-0.169[b]	0.866

All differences are defined as post-test—pre-test
p<=0.05
*indicates statistically significant change
[a] Based on negative ranks
[b] Based on positive ranks

Left Turn. The *left turn hazard* required participants to make a left turn at a green traffic light with oncoming traffic requiring the participants to judge timing between vehicles to safely turn. The oncoming traffic and the traffic light were analyzed as hazards. The Wilcoxon signed rank test showed no significant differences between pre-test and post-test for fixation count (Z = -1.071, p = 0.284), total fixation duration (Z = -1.412, p = 0.158), or time to first fixation (Z = -0.051, p = 0.959) for the oncoming traffic. It also showed no significant differences for fixation count (Z = -0.491, p = 0.624), total fixation duration (Z = -0.078, p = 0.937), or time to first fixation (Z = -0.415, p = 0.678) between pre-test and post-test for the traffic light. Table 6 provides Z scores and P values for each eye tracking metric for the left turn hazard oncoming traffic. Table 7 provides Z scores and P values for each eye tracking metric for the left turn hazard traffic light.

Table 6. Wilcoxon Signed Rank Test Comparing Eye Tracking Metrics for Left Turn Oncoming Traffic.

Eye Tracking Measure	**Pre-test Statistics**			**Post-test Statistics**			**Test Statistics**	
	Median	**Mean**	**Std. Deviation**	**Median**	**Mean**	**Std. Deviation**	**Z Statistic**	**P-Value**
Fixation Duration	7.22	8.15	7.68	2.78	6.23	6.79	-1.412[b]	0.158
Fixation Count	17.00	13.27	8.60	9.00	11.18	10.57	-1.071[b]	0.284
Time to First Fixation	8.26	12.25	11.23	10.19	13.00	12.64	-0.051[a]	0.959

All differences are defined as post-test—pre-test
p<=0.05
*indicates statistically significant change
[a] Based on negative ranks
[b] Based on positive ranks

Table 7. Wilcoxon Signed Rank Test Comparing Eye Tracking Metrics for Left Turn Traffic Light.

Eye Tracking Measure	**Pre-test Statistics**			**Post-test Statistics**			**Test Statistics**	
	Median	**Mean**	**Std. Deviation**	**Median**	**Mean**	**Std. Deviation**	**Z Statistic**	**P-Value**
Fixation Duration	3.06	2.81	2.48	0.94	2.52	3.07	-0.078[a]	0.937
Fixation Count	6.00	6.36	4.37	2.00	5.64	6.45	-0.491[b]	0.624
Time to First Fixation	5.91	8.42	7.59	8.95	8.81	6.85	-0.415[a]	0.678

All differences are defined as post-test—pre-test
p<=0.05
*indicates statistically significant change
[a] Based on negative ranks
[b] Based on positive ranks

Social Hazards

Bicyclist. The *bicyclist hazard* was a bicyclist pulling in front of the participant on an urban street requiring the participant to slow down to avoid a collision. The bicyclist was analyzed as the hazard. The Wilcoxon signed rank test showed no significant differences between pre-test and post-test for time to first fixation (Z = -0.420, p = 0.674) for the bicyclist. It did show significant differences for fixation count (Z = -2.532, p = 0.019), and total fixation duration (Z = -2.045, p = 0.041) for the bicyclist with pre-test having higher means. Participants in the pre-test looked at the bicyclist more times and for a longer amount of time than participants in the post-test. Interestingly, all 11 participants in the pre-test looked at the bicyclist, but three participants in the post-test never looked at the bicyclist according to the eye tracking data. Table 8 provides Z scores and P values for each eye tracking metric for the bicyclist.

Table 8. Wilcoxon Signed Rank Test Comparing Eye Tracking Metrics for Bicyclist.

Eye Tracking Measure	Pre-test Statistics			Post-test Statistics			Test Statistics	
	Median	Mean	Std. Deviation	Median	Mean	Std. Deviation	Z Statistic	P-Value
Fixation Duration	8.65	7.17	3.95	1.81	3.47	6.50	-2.045[b]	0.041*
Fixation Count	8.00	9.27	6.39	2.00	3.09	3.24	-2.352[b]	0.019*
Time to First Fixation	.340	3.63	6.28	1.33	4.92	7.45	-0.420[a]	0.674

All differences are defined as post-test—pre-test
p<=0.05
*indicates statistically significant change
[a] Based on negative ranks
[b] Based on positive ranks

Pedestrian. The *pedestrian hazard* occurs when the simulator commands the participant to turn right at an intersection as a pedestrian begins to walk into the crosswalk. The pedestrian was analyzed as the hazard. The Wilcoxon signed rank test showed no significant differences between pre-test and post-test for fixation count (Z = -1.138, p = 0.255) and total fixation duration (Z = -8.66, p = 0.386) for the pedestrian. The Wilcoxon signed rank test did show significantly shorter mean in the pre-test for time to first fixation (Z = -2.666, p = 0.008) for the pedestrian. On average, participants in the pre-test were 45% faster at fixating on the pedestrian than participants in the post-test. Table 9 provides Z scores and P values for each eye tracking metric for the pedestrian.

Table 9. Wilcoxon Signed Rank Test Comparing Eye Tracking Metrics for Pedestrian.

Eye Tracking Measure	Pre-test Statistics			Post-test Statistics			Test Statistics	
	Median	Mean	Std. Deviation	Median	Mean	Std. Deviation	Z Statistic	P-Value
Fixation Duration	4.70	6.25	6.50	3.06	3.85	3.45	-0.866[b]	0.386
Fixation Count	10.00	11.60	8.45	8.00	8.80	7.73	-1.138[b]	0.255
Time to First Fixation	4.62	5.12	2.86	9.59	10.34	6.83	-2.666[a]	0.008*

All differences are defined as post-test—pre-test
p<=0.05
*indicates statistically significant change
[a] Based on negative ranks
[b] Based on positive ranks

School Crosswalk. The *school crosswalk hazard* occurred in a marked 25-mph school zone, where pedestrians from the right and left sides of the road began crossing the crosswalk as the participant drove close to the crosswalk. If participants were going faster than 35 mph (more than 10 mph over the speed limit), they could pass through the crosswalk before the pedestrians began crossing. The pedestrians and crosswalk were analyzed as hazards. The Wilcoxon signed rank test showed no significant differences for fixation count (Z = -0.461, p = 0.645), total fixation duration (Z = -0.153, p = 0.878), and time to first fixation (Z = -0.560, p = 0.575) between pre-test and post-test for the crosswalk. The Wilcoxon signed rank test did show significantly higher numbers for fixation count (Z = -2.025, p = 0.43) and means for total fixation duration (Z = -2.045, p = 0.041) for pre-test participants for the pedestrians. It did not show significant differences for time to first fixation (Z = -1.014, p =.310) for the pedestrians. Participants in the pre-test looked at the pedestrians longer than participants in the post-test.

Participants in the pre-test also looked at the pedestrians more times altogether (48 fixations), compared to participants in the post-test (25 fixations). Table 10 provides Z scores and P values for each eye tracking metric for the school crosswalk. Table 11 provides Z scores and P values for each eye tracking metric for the pedestrians.

Table 10. Wilcoxon Signed Rank Test Comparing Eye Tracking Metrics for School Crosswalk.

Eye Tracking Measure	**Pre-test Statistics**			**Post-test Statistics**			**Test Statistics**	
	Median	**Mean**	**Std. Deviation**	**Median**	**Mean**	**Std. Deviation**	**Z Statistic**	**P-Value**
Fixation Duration	2.96	3.01	2.00	1.34	2.98	3.24	-0.153[b]	0.878
Fixation Count	6.00	7.36	5.92	4.00	6.55	7.24	-0.461[b]	0.645
Time to First Fixation	.800	2.25	3.20	1.26	6.72	9.08	-0.560[a]	0.575

All differences are defined as post-test—pre-test
p<=0.05
*indicates statistically significant change
[a] Based on negative ranks
[b] Based on positive ranks

Table 11. Wilcoxon Signed Rank Test Comparing Eye Tracking Metrics for Pedestrians.

Eye Tracking Measure	**Pre-test Statistics**			**Post-test Statistics**			**Test Statistics**	
	Median	**Mean**	**Std. Deviation**	**Median**	**Mean**	**Std. Deviation**	**Z Statistic**	**P-Value**
Fixation Duration	2.18	2.11	1.83	.460	.863	.947	-2.045[b]	0.041*
Fixation Count	4.00	4.36	3.17	2.00	2.27	2.05	-2.025[b]	0.043*
Time to First Fixation	2.76	3.32	2.24	3.55	7.69	9.09	-1.014[a]	0.310

All differences are defined as post-test—pre-test
p<=0.05
*indicates statistically significant change
[a] Based on negative ranks
[b] Based on positive ranks

Chapter 5: Discussion

The purpose of this study was to explore if training on a driving simulator could improve driving ability and hazard perception and response in adolescents with HFASD. Results suggest training on a driving simulator does improve overall driving performance. Results for hazard perception and response were varied, but drivers avoided hazards and received higher scores on the *P-Drive* during the post-test than they did on the pre-test.

Change in Driving Performance

The first research question is whether overall driving performance scores would be significantly different between pre- and post-training as measured by the *P-Drive*. Overall, participants achieved significantly higher scores after training when compared to their pre-training scores. This significant change in performance was expected due to previous findings by studies exploring simulator training in adolescents with HFASD (Brooks et al., 2016; D. J. Cox et al., 2017; Meeks, 2017; Wade et al., 2017). All participants were taught in a series of skill-based learning modules, building on the basic skills first, then increasing the degree of difficulty. Participants also had multiple attempts to practice scenarios within the learning modules and skills that were more difficult for them. This needed repetition was expected as it was a suggestion from parents of adolescent drivers with HFASD in the 2012 study by Cox et al. (2012).

Another aspect of the simulator training that could have contributed to increased overall driving performance was the individualized and therapeutic nature of the training. In the majority of GDL programs, driver's education occurs in a group-setting. In contrast, the driving simulator training occurred in a one-to-one or two-to-one ratio and participants were able to move through the training at their own pace. Participants also received occupational therapy therapeutic guidance and an opportunity to ask questions, discuss performance, and practice. Occupational therapy therapeutic guidance is a holistic approach, which considers the participant's personality, learning style, diagnosis, and specific characteristics. It allows the occupational therapist to use specific cues, which are most likely to assist the participant in understanding the task and improving their performance.

The change in performance also suggests that an interactive driving simulator is an effective tool for individuals with ASD. The evidence has shown the simulator itself has reliability, concurrent validity, and relative validity with real world driving (Classen & Akinwuntan, 2017; Mullen et al., 2011; Bella, 2008; Lee et al., 2003; Shechtman et al., 2009). However, for adolescent drivers with ASD it allows them to focus on driving more fully as participants did not have to be worried about real-world consequences unlike when driving on the road with a driving instructor. This likely decreased participant's feelings of anxiety or pressure, which could affect participant's driving performance as hypothesized by the 2015 study by Chee et al. (2015).

Another factor that could have contributed to the significant overall performance change is the learning module protocol. The 30 learning modules were specifically chosen to ensure participants had the ability to practice driving skills in sequence and separately (e.g., steering wheel without pedals, brake pedal without gas pedal) which is not typically possible in real world driving. The protocol also ensured participants could practice and become competent at operational level skills first, which could increase driving performance based on evidence from prior research (Brooks et al., 2016; Classen, Monahan, & Hernandez, 2013). The protocol decreased focus on executive functioning or strategic skills until motor skills or operational level skills were sufficiently practiced. This is likely to increase overall driving performance in adolescent drivers with HFASD due to the significant results related to executive functioning in this population reported previously (S. M. Cox et al., 2016). Another possible reason for the increase in overall driving performance after training is the focus on hazard perception during this study. Ten of the 30 learning modules during the simulator training related specifically to hazard perception and reaction of the participants. This finding supports the hypothesis by Sheppard et al. (2017) that hazard perception training for adolescents with HFASD would improve driving performance overall.

Driving Performance Change due to Training

Overall, participants also improved their driving performance scores in three out four P-Drive categories: *maneuvers*, *follows regulations,* and *attending/responding.* This is likely due to the specific skills chosen for focused training in the learning modules and within each scenario.

For example, the *maneuvers* category included items related to steering, using the pedals, and using the turn signals. These skills are most related to the operational level of driving. These specific skills were focused on in approximately 12 learning modules. In terms of *steering* and *pedals,* learning Modules 2 and 3 included scenarios such as holding the steering wheel, brake pedal, or gas pedal in a static target zone for a specified amount of time. In later learning modules, participants repeated these static holds in smaller target zones, increasing the difficulty and ensuring participants were competent at these motor skills. In learning modules, 9 and 10 participants had to use both the pedals and steering wheel simultaneously to hold in a static zone. Learning modules 4 and 8 required participants to respond to a traffic light and arrows appropriately (e.g. green light=gas pedal, left arrow=turn steering wheel to left), which allowed them to better understand the function of the pedals and steering wheel. Participants also reported it was helpful to separately use the gas/brake pedals and the steering wheel/pedals before using them in combination during training. Learning module 11 related to turn signal usage and allowed participants to practice using their turn signals to change lanes. Participants were also able to comprehensively practice use of turn signals in modules 13 and 14 where they repeatedly turned left or right in various driving environments. These learning modules all directly related to items in the *maneuvers* category, making it likely for participants to significantly change their performance in this category after training.

P-Drive's follows regulations category included items related to obeying stop signs, following speed regulations, and yielding. These skills are most related to the tactical level of driving and were addressed in approximately six learning modules. For example, *obeying stop signs* occurred in learning modules 18 and 20 where participants had the opportunity to repeatedly practice using the pedals to make complete stops at stops signs, stop lights, and intersections. In terms of *speed regulations*, learning module 12 included scenarios designed for the participant to maintain target speeds while driving on a straight road. In terms of *yielding*, learning module 19 focused on participants yielding to other traffic as they repeatedly practiced merging on and off highways. The training during these learning modules likely improved participant's significant change in performance for the *follows regulations* category.

P-Drive's attending and responding category included items related to attending and responding to different stimuli related to the traffic environment and to regulatory or advisory signs. It also included items related to cognition like *reacting*, *focusing*, and *problem solving*. It is likely this category showed significant results in the post-test because these skills were repeatedly practiced in learning modules 21-30 with specific focus on hazard perception and response. For example, learning modules 22, 23, and 28 included scenarios requiring the participant to visually scan and identify target objects. As the difficulty in these modules increased, participants had to identify target objects, respond to a lead car's braking, and maintain their road positioning on a straight road simultaneously. Learning modules 21 and 26 allowed participants to practice appropriately and safely avoiding obstacles. Participants were required to attend to the road ahead and determine the safest action to avoid obstacles in the vehicle's path. Learning module 24 was unique as it contained multiple scenarios allowing participants to practice using their mirrors. During the scenarios in this module, participants had the opportunity to independently decide to change lanes with various traffic and continue to practice awareness of fellow road users. Learning modules 25, 27, 29, and 30 focused on hazard detection and response in various driving environments. These drives included social and non-social hazards and the researcher reviewed performance with the participant after each hazard occurred. The cognitive-related items of *reacting*, *focusing*, and *problem solving* were more difficult to train as they are related to the strategic level and are dependent on the participant's independent use of their cognitive skills. However, occupational therapy therapeutic guidance was repeatedly used during the hazard perception modules to increase participant's visual scanning, attention to road signs, and response time to hazards. Participants likely improved in these items due to the nature of the individualized therapeutic guidance they received, and/or improvement of these items was inherent in the completion of the learning modules themselves.

Orientate was the only category that did not show a significant change from pre-test to post-test. The *orientate* category included skills related to planning, following instructions, road position, and keeping distance. Participants may not have demonstrated significant change in this category due to the *planning* item being scored in this category. *Planning* is a strategic level driving ability and is difficult to practice and observe on a driving simulator. Achieving a high score in *planning* required the participant to anticipate required driving maneuvers and accomplish them correctly and safely without verbal cues, due to the scoring requirements outlined in the *P-Drive* and the nature of planning itself. Change or significant results for this item may not have been achievable in the structure of this intervention.

Another item scored in the *orientate* category, *following instructions* was not directly addressed by learning modules in the driving simulator training, which could explain why participants did not significantly change their scores in this category. Instead, *following instructions* was generally addressed as participants had to follow standardized instructions given by the researcher to complete the learning modules. Also, the simulator itself gave standardized instructions in some scenarios to prompt the participant to turn, change lanes, or stop. Participants could not have completed the learning modules and moved forward in the training protocol without following the instructions to succeed at the learning module objective but specific training on this item did not occur.

In terms of *positioning on road* and *keeping distance,* three learning modules specifically focused on these skills. For example, learning module 5 included scenarios where participants had to maintain their lane position on a straight road for a specified amount of time. Learning module 15 included scenarios designed to teach participants the difference between unsafe and safe following distances and allowed them to practice following distance behind a lead car. These items are related to the tactical level of driving, unlike planning.

It is possible the item *positioning on road* may have lacked changes in scores due to the simulator's programming. Although the driving simulator does have concurrent and relative validity with on road driving (Shechtman et al., 2009; Mullen et al., 2011; Bella, 2008; Lee et al., 2003), the driving simulator does not provide as much sensory perceptual feedback as real world vehicles and driving environments. For example, the simulator did not give feedback when a participant was not centered in the road, unlike what a driver might experience in the real world. In the real world, a driver could expect to feel the road become bumpier or see dust/gravel flying up when they were not positioned in the center of their lane. The simulator did not have animated gravel or dirt kicking up when the participant was off to the side of the road and there were no rumble strips to alert the participant they were drifting, which would occur in some on road driving. Also, sounds from the traffic and driving environment of the simulator were only produced by speakers located in front of the driver. On the real road, auditory stimuli typically occur in surround sound, from all areas inside and around the car. Therefore, the simulator could have caused participants to have lower scores on the *positioning on road* item in the *orientate* category due to a combination of decreased sensory perceptual stimuli and lack of feedback, which decreased participant's awareness of their positioning on the simulated road. Although it is not clear, specific items in the *orientate* category, which were difficult train or practice on the simulator likely contributed to the lack of significant results for this category.

Change in Hazard Perception

Overall, results of hazard perception using eye tracking technology tended towards improvement overall, but specific hazard results were inconsistent and varied for both social and non-social hazards in terms of fixation duration, fixation count, and time to first fixation. Only one hazard (left turn) did not return significant results for any of the eye tracking measures. All other hazards returned at least one significant result for eye tracking. Although, most results showed the pre-test eye tracking data for hazards was higher than the post-test numbers, which would suggest more attention to the hazard, it was not true in all cases.

Non-Social Hazards

The results of the non-social hazards were interesting as only two of the three non-social hazards produced significant results for at least one of the eye tracking measures. Interestingly, the left turn hazard did not produce significant results for either the oncoming traffic or the traffic light. It is possible this hazard had too much visual stimuli or was too complex to find significant results for eye tracking. Participants may have been fixating on more areas of the roadway environment than the two hazards studied during the left turn because they were required to consider multiple factors to determine the appropriate time to turn left. Further analysis will be required to determine appropriate hazards to use with eye tracking on the driving simulator.

There were also no significant results for the stop sign in the hidden stop hazard, likely due to the positioning of the trucks and the minimal number of participants that looked at the stop sign according to the eye tracking data. Surprisingly, for the trucks in the hidden stop hazard the change in fixation duration **decreased** in time post-test, not increased as expected. This may be due to the participants requiring less time (fixation duration) in the post-test to look at the trucks and determine the appropriate motor response required to stop at the stop sign. This finding is supported by the Sheppard et al. study (2017) where the motor response time for adolescents with HFASD was not significantly different than controls once the hazard was perceived on screen (Sheppard et al., 2017).

The head-on collision hazard was the only hazard in this study that had significant results for an eye tracking measure that **increased** in post-test as expected because time to first fixation was significantly **faster** for the head on collision in the post-test than it was in the pre-test. This could be due to participants' increased ability to scan the driving environment and detect hazards more quickly due to the hazard perception training they received on the simulator. The participants may also have been faster at reacting to this hazard as it was a non-social hazard and previous research has shown adolescents with HFASD are faster at identifying and reacting to non-social stimuli/hazards than social stimuli/hazards (Bishop et al., 2017; Guillon et al., 2014; Sheppard et al., 2010). However, this could also be due the nature of the hazard itself as no other hazards returned significantly faster results for the post-test in time to first fixation. Additional research will need to be completed to further explore the eye tracking and motor responses to these specific non-social hazards on the driving simulator.

Head-On Collision. Participants during the head-on collision hazard fixated on the head-on car significantly faster in the post-test than they did in the pre-test. This may be due to the specific scenarios focusing on hazard perception and awareness of various stimuli in the driving environment. Four learning modules required participants to perceive and quickly react to various hazards. During this portion of simulator training, any collisions that occurred were thoroughly discussed with the researcher. Participants were asked to discuss what they could have done differently to avoid a collision and how they would react to a similar situation in the future. If participants did not collide with any hazards during these scenarios, the researcher reviewed their performance at the end and discussed the correct decisions the participant had made to avoid collisions Although the learning modules did not include any head-on collisions, participants were required to avoid collisions with other cars in the learning modules.

Another explanation for the faster reaction time in the post-test could have been the head-on collision hazard itself. The head-on collision occurred in a 70-mph zone on a highway, where all other hazards explored in this study occurred in speed zones of 45 mph or less. Also, this hazard may have required more aggressive actions from the participant, where other hazards allowed for more passivity. During this hazard, the participant had to use the car's brake to decrease the car's speed, but also had to turn the wheel to move off the edge of the road to entirely avoid the collision. The participants likely learned through training that hazards at higher speeds are typically more difficult to avoid and participants could have been more visually attentive to the driving environment in preparation for making assertive actions required to avoid collisions such as this one.

Hidden Stop.

Hidden Stop. Participants demonstrated no significant change in the eye tracking metrics for the hidden stop itself. The eye tracking data showed only 3 participants in the pre-test and 4 participants in the post-test fixated on the stop sign hazard. The stop sign may have been difficult to fixate on due to the positioning of the trucks. Also, participants had other methods of determining a stop sign existed without fixating on the stop sign itself as there were "limit lines" on the road next to each stop sign indicating to the driver where to stop. This lack of finding could also be explained by participants using their peripheral vision to notice the stop sign. If participants used their peripheral vision for the stop sign in either the pre-test or the post-test the eye tracking technology would not have the capability to record periphery eye movements. It is possible the stop sign itself was not an appropriate hazard for the eye tracking technology as some participants were observed running the stop sign during the pre-test and the post-test, which may have decreased the ability to determine significant results for this hazard.

Trucks. The trucks hiding the stop sign did produce significant results for total fixation duration as it was significantly less for participants in the post-test. Although the overall average difference from pre-test to post-test was about one second, this was found to be significantly different. This is likely due to the practice participants received during training on stopping at intersections and at stop lights in multiple different scenarios. Participants repeatedly practiced anticipating where stop signs should be based on "limit lines" and how to stop appropriately for a stop sign. Also, participants in the post-test may have looked at the trucks for less time as they were already anticipating the stop sign behind the trucks and did not have to look at the trucks blocking the way for as long as they did in the pre-test to make a decision. The simulator training could have increased the speed the participants required to understand how to respond to the trucks meaning they spent less time looking at them overall.

Left Turn.

Left Turn Oncoming Traffic and Traffic Light. There were no significant results for the left turn oncoming traffic or left turn traffic light. Participants in both the pre-test and the post-test had similar eye tracking measures related to this hazard. This is likely due to the nature of the hazard itself, which was complex with multiple visual stimuli and had unique aspects compared to the other hazards investigated in this study. During the left turn hazard, participants were prompted to make a left turn at a 4-way intersection but did not have the right of way and were required to wait until it was safe to turn in between oncoming traffic. Participants had to use cognitive processing skills to determine the appropriate time to complete the left turn. Participants may have been fixating on other pertinent areas or visual stimuli in both the pre-test and post-test during the left turn hazard. It is also possible this hazard caused the participant to use their peripheral vision or turn their head to maintain visual attention on the various stimuli, which the eye tracking technology could not record. An interesting aspect of this hazard was the amount of time participants spent waiting to complete the left turn itself. Both the pre-test and post-test numbers on all eye tracking measures for this hazard were higher compared to other hazards investigated in this study. Although the results are not clear, it is possible hazards that include complex cognitive processing, multiple visual stimuli, or increased stationary time may not be appropriate for determining significant results related to eye tracking. Further analysis is required to determine the most appropriate hazards for eye tracking measures in this population.

Social Hazards

The most interesting results were related to the social hazards. There were significant changes for at least one of the eye tracking measures in the bicyclist, pedestrian, and school crosswalk hazards. Surprisingly, for the bicyclist and the pedestrians in the school crosswalk, the changes in fixation duration and fixation count **decreased** in time on post-test, not increased as expected. Time to first fixation did not show a significant change for these hazards. This would suggest that the participants saw the hazard (bicyclist/pedestrians) as they appeared in the drive at about the same time in the pre-test and post-test (thus no change in time to first fixation) and understood what the hazard was and their likely path of progress. This would account for less amount of time looking at the hazard (fixation duration) and decrease the need to look at the hazard multiple times (fixation count). As such the participants may be focusing on driving more effectively and attending to other aspects of driving competence. Conversely, it may be an affirmation of other studies that show individuals with HFASD disregarding social hazards (Bishop et al., 2017; Guillon et al., 2014; Sheppard et al., 2010; Sheppard et al., 2017).

In terms of the pedestrian hazard, the time to first fixation was significantly different, showing a slower time to the first view of the hazard in the post-test. This may be an outlier, as it is a social hazard, or the focus of the participants was on the operational and tactical components of making the turn. It is possible the participants were more focused in the post-test on correctly making the turn using skills practiced in training, which decreased their visual attention and made them slower to fixate on the pedestrian. Additional result and analysis will be needed to investigate these unique situations.

Bicyclist. Both fixation count and fixation duration were higher in the pre-test than they were in the post-test for the bicyclist hazard indicating participants in the pre-test visually attended to the hazard for longer and more often. However, as the participants' overall driving performance significantly increased during post-test, this finding does not indicate increased visual attention always causes increased performance. Instead, it is likely participants in the post-test required less fixations on the bicyclist and less time looking at the bicyclist to understand and respond to the hazard. Participants in the pre-test may have needed to repeatedly look at the bicyclist to decide what to do and how to react and to keep track of what the bicyclist was doing. Participants in the post-test perceived the bicyclist in about the same time as they did in the pre-test, but they decided on a motor response more quickly reducing the number and amount of times they needed to fixate. During the simulator training, participants were required to react quickly to avoid pedestrian hazards, but there were no bicyclist hazards in the learning modules. This suggests the pedestrian hazard training on the simulator was adequate to increase the decision-making ability of the participants when they encountered the bicyclist during the post-test.

Pedestrian. Although there were no significant results for fixation count and fixation duration for the pedestrian, participants were significantly faster at fixating on the pedestrian in the pre-test (time to first fixation). Participants had multiple learning modules with training related to perceiving and avoiding pedestrian hazards. However, most pedestrian hazards during training occurred on a straight road, whereas the pedestrian hazard being studied occurred while the participant was making a right turn at an intersection. It is possible the participant was spending more time scanning the visual stimuli in the intersection causing them to take more time to notice the pedestrian once they began turning in the post-test. Visual scanning was emphasized during training and participants were reminded to focus on all areas outside the car, not only directly in front of them or at the horizon as adolescents with HFASD may be prone to do as evidenced by Reimer et al. (2017). If participants were visually scanning more competently in the post-test, it is possible they took more time to fixate on the pedestrian. However, it is also possible participants were more focused on the operational level components of making the turn (e.g., steering, turn signals, gas/brake pedals) or the tactical level component of turning. If participants were more focused on these aspects of driving, it could have decreased their visual attention to the pedestrian. In contrast, participants in the pre-test had not received training on the operational components of turning and may have noticed the pedestrian more quickly but completed an unsafe or illegal turn during this hazard. It may be possible participants in the post-test were performing the correct motor actions, but this adversely affected the speed of their hazard perception for the pedestrian. It is interesting to note only the hazards that included a turn (left turn and pedestrian) returned significant results for time to first fixation. This could indicate a component of “turning hazards” makes them more likely to affect time to first fixation or these hazards may not be appropriate for accurate results related to the specific eye tracking measures investigated in this study.

School Crosswalk.

School Crosswalk. Participants demonstrated no significant change in the eye tracking measures for the school crosswalk itself. Unlike the stop sign hazard, almost all the participants fixated on the crosswalk at least once. Eye tracking data showed only 2 participants in the pre-test and 2 participants in the post-test did not fixate on the school crosswalk. It is likely this hazard did not produce significant results as the participants were more focused on the pedestrians and they already had knowledge of school crosswalks in the pre-test. Participants in both the pre-test and the post-test may have determined the school crosswalk itself did not require visual attention if they were visually attentive to the pedestrians utilizing the crosswalk. Participants in the pre-test and the post-test could have fixated on the hazard similarly as they may have already been familiar with the nature of a school crosswalk during the pre-test and did not need training to understand where to look. School crosswalks are a common occurrence and participants may have utilized a crosswalk or been taught about them in school prior to this study. Although training on crosswalks did occur during the simulator training, it was not emphasized and there were no school crosswalks, which require a change in speed. Also, the school crosswalk hazard is the only hazard investigated in this study that could be predicted by participants based on the simulator graphics. In both the pre-test and post-test, the school crosswalk was preceded by two school crosswalk signs alerting the participant to slow down in preparation. As they knew the school crosswalk was going to occur, it could have affected the participants' visual attention and decreased the likelihood for statistically significant results.

School Crosswalk Pedestrians. Both fixation count and fixation duration were higher in the pre-test than they were in the post-test for the pedestrians in the school crosswalk hazard. This is likely due to participants requiring less time to determine the appropriate motor response to the pedestrians in the crosswalk after training, as theorized for the results of the bicyclist hazard. The simulator learning modules included multiple instances of pedestrians and repeated practice occurred to increase the reaction time of the participants and ensure they avoided collision. Time to first fixation for the pedestrians was similar for the pre-test and post-test indicating participants perceived them in about the same time after they appeared on screen.

However, in the post-test it is likely participants were quicker at choosing a motor response and could switch to visually scanning or fixating on other stimuli, instead of repeatedly fixating on the pedestrians.

Skill Development

As designed, the participants completed the learning modules which included scenarios in sequence beginning with simpler skills (e.g., steering, use of pedals, lane keeping) before moving onto more complex skills (turning, use of mirrors, lane changing, merging). The participant was provided with an explanation of the objective and instructions to complete the overall objective at the beginning of each learning module and scenario. This specific information was provided in a standardized script by the DriveSafety company related to the SimClinic software learning modules, meaning each participant received the same instructions related to the objectives before beginning each module. However, verbal cues given during the training varied depending on the participant’s performance, understanding, and level of competence at each skill. Some participants moved quickly through the scenarios, while others required repetition to gain competence for each skill set. The Meeks (2017) study also used this progressive skills development with opportunities for repetition with adolescent drivers with HFASD on the driving simulator. Once the participant was competent at a specific skill being targeted, they were able to move on until all 30 learning modules had been completed. Total time to complete the 30 learning modules ranged from 2.5 to 5.5 hours, due to the individualized nature of repeated practice and the differing driving skill levels of the participants.

Implications for Occupational Therapy Practice

This study informs occupational therapists that driving simulator training is appropriate for improving driving performance in adolescents with HFASD. This supports previous research that concluded driving simulators were appropriate, objective methods for clinicians and researchers to evaluate and train driving skills in adolescents with HFASD (Classen, 2017; Brooks et al., 2016; D. J. Cox et al., 2017; N. B. Cox et al., 2012; S. M. Cox et al., 2016). It also informs occupational therapy practitioners that their knowledge of driving and community mobility and their ability to provide individualized therapeutic guidance may make training on the driving simulator more effective for adolescents with HFASD. Occupational therapy practitioners should also be aware that hazard perception specific training does effect hazard perception and response in this population. However, results related to specific social and non-social hazards using eye tracking measures may not be appropriate for research or general occupational therapy practitioners as findings in this study were inconsistent. Further research will need to be completed using eye tracking response in this population related to social and non-social hazards.

Limitations

One specific limitation of this study is the sample itself. Recruiting individuals with HFASD with a desire to learn to drive or improve their driving skills was difficult because adolescents with HFASD are less likely to drive themselves and obtain a driver's license than their typically developing peers (Curry et al., 2017; Lubin & Feeley, 2016). Therefore, the sample size of this study was small, and this could limit the power of the statistical analyses used. The sample was also a convenience sample which may affect the generalizability of the results. However, to attempt to mitigate this limitation, demographic information was provided about the participants, and it is assumed the participant sample is representative of the HFASD population in Eastern. NC. Also, occupational therapy practitioners and researchers would also find this a limitation when designing interventions for this population related to independent driving. The use of a convenience sample could have caused selection bias (adolescents enrolling in the study with interest in eye tracking affecting their driving skills) or the Hawthorne effect (alteration of behavior in simulated driving because of the researcher's presence). Participants may also have had trouble completing driving simulator scenarios and focusing due to the symptoms associated with their ASD diagnosis, but participants in this study did not self-report any other diagnoses, which would affect their attention.

Technical difficulties were also a study limitation as the driving simulators, Tobii Pro Glasses 2, and Tobii Pro Lab Analyzer software are all technologically complex. Accurate and consistent data for each participant could be interrupted by lost connections. Also, some participants were unable to use the eye tracking data as an outcome measure. Only eye tracking data from participants whose gaze points were tracked at least 75% of the time was included. Participants with less than 75% gaze samples were typically unable to properly wear and use the Tobii Pro Glasses 2 due to squinting, peripheral vision usage, or a vision prescription higher than the technology has available. In an attempt mitigate instances of technical difficulties training with Tobii Pro repeatedly occurred throughout the study to address issues and ensure all technology was up to date and well maintained for the duration of the study (Case, 2016).

Also, participants in the study had varying levels of driving experience. Some had their driver's license, while others had not completed driver's education. These differing levels of driving experience could have an adverse effect on the strength of the statistical analyses and their ability to show significant change. However, we wanted to include adolescents with

HFASD with different levels of driving experience, as this increased the sample size and allowed for better generalization of findings to a variety of adolescent drivers with HFASD.

Finally, a limitation of the study was the diversity of individuals with HFASD. The intervention was tailored and included individualized occupational therapy therapeutic guidance and therefore was not identical for each participant. Some participants moved faster than others through the learning modules and scenarios, but the focus was continuously on matching the pace that was best for the specific participant. However, no matter the characteristics or driving difficulties each participant had, the focus was on training general driving skills and hazard perception and response, and completing the modules competently.

Chapter 6: Conclusion

The literature overall indicates adolescents with HFASD may have characteristics that make driving independently a difficult, but obtainable goal. Research has shown, training on a driving simulator can increase driving performance in adolescents with HFASD. Overall, findings in this study supported this previous research as adolescents with HFASD improved their driving performance scores after training.

Existing studies have begun to explore using eye tracking in combination with simulator training as adolescents with HFASD exhibit difference in eye gaze, visual attention, visual scanning, and hazard perception and these are all important factors related to driving safely and avoiding collisions. This study found hazard perception training on a simulator had varying effects on hazard perception and response to social and non-social hazards in adolescent drivers with HFASD. The training protocol may have given participants the ability to more quickly perceive and decide on a course of action when encountering a hazard. However, due to the inconsistency in results related to the eye tracking measures, further research needs to be completed to help determine the efficacy of using eye tracking technology to determine a change in hazard perception and response in this population.

References

Advanced Therapy Products (2014). WT-690 transit car transfer simulator. Atpwork. http://www.atpwork.com/WT960.html

Almberg, M., Selander, H., Falkmer, M., Vaz, S., Ciccarelli, M., & Falkmer, T. (2017). Experiences of facilitators or barriers in driving education from learner and novice drivers with ADHD or ASD and their driving instructors. Developmental *Neurorehabilitation, 20*(2), 59-67. https://doi.org/10.3109/17518423.2015.1058299

American Occupational Therapy Association. (2014). Occupational therapy practice framework: Domain and process. *American Journal of Occupational Therapy, 68*(suppl.1), S1-S48. https://doi.org/10.5014/ajot.2014.682006

American Psychiatric Association. (2013). Autism spectrum Disorder. *In diagnostic and statistical manual of mental disorders* (5th ed.). https://doi.org/10.1176/appi.books.9780890425596

American Psychological Association. (2020). *Anxiety*. APA. https://www.apa.org/topics/anxiety/index.html

Chen, L.-H., Baker, S. P., & Li, G. (2006). Graduated driver licensing programs and fatal crashes of 16-year-old drivers: a national evaluation. *Pediatrics*, *118*(1), 56-62. https://doi.org/10.1542/peds.2005-2281

Bella, F. (2008). Driving simulator for speed research on two-lane rural roads. *Accident Analysis & Prevention, 40(3)*, 1078-1087. https://doi.org/10.1016/j.aap.2007.10.015

Bishop, H. J., Biasini, F. J., & Stavrinos, D. (2017). Social and non-social hazard response in drivers with autism spectrum disorder. *Journal of Autism and Developmental Disorders, 47*(4), 905-917. https://doi.org/ 10.1007/s10803-016-2992-1

Blane, A., Falkmer, T., Lee, H. C., & Dukic Willstrand, T. (2018). Investigating cognitive ability and self-reported driving performance of post-stroke adults in a driving simulator. *Topics in Stroke Rehabilitation, 25*(1), 44-53. https://doi.org/10.1080/10749357.2017.1373929

Fisher, A. G. & Griswold, L. A. (2014). Performance skills: implementing performance analyses to evaluate quality of occupational performance. In B. A. Schell, G. Gillen, M. E. Scaffa, and E. S. Cohn (Eds .), *Willard and Spackman's Occupational Therapy* (12th ed., p. 1241). Wolters Kluwer/Lippincott Williams & Wilkins.

Brooks, J., Kellett, J., Seeanner, J., Jenkins, C., Buchanan, C., Kinsman, A., Kelly D., & Pierce, S. (2016). Training the motor aspects of pre-driving skills of young adults with and without autism spectrum disorder. *Journal of Autism and Developmental Disorders, 46*(7), 2408-2426. https://doi.org/10.1007/s10803-016-2775-8

Brooks, J., Mossey, M. E., Tyler, P., & Collins, J. C. (2014). An exploratory investigation: are driving simulators appropriate to teach pre-driving skills to young adults with intellectual disabilities? *British Journal of Learning Disabilities, 42*(3), 204-213. https://doi.org/10.1111/bld.12029

Case, R. (2016). Perceived effectiveness of a driving and community mobility bootcamp for individuals with autism spectrum disorder. [Unpublished master’s thesis]. East Carolina University. https://hdl.handle.net/10342/6021

Cederlund, M., Hagberg, B., Billstedt, E., Gillberg, I. C., & Gillberg, C. (2008). Asperger syndrome and autism: A comparative longitudinal follow-up study more than 5 years after original diagnosis. *Journal of Autism and Developmental Disorders, 38*(1), 72-85. https://doi.org/10.1007/s10803-007-0364-6

Chee, D. Y., Lee, H. C., Patomella, A.-H., & Falkmer, T. (2017). Driving behaviour profile of drivers with autism spectrum disorder (ASD). *Journal of Autism and Developmental Disorders, 47*(9), 2658-2670. https://doi.org/10.1007/s10803-017-3178-1

Chee, D. Y., Lee, H. C., Falkmer, M., Barnett, T., Falkmer, O., Siljehav, J., & Falkmer, T. (2015). Viewpoints on driving of individuals with and without autism spectrum disorder. *Developmental Neurorehabilitation, 18*(1), 26-36. https//:doi.org/10.3109/17518423.2014.964377

Classen, S. (Ed.). (2017). *Driving simulation for assessment, intervention, and training: A guide for occupational therapy and health care professionals*. AOTA Press, The American Occupational Therapy Association.

Classen S., & Akinwuntan, A. (2017). Validity and reliability in driving simulation. In: Classen S. (Ed.), *Driving simulation for assessment, intervention, and training:A guide for occupational therapy and health care professionals* (pp. 95-103). AOTA Press, The American Occupational Therapy Association.

Classen, S., & Monahan, M. (2013). Evidence-based review on interventions and determinants of driving performance in teens with attention deficit hyperactivity disorder or autism spectrum disorder. *Traffic Injury Prevention, 14*(2), 188-193. https://doi.org/10.1080/15389588.2012.700747

Classen, S., Monahan, M., & Brown, K. (2014). Indicators of simulated driving skills in adolescents with attention deficit hyperactivity disorder. *The Open Journal of Occupational Therapy, 2*(1), 3. https://doi.org/10.15453/2168-6408.1066

Classen, S., Monahan, M., Brown, K. E., & Hernandez, S. (2013). Driving indicators in teens with attention deficit hyperactivity and/or autism spectrum disorder: Indicateurs de la conduite automobile chez les jeunes ayant un déficit de l'attention avec hyperactivité ou un trouble du spectre autistique. *Canadian Journal of Occupational Therapy, 80*(5), 274-283. https://doi.org/10.1177/0008417413501072

Classen, S., Monahan, M., & Hernandez, S. (2013). Indicators of simulated driving skills in adolescents with autism spectrum disorder. *The Open Journal of Occupational Therapy, 1*(4), 2. https://doi.org/10.15453/2168-6408.1051

Classen, S., Monahan, M., & Wang, Y. (2013). Driving characteristics of teens with attention deficit hyperactivity and autism spectrum disorder. *American Journal of Occupational Therapy, 67*(6), 664-673. https://doi.org/10.5014/ajot.2013.008821

Cox, D. J., Brown, T., Ross, V., Moncrief, M., Schmitt, R., Gaffney, G., & Reeve, R. (2017). Can youth with autism spectrum disorder use virtual reality driving simulation training to evaluate and improve driving performance? An exploratory study. *Journal of Autism and Developmental Disorders, 47*(8), 2544-2555. https://doi.org/10.1007/s10803-017-3164-7

Cox, N. B., Reeve, R. E., Cox, S. M., & Cox, D. J. (2012). Brief report: Driving and young adults with ASD: Parents' experiences. *Journal of Autism and Developmental Disorders, 42*(10), 2257-2262. https://doi.org/10.1007/s10803-012-1470-7

Cox, S. M., Cox, D. J., Kofler, M. J., Moncrief, M. A., Johnson, R. J., Lambert, A. E., Cain, S. & Reeve, R. E. (2016). Driving simulator performance in novice drivers with autism spectrum disorder: The role of executive functions and basic motor skills, 46(4), 1379-1391. https://doi.org/10.1007/s10803-015-2677-1

Curry, A. E., Yerys, B. E., Huang, P., & Metzger, K. B. (2017). Longitudinal study of driver licensing rates among adolescents and young adults with autism spectrum disorder. Autism, 22(4), 479-488. https://doi.org/10.1177/1362361317699586

Daly, B. P., Nicholls, E. G., Patrick, K. E., Brinckman, D. D., & Schultheis, M. T. (2014). Driving behaviors in adults with autism spectrum disorders. *Journal of Autism and Developmental Disorders, 44*(12), 3119-3128. https://doi.org/10.1007/s10803-014-2166-y

Devos, H., Morgan, J. C., Onyeamaechi, A., Bogle, C. A., Holton, K., Kruse, J., Sasser, S., & Akinwuntan, A. E. (2016). Use of a driving simulator to improve on-road driving performance and cognition in persons with Parkinson's disease: A pilot study. *Australian Occupational Therapy Journal, 63(*6), 408-414. https://doi.org/10.1111/1440-1630.12263

Dickerson, A. E., & Niewoehner, P. (2012). Chapter 6: Analyzing the complex IADLs of driving and community mobility. In M. J. McGuire & E. Schold Davis (Eds.), *Driving and Community Mobility: Occupational Therapy Strategies Across the Lifespan* (pp. 115-135). AOTA Press, The American Occupational Therapy Association.

Dickerson, A., Schold Davis, E., & Carr, D. (2018). Driving decisions: Distinguishing evaluations, providers, and outcomes. *Geriatrics, 3*(2), 25. https://doi.org/10.3390/geriatrics3020025

Drive Safety Incorporated & Clemson University. (2019). SimClinic Scenario Descriptions.

Evans, D. & Lavallière, M. (2017). Fidelity. Physical fidelity in driving simulation. In: Classen S. (Ed.), *Driving simulation for assessment, intervention, and training:A guide for occupational therapy and health care professionals* (pp. 67-74). AOTA Press, The American Occupational Therapy Association.

Fournier, K. A., Hass, C. J., Naik, S. K., Lodha, N., & Cauraugh, J. H. (2010). Motor coordination in autism spectrum disorders: A synthesis and meta-analysis. *Journal of*

Autism and Developmental Disorders, 40(10) 1227-1240. https://doi.org/10.1007/s10803-010-0981-3

George, S., & de la Perrelle, N. (2017). Simulator-based occupational therapy driving intervention can reduce driving errors on a simulator-based driving assessment in combat veterans with polytrauma. *Australian Occupational Therapy Journal, 64*(6), 512-513. https://doi.org/10.1111/1440-1630.12435

Grynszpan, O., & Nadel, J. (2015). An eye-tracking method to reveal the link between gazing patterns and pragmatic abilities in high functioning autism spectrum disorders. *Frontiers in Human Neuroscience, 8,* para. 12. https://doi.org/10.3389/fnhum.2014.01067

Guillon, Q., Hadjikhani, N., Baduel, S., & Rogé, B. (2014). Visual social attention in autism spectrum disorder: Insights from eye tracking studies. *Neuroscience and biobehavioral reviews, 42*, 279-297. https://doi.org/10.1016/j.neubiorev.2014.03.013

Harand, C., Mondou, A., Chevanne, D., Bocca, M. L., & Defer, G. (2018). Evidence of attentional impairments using virtual driving simulation in multiple sclerosis. *Multiple Sclerosis and Related Disorders, 25*, 251-257. https://doi.org/10.1016/j.msard.2018.08.005

Hill, E. L. (2004). Evaluating the theory of executive dysfunction in autism. *Developmental Review, 24*(2), 189-233. https://doi.org/10.1016/j.dr.2004.01.001

Howlin, P. (2000). Outcome in adult life for more able individuals with autism or Asperger Syndrome. *Autism, 4*(1), 63-83. https://doi.org/10.1177/1362361300004001005

Huang, P., Kao, T., Curry, A., & Durbin, D. (2012). Factors associated with driving in teens with autism spectrum disorders. *Journal of Developmental & Behavioral Pediatrics, 33(*1), 70-74. https://doi.org/10.1097/DBP.0b013e31823a43b7

Hunt, L. A. & Slater L. (2012). Occupational therapy's ethical obligation to address driving and community mobility. In M. J. McGuire & E. Schold Davis (Eds.), *Driving and community mobility: Occupational therapy strategies across the lifespan* (pp. 101–113). AOTA Press, The American Occupational Therapy Association.

Lai, M.-C., Lombardo, M. V., & Baron-Cohen, S. (2014). Autism. *The Lancet, 383*(9920), 896-910. https://doi.org/10.1016/S0140-6736(13)61539-1

Lee, H. C., Cameron, D., & Lee, A. H. (2003). Assessing the driving performance of older adult drivers: On-road versus simulated driving. *Accident Analysis & Prevention, 35*(5), 797-803. https://doi.org/10.1016/S0001-4575(02)00083-0

Levy, A., & Perry, A. (2011). Outcomes in adolescents and adults with autism: A review of the literature. *Research in Autism Spectrum Disorders*, *5*(4), 1271-1282. https://doi.org/10.1016/j.rasd.2011.01.023

Lubin, A., & Feeley, C. (2016). Transportation issues of adults on the autism spectrum: Findings from focus group discussions. *Transportation Research Record: Journal of the Transportation Research Board, 2542*(1), 1-8. https://doi.org/10.3141/2542-01

Maenner, M. J., Shaw K. A., Baio J., Washington, A., Patrick, M., DiRienzo, M., Christensen, D. L., Wiggins, L. D., Pettygrove, S., Andrews, J. G., Lopez, M., Hudson, A., Baroud, T., Schwenk, Y., White, T., Rosenburg, C. R., Lee, L. C-., Harrington, R. A., Huston, M.,… Dietz, P.M. (2020). Prevalence of autism spectrum disorder among children aged 8 Years--Autism and Developmental Disabilities Monitoring Network, 11 sites, United States, 2016. *MMWR Surveillance Summaries, 69*(4), 1-12. https://doi.org/ 10.15585/mmwr.ss6904a1

Meeks, L. T. (2017). Effective use of a driving simulator as an intervention tool for adolescents and young adults with autism spectrum disorder. [Unpublished master's thesis]. East Carolina University. https://hdl.handle.net/10342/6486

Michon, J. A. (1985). A critical view of driver behavior models: What do we know, what should we do? In L. Evans & R. C. Schwing (Eds.), *Human behavior and traffic safety,* (pp. 485–520). Plenum Press.

Monahan, M. (2012). Assessing, treating, and preparing youth with special needs for driving and community mobility. In M. J. McGuire & E. Schold Davis (Eds.), *Driving and community mobility: Occupational therapy strategies across the lifespan* (pp. 383-410). AOTA Press, The American Occupational Therapy Association.

Mullen, N., Charlton, J., Devlin, A., & Bedard, M. (2011). Simulator validity: Behaviours observed on the simulator and on the road. In D. L. Fisher, M. Rizzo, J. K. Caird, & J. D. Lee (Eds.), *Handbook of Driving Simulation for Engineering, Medicine and Psychology* (pp. 1-18) CRC Press.

Nonverbal communication. (2004). In W. E. Craighead & C. B. Nemeroff (Eds.), *The concise Corsini encyclopedia of psychology and behavioral science* (3rd ed.). Wiley Credo Reference.

Patomella, A.-H. (2014). P-Drive Manual and Guidelines.

Patomella, A.-H., & Bundy, A. (2015). P-Drive: Implementing an assessment of on-road driving in clinical settings and investigating its internal and predictive validity. *The American Journal of Occupational Therapy, 69*(4), 1-8. https://doi.org/10.5014/ajot.2015.015131

Patomella, A.-H., Tham, K., Johansson, K., & Kottorp, A. (2010). P-Drive on-road: Internal scale validity and reliability of an assessment of on-road driving performance in people with neurological disorders. *Scandinavian Journal of Occupational Therapy, 17*(1), 86-93. https://doi.org/ 10.3109/11038120903071776

Reimer, B., Fried, R., Mehler, B., Joshi, G., Bolfek, A., Godfrey, K. M., Zhao, N., Goldin, R., & Biederman, J. (2013). Brief report: Examining driving behavior in young adults with high functioning autism spectrum disorders: A pilot study using a driving simulation paradigm. *Journal of Autism and Developmental Disorders, 43*(9), 2211-2217. https://doi.org/10.1007/s10803-013-1764-4

Ross, V., Cox, D. J., Reeve, R., Brown, T., Moncrief, M., Schmitt, R., & Gaffney, G. (2017). Measuring the attitudes of novice drivers with autism spectrum disorder as an indication of apprehensive driving: Going beyond basic abilities. *Autism, 22*(1), 62-69. https://doi.org/10.1177/1362361317735959

Selander, H., Stave, C., Willstrand, T. D., & Peters, B. (2019). Driving simulator-based training to improve self-rating ability of driving performance in older adults – a pilot study. *European Transport Research Review, 11*(1), 1-7. https://doi.org/10.1186/s12544-019-0372-6

Shechtman, O., Classen, S., Awadzi, K., & Mann, W. (2009). Comparison of driving errors between on-the-road and simulated driving assessment: A validation study. *Traffic Injury Prevention, 10*(4), 379-385. https://doi.org/10.1080/15389580902894989

Sheppard, E., Ropar, D., Underwood, G., & van Loon, E. (2010). Brief report: Driving hazard perception in autism. *Journal of Autism and Developmental Disorders, 40*(4), 504-508. https://doi.org/10.1007/s10803-009-0890-5

Sheppard, E., van Loon, E., Underwood, G., & Ropar, D. (2017). Attentional differences in a driving hazard perception task in adults with autism spectrum disorders. *Journal of*

Autism and Developmental Disorders, 47(2), 405-414. https://doi.org/10.1007/s10803-016-2965-4

Simons-Morton, B., & Ouimet, M. C. (2006). Parent involvement in novice teen driving: a review of the literature. *Injury Prevention, 12*(suppl.1), i30-i37. https://doi.org/10.1136/ip.2006.011569

Systems Technology Inc. (2013). STISIM drive for occupational therapists: SDOT user manual.

Tobii Pro (2017). Eye tracker data quality report: Accuracy, precision, and detected gaze under optimal conditions- controlled environment. *Unpublished Report.* https://www.tobiipro.com/siteassets/tobii-pro/accuracy-and-precision-tests/tobii-pro-glasses-2-accuracy-and-precision-test-report.pdf

Tobii Pro (2018a). *Tobii Pro Glasses 2 Brochure.* https://www.tobiipro.com/siteassets/tobii-pro/brochures/tobii-pro-glasses-2-brochure.pdf/?v=5

Tobii Pro (2018b). *Tobii Pro Lab Brochure.* https://www.tobiipro.com/siteassets/tobii-pro/brochures/tobii-pro-lab-brochure.pdf/?v=1.76

Transportation Research Board (2016). Taxonomy and Terms for Stakeholders in Senior Mobility. *Transportation Research Circular.* http://onlinepubs.trb.org/Onlinepubs/circulars/ec211.pdf

Underwood, G. (2007). Visual attention and the transition from novice to advanced driver, *Ergonomics, 50*(8), 1235-1249. https://doi.org/10.1080/00140130701318707

U.S. Department of Transportation Federal Highway Administration (2011). Drivers. *Our Nation's Highways: 2011*. pp. 25-36. https://www.fhwa.dot.gov/policyinformation/pubs/hf/pl11028/

Wade, J., Weitlauf, A., Broderick, N., Swanson, A., Zhang, L., Bian, D., Sarkar, M., Warren, Z., & Sarkar, N. (2017). A pilot study assessing performance and visual attention of teenagers with ASD in a novel adaptive driving simulator. *Journal of Autism and Developmental Disorders, 47*(11), 3405-3417. https://doi.org/10.1007/s10803-017-3261-7

Wang, S., Jiang, M., Duchesne, X. M., Laugeson, E. A., Kennedy, D. P., Adolphs, R., & Zhao, Q. (2015). Atypical visual saliency in autism spectrum disorder quantified through model-based eye tracking. *Neuron*, *88*(3), 604-616. https://doi.org/10.1016/j.neuron.2015.09.042

Zhang, L., Wade, J., Bian, D., Fan, J., Swanson, A., Weitlauf, A., Warren, Z., & Sarkar, N. (2017). Cognitive load measurement in a virtual reality-based driving system for autism intervention. *IEEE Transactions on Affective Computing*, *8(*2), 176-189. https://doi.org/10.1109/TAFFC.2016.2582490

Appendix A:
IRB Approval Letter

EAST CAROLINA UNIVERSITY
University & Medical Center Institutional Review Board
4N-64 Brody Medical Sciences Building· Mail Stop 682
600 Moye Boulevard · Greenville, NC 27834
Office **252-744-2914** · Fax **252-744-2284** · **www.ecu.edu/ORIC/irb**

Notification of Initial Approval: Expedited

From:	Social/Behavioral IRB
To:	Tara Baran
CC:	Anne Dickerson
Date:	12/18/2018
Re:	UMCIRB 18-002318 Driving Simulator, Eye Tracking, and P-Drive

I am pleased to inform you that your Expedited Application was approved. Approval of the study and any consent form(s) is for the period of 12/18/2018 to 12/17/2019. The research study is eligible for review under expedited category # 6, 7. The Chairperson (or designee) deemed this study no more than minimal risk.

Changes to this approved research may not be initiated without UMCIRB review except when necessary to eliminate an apparent immediate hazard to the participant. All unanticipated problems involving risks to participants and others must be promptly reported to the UMCIRB. The investigator must submit a continuing review/closure application to the UMCIRB prior to the date of study expiration. The Investigator must adhere to all reporting requirements for this study.

Approved consent documents with the IRB approval date stamped on the document should be used to consent participants (consent documents with the IRB approval date stamp are found under the Documents tab in the study workspace).

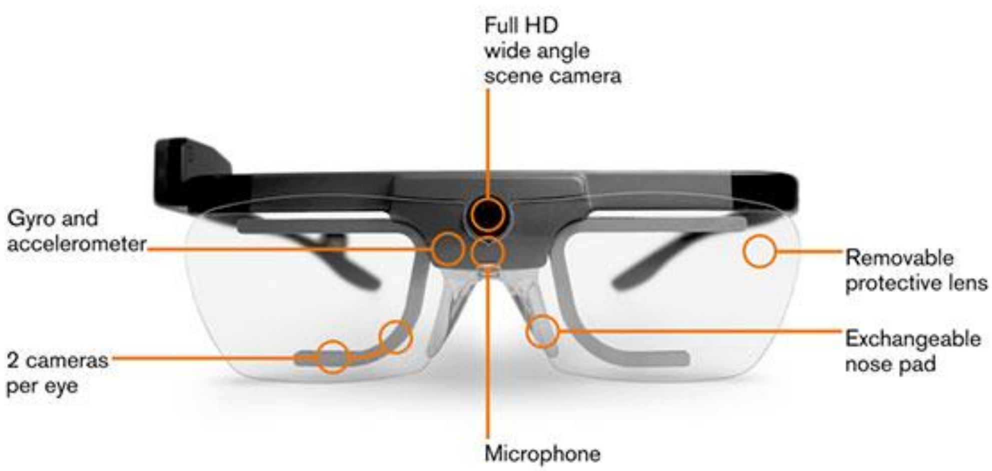
The approval includes the following items:

Name	Description
15-17 year assent	Consent Forms
18 and up Consent	Consent Forms
Parent Consent	Consent Forms
Recruitment Email	Recruitment Documents/Scripts
Recruitment Flyer	Recruitment Documents/Scripts
Thesis Proposal	Study Protocol or Grant Application

The Chairperson (or designee) does not have a potential for conflict of interest on this study.

IRB00000705 East Carolina U IRB #1 (Biomedical) IORG0000418
IRB00003781 East Carolina U IRB #2 (Behavioral/SS) IORG0000418

Appendix B:
Tobii Pro Glasses 2 Photos



Appendix C:

Description of Tobii Software Terms and Tools

Area of interest (AOI): Tool to select subregions of a displayed image or video and extract metrics related to these subregions. In this study, AOIs will be specifically used for specific hazards in the driving simulation scenarios

Gaze point: Show each individual place the eyes are looking during eye tracking

Fixation: Series of gaze points extremely close together, meaning the eyes are fixed on an object during eye tracking

Visual heat maps: Visual representation of fixations and gaze points of a single participant or an entire study, areas where fixations are more common will be denoted in red, followed by yellow and then green

Manual mapping: When a researcher clicks each individual gaze point to map it on a still picture, diagram, or schematic

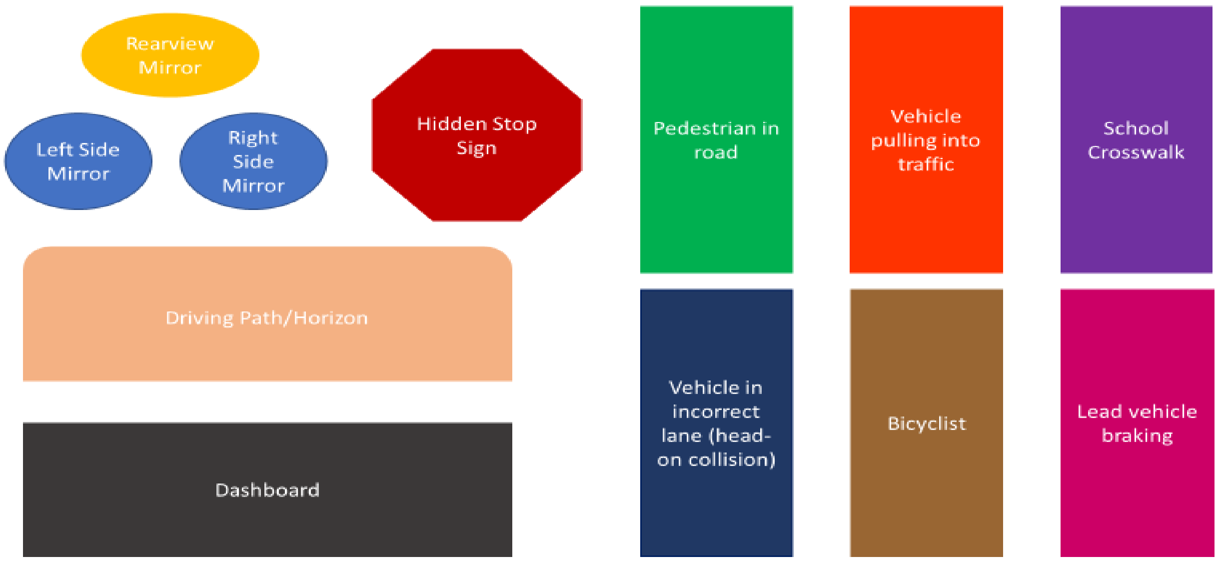
AOI diagram: Used to manually map individual gaze points on subregions of a displayed image

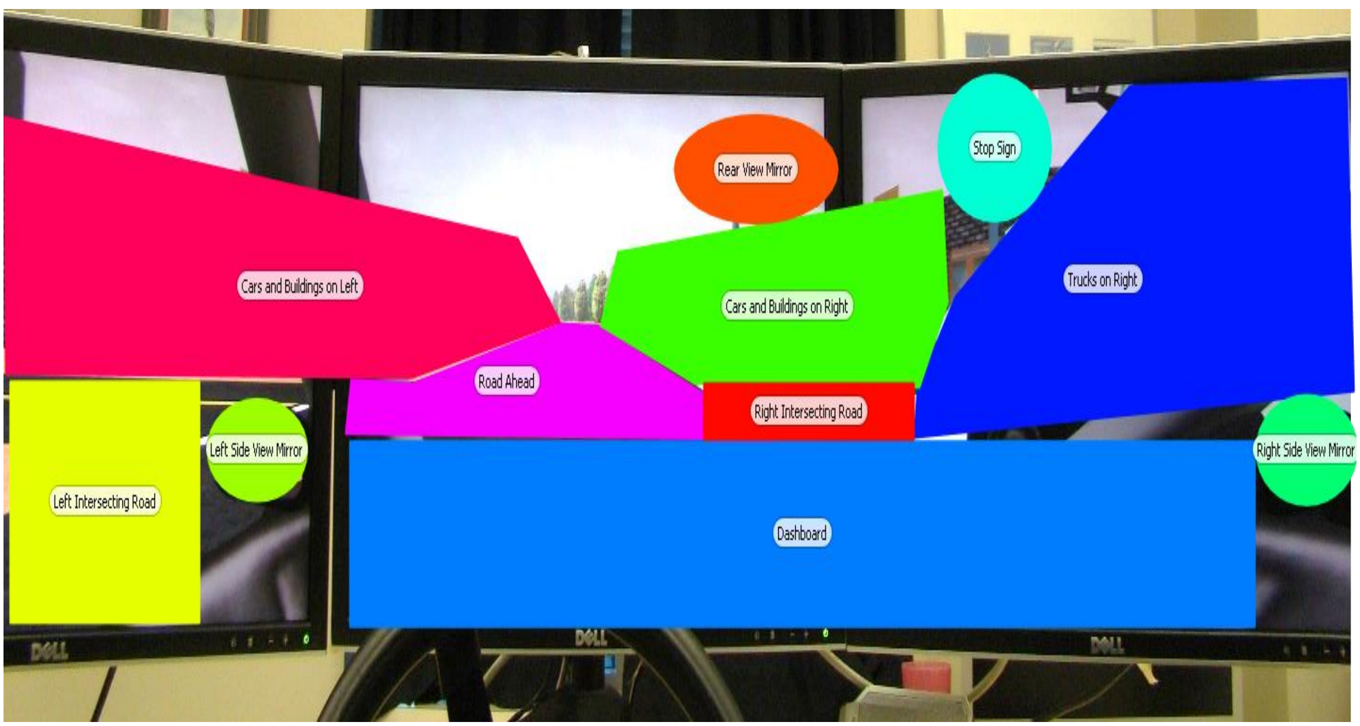
Fixation duration on AOIs: Measurement of the amount of time in seconds a participant spends looking at an AOI

Time to first fixation on AOIs: Measurement of how long it takes a participant to look at an AOI once it is visible

Fixation count on AOIs: Measurement of how many times a participant looks at a specific AOI while it is visible

Appendix D:
Example Diagrams of AOIs





Appendix E:
P-Drive Scoring Manual

P -Drive

P-Drive Items to Score (N = 25):

1. Steering

This item is about steering the vehicle in a competent and safe manner. The grading is influenced by the quality of the grasp of the steering wheel and coordination of steering to maintain the correct road position.

Examples of scoring:

4 = Has no problem steering the vehicle in a competent and safe manner.
3 = Steers the vehicle with some hesitancy. Example: Uses a questionable grip of the steering wheel such as one-handed steering.
2 = Unsafe steering has a potential to create a risky situation. Example; Steering in a risky manner such as hitting the curb.
1 = Loses control of the steering or incompetent steering that has potential for crash or running off the road. Intervention is required to assist with steering.

3. Using pedals

This item is about using the pedals in a competent and secure manner during the driving test. Observe the client's ability to locate the pedals accurately and apply the brake and accelerator in a smooth and coordinated manner without looking at pedals.

Examples of scoring:

4 = Competent and secure use of pedals
3 = Shows hesitancy in the calibration of pressure on one or both pedals. Example: Slow or late in taking action but does not impinge action.
2 = Delay in the use of pedals leads to a potentially risky situation. For example: Uses too little pressure on the brake, stops abruptly causing difficulty for vehicles behind.
1 = Makes mistakes or physically does not use the pedals in a secure manner. Examples: Brakes too late, mistakes the brake for accelerator or reverse, applies the accelerator and brake at the same time, physically cannot use the pedals.

4. Controlling speed - too slow

This item is about being able to control and adapt the vehicle's speed without being too slow for the conditions. Observe ability to drive at a speed appropriate to the conditions and without slowing other traffic down. A low speed that is unjustified and hinders other traffic will lead to a lower score.

Examples of scoring:

4 = Selects and adapts an appropriate speed for the traffic conditions without hindering other road users.
3 = Choice of speed is questionable. Example: Drives at a speed that would have some other road users overtake or pass the client's vehicle.
2 = Choice of speed is unjustified and too slow for the situation in that all drivers are needing to overtake or pass the client's vehicle or other road users are significantly slowed down. Example: Drives approximately at 25-30 mph on a 40-50 mph road where it is warranted to keep up the speed.
1 = Does not maintain a speed appropriate for other traffic and the road conditions so that driving is not performed in a safe and competent manner. Example: Causes other road users to slow or brake suddenly, potentially increasing the risk of a crash.

5. Controlling speed- too fast

This item is about being able to control and adapt speed according to the traffic situation without driving too fast. Ability to stay within the speed limit and reduce speed when necessary for the situation (e.g., due to other traffic, school zones or pedestrians) is observed. Driving at a speed that is above the client's ability or inappropriate for the traffic conditions will lower the score.

Examples of scoring:

4 = Selects and adapts an appropriate speed for the traffic situation by remaining within the speed limit.
3 = Choice of speed is questionable. Example: Overtakes a slower vehicle going slightly over speed limits.
2= Choice of speed is risky for driving conditions or drives at a speed potentially above driver's ability to safely control the vehicle.
1= Does not adapt speed for driving conditions, driving too fast and it unsafe manner. Repeatedly drives over the speed limit or for the road conditions (rain, traffic, intersections).

6. Using turn signals (indicators)

This item concerns the use of indicators in a safe and appropriate manner. Difficulties that would lead to a lower score include; 1) Difficulties in planning and correctly sequence the use of the indicator, or 2) incorrect use of the left and right indicator depending of the direction of the turn or 3) applying the indicator unnecessarily (when not turning). Although many drivers have bad habits, this should be scored for the safety and competence of the skills observed.

Examples of scoring:

4 = Uses the correct indicators in an appropriate manner.
3 = Misses or is late in application of the indicator without compromising safety.
2 = Does not use the indicator consistently, but use does not lead to any risky issues in the traffic situation.

1 = Does not use the indicator when needed to prevent a risky situation or uses the indicator I inaccurate way causing a risky situation, such as indicating the wrong direction without correction.

8. Following instructions

This item is about being able to follow verbal instructions in a competent and secure manner. Ability to follow verbal instructions without hesitation or the need for prompts or repeated instructions or the need for clarification is observed.

Examples of scoring:

4 = Follows instructions appropriately and in accordance with situational needs.
3 = Hesitates with directions or asks a single confirming question such as "*Which way did you say to turn?*"
2 = Does not follow instructions, needs repeated directions, or needs cues to follow the instructions.
1 = Does not follow instructions and requires significant intervention to manage traffic situations.

10. Positioning on the road

This item is about being able to select the correct position on the road in a competent and safe manner. Ability to stay within the lane, maintain a straight course, avoid cutting corners or taking wide corners, and maintain appropriate buffer zones from other vehicles and object in other lanes or at the side of the road is scored.

Examples of scoring:

4 = Maintains a correct and secure lane position on the roadway.
3 = May move into an incorrect position on the road but corrects the mistake. Becomes aware of any incorrect lane position and self corrects without prompting. Hesitates in the choice of lane when required.
2 = Lane position is too much to the right or the left, does not maintain correct lane position or chooses incorrect lane. Does not present a risk for a crash.
1 = Does not maintain correct lane position on the road even with cueing. Repeatedly drives too close to other vehicles or objects on either side of the lane. Chooses incorrect lane which may cause a crash, as in a two lane turn and moving into the other lane).

11. Keeping distance

This item is about maintaining adequate buffer zones (distances) around the vehicle and selecting the right distance to other cars and objects. This includes being able to keep a secure distance to pedestrian crossings, traffic lights, stop lines, other vehicles, moving and still objects, parking spaces, and/or road signs.

Examples of scoring:

4 = Keeps an adequate buffer zones or distances to objects in front and to the side of the vehicle.
3 = Buffer zones to other objects are too close or too far but does not impact safety. Does not adapt to distances smoothly as in stopping abruptly just before the stop line.
2 = Buffer zones are too close which may create a risky situation, as in tailgating, although corrects when cued.
1 = Does not keep a safe distance without intervention or stops the vehicle over the stop line in an intersection when traffic lights are red putting the vehicle at risk for a crash.

12. Planning

This item is about being able to plan driving maneuvers and sequences in a competent and safe manner. This includes being able to plan the next maneuver, such as changing lanes before an intersection, slowing down before a roundabout and knowing when to merge into a lane on a highway. (The item is about finding a flow in the driving and being able to plan the driving from place A to place B).

Examples of scoring:

4 = Competently plans driving maneuvers in a way that facilitates performance of other actions
3 = Hesitates in the planning of the driving maneuvers. Does not follow directions to a specified place or positions but chooses a different route with the same outcome (although signage was present).
2 = Does not plan appropriate maneuvers resulting in a different outcome from expected. Poor planning may put vehicle in risky situations.
1 = Does not plan appropriate or safe maneuvers resulting in intervention or several risky actions.

13. Yielding

This item is about being able to yield to other traffic in compliance with road law in a competent and safe manner. This includes understanding when specific road rules apply and being able to drive in a way that indicates the rules are understood. Understanding includes both for when yielding is needed as well as when other traffic needs to yield for him or her.

Examples of scoring:

4 = Yields appropriately for traffic situation in a competent and safe manner and in compliance with road laws.
3 = Hesitates in yielding such as in merging
2 = Does not yield according to the road rules or needs to be cued to yield appropriately and safely. Example: Does not slow down enough so that other vehicles can pass or yield while in a roundabout.
1 = Repeatedly fails to yield according to road rules leading to risky driving needing intervention.

14. Obeying stop signs and traffic lights

This item is about being able to stop the vehicle at a stop sign or traffic light in a competent and safe manner including being able to decide when to stop in accordance with current road law. Ability to drive in a confident and competent manner without hesitating is observed (demonstrating knowledge of the road rules for stopping). Failure to stop the car completely at a stop sign leads to a lower score.

Examples of scoring:

4 = Obeys the stop regulations and road laws appropriately and adequately.
3 = Hesitates to stop at stop sign or traffic light.
2 = Inadequate actions at stop signs or traffic lights including not stopping completely as in yielding instead of stopping.
1= Does not stop at stop sign or red light or slowing down to assess risk, requiring intervention.

15. Following speed regulations

This item is about being able to follow speed regulations in a competent and safe manner, without speeding. Violating the speed limit is a more severe error in low speed zones such as 25 mph school zones. Be aware that only speeding is scored for this item. If the driver is driving is too slow or hindering other traffic but the speed limit is not exceeded, this is still scored as a 4.

Examples of scoring:

4 = Adheres to posted speed limits.
3 = Hesitates in response to speed limit signs and/or drives up to 5 mph over the limit
2 = Drives over the speed limit; but within 10 mph over the limit.
1 = Drives consistently over the speed limit and over the 10 mph limit; Potential risky situations due to speeding.

16. Attending and responding to the road environment ahead

This item is about being able to attend to the forward road environment ahead in a competent and safe manner, including attending to and acting upon stimuli in the traffic environment (e.g. other cars, signs and pedestrians). A slowed action will lead to a lower score.

Examples of scoring:

4 = Attends and responds to road signs, hazards and traffic in the road environment ahead.
3 = Hesitant in attending to and responding to road environment ahead.
2 = Late or slow in attending and responding to road environment ahead.
1 = Does not attend and respond to road environment ahead or needs intervention.

17. Attending and responding to the right

This item is about being able to attend the right side of the vehicle and then respond in a competent and safe manner. The right is defined as the area immediately to the right of the vehicle. This includes being able to attend and respond to stimuli in the traffic environment that is to the right of the vehicle, such as other vehicles, signs and pedestrians. It also includes ability to attend and act upon traffic in the blind spot. A slowed action will lead to a lower score.

Examples of scoring:

4 = Attends and responds to signs, traffic and hazards on the right of the vehicle
3 = Hesitant in attending and responding to stimuli on the right side of the vehicle.
2 = Late or slow in attending and responding to stimuli on the right side of the vehicle
1 = Does not attend and respond to stimuli on the right side of the vehicle or needs intervention.

18. Attending and responding to the left

This item is about being able heed to the left in a competent and safe manner, attending and responding to stimuli in the traffic environment that is to the left of the vehicle such as other vehicles, signs and pedestrians etc. Also, ability to attend and act upon traffic in the left blind spot is scored. A slowed action will lead to a lower score.

Examples of scoring:

4 = Attends and responds to signs, traffic and hazards on the left side of the vehicle
3 = Hesitant in attending and responding to stimuli on the left side of the vehicle.
2 = Late or slow to attending and responding to stimuli on the left side of the vehicle.
1= Does not attend and respond to stimuli to the left side of the vehicle or needs intervention in it requires intervention.

19. Attending and responding to mirrors

This item is about being able to use mirrors to attend and respond to stimuli in the traffic environment to either side or the rear of the vehicle in a competent and safe manner. This includes awareness of other vehicles to the side/behind the vehicle and when changing lanes. A slowed action will lead to a lower score.

Examples of scoring:

4 = Actively uses mirrors to attend and respond to stimuli in the road environment such as other vehicles.
3 = Hesitant in using mirrors to attend and respond to stimuli to the side or rear of the vehicle.
2 = Does not use mirrors consistently or adequately to attend and respond to stimuli in the mirrors / to the side or rear of the vehicle so that there is potential for risk.
1= Does not use mirrors to respond to stimuli in the road environment. Example: Changing lanes increases risk of crash or requires intervention.

20. Attending and responding to regulatory signs

This item is about being able to attend and respond to signs of regulation in a competent and safe manner and appropriately following the intent of the signs. A slowed action will lead to a lower score.

Examples of scoring:

4 = Appropriately attends and responds to regulatory signs.
3 = Hesitate in attending or responding to regulatory signs
2 = Late in attend or respond to regulatory signs or corrects a mistake when made.
1 = Does not attend or respond to regulatory signs repeatedly or requires repeated cueing or intervention to avoid an adverse incident.

21. Attending and responding to advisory road signs

This item is about being able attend and respond to advisory signs in a competent and safe manner and appropriately responds to the intent of the advisory signs. A slowed action will lead to a lower score.

Examples of scoring:

4 = Attend and respond with the appropriate respond to advisory signs.
3 = Hesitant to attending and responding to advisory signs.
2 = Late in attending and responding to advisory signs or corrects a mistake when made.
1 = Does not attend or respond to advisory signs repeatedly or requires cueing or intervention to avoid an adverse incident.

22. Attends and responds to fellow road users

This item is about being aware of fellow road users and adjusting driving performance in a competent and safe manner as required. This includes being able to interact appropriately with fellow road users. A slowed action will lead to a lower score.

Examples of scoring:

4 = Attends and responds appropriately towards the intentions of fellow road users.
3 = Hesitant in attending and responding with fellow road users.
2 = Slowed or late in attending and responding to fellow road users.
1 = Does not attend or respond to fellow road users and requires intervention.

23. Reacting

This item is about being able to react in a timely manner and act appropriately to expected, unexpected, and hazardous road situations. A slowed action will lead to a lower score.

Examples of scoring:

4 = Reacts in advance to unexpected situations involving fellow road users or situations.
3 = Hesitant in response to unexpected situations in the road environment actions ore expected actions such as a red light.
2 = Late reaction to an unexpected action but manages to respond appropriately to the situation.

1 = Does not react appropriately to an expected or unexpected action causing a risky situation and/or needing intervention.

24. Focusing

This item is about concentrating on the driving task in a competent and safe manner. This involves being able to focus on the task at hand and prioritize safety during driving. To be easily distracted leads to a lower score.

Examples of scoring:

4 = Concentrates on the driving task even with conversation.
3 = Increased hesitancy with maneuvers with any distraction, but able to complete the task. Example: Late in planning turn due to a conversation in the vehicle or can correct mistake without help.
2 = Late or misses maneuvers of the driving task with distractions. Example: Misses turn or signs during drive because talking instead of focusing on driving.
1 = Late or misses maneuvers of the driving task with distractions, is easily distracted, cannot correct mistakes, and needs intervention.

25. Problem solving

This item is about solving problems in a competent and safe manner without assistance.

Examples of scoring:

4 = Solves a problem or situation that arise during driving independently and adequately
3 = Hesitate in the solving of problems but resolves the issue with little or no intervention.
2 = Late problem solving, requires prompting to solve problems.
1 = Unable to solve problems. Requires verbal or physical intervention.

Other:

Weather and road conditions: Note the circumstances for the test, for example slippery roads, rush hour or rain.

Standard route or special route: Specify which route was used. It is allowed to mark more than one.

General rules for scoring:

- Only score what you have observed.
- The worst behavior observed is scored; record and score error items even if the client has been driving well for the rest of the test.
- When you are hesitating between two scores, give the lower score.
- If an item has not been observed, do not score this item.

- When the car is adapted, do not give the client a lower score due to the adaption, but make sure that you have made a note about the modification on the score protocol.
- When you observe an error, it is usually scored down on several items.

Items 2, 7, and 9 have been removed as they will not be scored in this study

Appendix F:
P-Drive Score Sheet

P -Drive

Performance Analysis of Driving Ability

Name (not to be written for research)		Rater	Position in car (front or rear)
Id.no.	Age	Date for assessment	
Diagnosis		Date of onset	Time since diagnosis (months)
Cognitive tests done		Advised not to drive (y/n)	Driving anyway (y/n)

☐ **Manual** ☐ **Automatic** ☐ **Modification/s**___________

Actions (1-26):

Maneuvers

1. steering	4	3	2	1
2. changing gears	4	3	2	1
3. using pedals	4	3	2	1
4. contr speed, slow	4	3	2	1
5. contr speed, fast	4	3	2	1
6. using indicator	4	3	2	1
7. reversing	4	3	2	1

Orientate

8. following instruct	4	3	2	1
9. wayfinding	4	3	2	1
10. positioning on road	4	3	2	1
11. keeping distance	4	3	2	1
12. planning	4	3	2	1

Follow regulations

13. yielding	4	3	2	1
14. obeying stop	4	3	2	1
15. follow speed reg	4	3	2	1

Attending and responding (heeding)

16. straight ahead	4	3	2	1
17. to the right	4	3	2	1
18. to the left	4	3	2	1
19. to mirrors	4	3	2	1
20. to regulatory sign	4	3	2	1
21. to advisory sign	4	3	2	1
22. to fellow road users	4	3	2	1
23. reacting	4	3	2	1
24. focusing	4	3	2	1
25. problem solving	4	3	2	1

Rating scale	**Quality of performance**	**Impact on the activity**
4	Good **Competent performance**	Positive, facilitating
3	Questionable **Hesitant performance**	Causing insecurity (asking questions)
2	**Ineffective Performance**	Causing risky situation
1	**Incompetent performance**	Causing repeated risky or dangerous situations. Interruption

Other information:

Standard route ☐ Special route ☐

Signed consent form ☐

Time on-road (min):________

OUTCOME: ☐ Pass ☐ Fail

☐ Fail with lessons

☐ Other____________

Appendix G:
Road Test Version 1 and 2 Description

SCENARIO	DESCRIPTION	MEASURES	
 **Road Test Version 1**	Length/Time: 4.2 miles (22000 feet) / ≈ 10.5 minutes Scenario runs through metro, rural, farmland, school zone, and residential condos scenes. The basic scenario scenes are identical except for the presentation order. The presentation of various hazards does change for each version of the Road Test. Road Test Versions can be used for pre/post rehabilitation assessments. *- Has to be left of center once to pass bus and bicycle ** - Has to be off road once due to Head on Collision	Total Off Road Crashes Total Collisions with Vehicles & Roadway Objects Total Traffic Light Tickets Total Times Over the Posted Speed Limit Percentage of Time Over the Posted Speed Limit Total Times Center Line was Crossed* Total Times the Driver went Off the Road** Percentage of Time Out of Lanes **Pedestrian Collision Avoidance:** Collision with Pedestrians? Total Pedal Reaction Time Gas Pedal Reaction Time Minimum Time to Collision with Pedestrians Minimum Distance to Pedestrian Did the Driver Exceed the Posted Speed Limit? Maximum Speed in School Zone **Amber Dilemma Performance:** Did the Driver Stop? Total Pedal Reaction Time Gas Pedal Reaction Time **Turn Performance:** Did the Driver Turn in the Correct Direction? Did the Driver Crash While Turning? Was the Turn Signal Used Correctly? Did the Driver Pass in Front of Pedestrian? **Hidden Stop Performance** Did the Driver Stop in Time? Distance from Stop Sign when Brakes Applied	**Vehicle Pulling into Traffic:** Collision with Vehicles? Total Pedal Reaction Time Gas Pedal Reaction Time Minimum Time to Collision with Vehicles in the Driver's Lane Minimum Distance to Vehicles in the Driver's Lane **Vehicle Control Performance** Average Speed Speed Deviation Average Lane Position Lane Position Deviation Maximum Speed Minimum Speed **Head On Collision Avoidance:** Collision with Vehicles? Off Road Crash? Total Pedal Reaction Time Gas Pedal Reaction Time Was Excessive Steering Used? Minimum Time to Head on Collision Minimum Distance to Head on Collision **Sudden Lead Vehicle Braking** Collision with Vehicles? Total Pedal Reaction Time Gas Pedal Reaction Time Minimum Time to Collision with Vehicles in the Driver's Lane Minimum Distance to Vehicles in the Driver's Lane **Turn Performance** Did the Driver Turn in the Correct Direction? Collision with Vehicles? Collision with Pedestrians? Was the Turn Signal Used Correctly? Did the Driver Pass in Front of Pedestrians?

SCENARIO	DESCRIPTION	MEASURES	
 **Road Test Version 2**	Length/Time: 4.0 miles (21000 feet) / ≈ 10 minutes Scenario runs through metro, rural, farmland, school zone, and residential condos scenes. The basic scenario scenes are identical except for the presentation order. The presentation of various hazards does change for each version of the Road Test. Road Test Versions can be used for pre/post rehabilitation assessments. *- Has to be left of center once to pass bus and bicycle ** - Has to be off road once due to Head on Collision	Total Off Road Crashes Total Collisions with Vehicles & Roadway Objects Total Traffic Light Tickets Total Stop Sign Tickets Total Times Over the Posted Speed Limit Percentage of Time Over the Posted Speed Limit Total Times Center Line was Crossed* Total Times the Driver went Off the Road** Percentage of Time Out of Lanes **Sudden Lead Vehicle Braking** Collision with Vehicles? Total Pedal Reaction Time Gas Pedal Reaction Time Minimum Time to Collision with Vehicles in the Driver's Lane Minimum Distance to Vehicles in the Driver's Lane **Backing Vehicle Collision Avoidance** Collision with Backing Vehicle? Total Pedal Reaction Time Gas Pedal Reaction Time Minimum Time to Collision with Backing Vehicle Minimum Distance to Backing Vehicle **Hidden Stop Performance** Did the Driver Stop in Time? Distance from Stop Sign when Brakes Applied? **Pedestrian Collision Avoidance:** Collision with Pedestrians? Total Pedal Reaction Time Gas Pedal Reaction Time Minimum Time to Collision with Pedestrians Minimum Distance to Pedestrian Did the Driver Exceed the Posted Speed Limit? Maximum Speed in School Zone	**Vehicle Pulling into Traffic:** Collision with Vehicles? Total Pedal Reaction Time Gas Pedal Reaction Time Minimum Time to Collision with Vehicles in the Driver's Lane Minimum Distance to Vehicles in the Driver's Lane **Turn Performance (1 of 2)** Did the Driver Turn in the Correct Direction? Collision with Vehicles? Collision with Pedestrians? Was the Turn Signal Used Correctly? Did the Driver Pass in Front of Pedestrians? **Amber Dilemma Performance:** Did the Driver Stop? Total Pedal Reaction Time Gas Pedal Reaction Time **Vehicle Control Performance** Average Speed Speed Deviation Average Lane Position Lane Position Deviation Maximum Speed Minimum Speed **Head On Collision Avoidance:** Collision with Vehicles? Off Road Crash? Total Pedal Reaction Time Gas Pedal Reaction Time Was Excessive Steering Used? Minimum Time to Head on Collision Minimum Distance to Head on Collision

Appendix H:

Simulator Protocol Scenarios and Objectives (DriveSafety & Clemson University, 2019)

Learning Module	Qualifiers	Category	Objectives
Calibration-Interactive	--	Phase 1	1. Calibrate the pedals and steering wheel
Steering Static	Tutorial, Level 1	Phase 1	1. Effectively and efficiently move the steering wheel to a static target zone
Pedals Static	Level 1	Phase 1	1. Press the pedal to hold the indicator within a static target zone
Stop Light and Steering	Task Only, 32 symbols	Phase 1	1. Interact with the pedals and steering wheel 2. Interpret meaning of traffic lights and arrows
Lane Keeping Straight	--	Phase 2	1. Travel an appropriate speed while maintaining good lane positioning on a straight road (for 30 seconds)
Pedals Static	Level 2	Phase 1	1. Press the pedal to hold the indicator within a static target zone
Steering Static	Level 2	Phase 1	1. Effectively and efficiently move the steering wheel to a static target zone
Stop Light and Steering	Task Only, 64 symbols	Phase 1	1. Interact with the pedals and steering wheel 2. Interpret the meaning of on-screen symbols (traffic lights and arrow) in relation to steering and pedal responses
Combined Controls	Gas Level 1	Phase 1	1. Press the pedals and turn the wheel with a static target zone
Combined Controls	Brake Level 1	Phase 1	1. Press the pedals and turn the wheel with a static target zone
Lane Keeping, Changing Lanes	--	Phase 2	1. Practice changing lanes and using turn signals on straight road with no traffic

Speed Control Straight	--	Phase 2	1. Maintain target speeds while maintaining central lane position
Turning Left	--	Phase 3	1. Practice making left hand turns at intersections
Turning Right	--	Phase 3	1. Practice making right hand turns at intersections
Following Distance	--	Phase 3	1. Practice safe following distances
Pedals Static	Level 3	Phase 1	1. Press the pedal to hold the indicator within a static target zone
Steering Static	Level 3	Phase 1	1. Effectively and efficiently move the steering wheel to a static target zone
Pedals and Stopping	--	Phase 3	1. Become familiar with pedal operation and stop vehicle at stop signs and traffic lights
Merging	--	Phase 3	1. Introduce merging into freeway traffic
Changing Lanes and Braking	--	Phase 3	1. Practice lane changing and stop sign intersections
Obstacles on Straight	Beginner	Phase 3	1. Make smooth lane changes and avoid obstacles
FOD	Complete full tutorial procedure, cruise pop	Phase 2	1. Drive down a straight road while scanning the driving environment for targets 2. Respond to lead vehicle brake events
FOD	Do not complete full tutorial, no cruise pop	Phase 2	1. Drive down a straight road while scanning the driving environment for targets 2. Respond to lead vehicle brake events
Lane Keeping Mirrors	--	Phase 2	1. Practice mirror usage and awareness of surrounding vehicles Practice lane changing, can crash
Level 1 Hazards	--	Phase 4	1. Drive on a straight road, avoid (3) hazardous events, can crash 2. Park the car on the side of the road at end of drive

Obstacles on Straight	Advanced	Phase 3	1. Make smooth lane changes and avoid obstacles
Level 2 Hazards	--	Phase 4	1. Drive on a straight road, avoid (3) hazardous events
FOD- Advanced	All rows, no cruise pop, 0 distractors, 0 fade time, 2 display time, 1 presentation	Phase 4	1. Drive down a straight road while scanning the driving environment for targets 2. Respond to lead vehicle brake events
Level 3 Hazards	--	Phase 4	1. Drive on a straight road, avoid (3) hazardous events
City and Highway	--	Phase 4	