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Evaluating Driving Performance Of Adolescents And Young Adults With Autism Spectrum Disorders Around Social And Non-Social Hazards

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EVALUATING DRIVING PERFORMANCE OF ADOLESCENTS AND YOUNG ADULTS WITH AUTISM SPECTRUM DISORDERS AROUND SOCIAL AND NON-SOCIAL HAZARDS

by

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ABSTRACT

The leading cause of death among adolescents is motor vehicle collisions, which may be due to a number of factors including inexperience and incomplete brain development. These risks may be even more prominent for young drivers with Autism Spectrum Disorders (ASD) because of additional impairments in processing speed, social communication and emotional regulation. Despite elevated safety risks, little research has considered the impacts of ASD on driving. This study aimed to characterize driving performance and hazard perception of drivers with ASD, specifically various types of hazards (e.g., pedestrians or other cars). The study also aimed to investigate factors that predict driving performance. Drivers with ASD, drivers with ADHD and typically developing drivers drove in a simulator embedded with a series of hazards classified as either social (e.g., containing a visible human element) or non-social (e.g., no visible human element). An assessment battery measuring motor coordination, processing speed and social skill was used to identify potential predictors. Six indicators of driving performance were recorded by the driving simulator: (1) standard deviation of lane position (RMS), (2) reaction time to hazards, (3) standard deviation of speed, (4) average driving speed, (5) motor vehicle collisions (MVCs) and (6) number of speed exceedances. Results indicated that drivers with ASD drove significantly more slowly and had marginally less speed variability than drivers with ADHD. All participants had faster reactions times, fewer MVCs and drove slower around social driving hazards vs. non-social hazards. Drivers with ADHD and those with typical development had faster reaction times to social vs. non-social hazards whereas no difference was found for drivers with ASD. For ASD participants, age, driving experience, and ASD symptoms predicted simulated MVCs, while gender predicted simulated speed exceedances. Together, findings suggest that drivers with ASD may drive more cautiously compared to their ADHD counterparts and may not respond to social hazards the same way as drivers without social impairment. Future studies are needed to further investigate the differences in driving behaviors across developmental disabilities and how these driving behaviors may impact overall driving safety in these vulnerable road users.

Keywords: Autism Spectrum Disorder, Attention-Deficit/Hyperactivtity Disorder, Driving simulator, Hazard response, Neurodevelopmental disabilities

DEDICATION

This thesis work is dedicated to my Lord and Savior Jesus Christ who has given me everything I have and to whom I owe all. This work is also dedicated to my loving and supportive husband Justin Bishop who has been with me through the good times and the bad. I love you dearly and more and more with each day you put up with me. My work is also dedicated to my amazing father and mother, Jeff and April Johnson. You both have always pushed me to be my best, and I know for a fact that I would not be where I am today if I did not have you two as parents. I would also like to thank my mentor Despina, who has been more than just a faculty mentor, but a friend who has believed in me from the day I started working for her.

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EVALUATING DRIVING PERFORMANCE OF ADOLESCENTS AND YOUNG ADULTS WITH AUTSIM SPECTRUM DISORDERS AROUND SOCIAL AND NON-SOCIAL HAZARDS

Driving is an automatic process for most individuals. However, for some, driving is an obstacle that must be overcome every day to enjoy the independence that others may take for granted. Drivers with neurodevelopmental disabilities, more specifically Autism Spectrum Disorders (ASD), face this very problem. The prevalence of ASD is increasing at a rate never seen before in history, jumping from 1 in 88 children in 2008, to 1 in 68 children in 2014 (Centers for Disease Control and Prevention [CDC], 2015a). Many of these children are now transitioning into adulthood and they will soon be faced with the difficult decision of whether or not they will learn to drive (Hendricks & Wehman, 2009). Parents are often part of the decision-making process concerning driving and licensure as well (Huang, Kao, Curry, & Durbin, 2012). Unfortunately, parents have few resources to consult when making the decision to allow their child to drive, as little empirical evidence exists on the driving challenges and deficits associated with ASD. It is more important now than ever to begin understanding the specific challenges of driving for individuals with ASD and finding ways to meet specific driving needs of this vulnerable and growing population.

Through the use of a driving simulator, this study investigated whether adolescents and young adults with ASD exhibited specific driving impairments. The driving simulator provided a safe and ethical methodological approach for measuring driving capabilities and behaviors in high risk driving populations, like drivers with ASD. The following introduction addresses pertinent topics on ASD and driving and outlines specific study aims and associated hypotheses.

INTRODUCTION

Drivers with Autism

For the surge of children diagnosed with an Autism Spectrum Disorder (ASD) in the early 2000's, who will soon be approaching driving age, the decision to drive and the challenges that will accompany it are nearing quickly (Centers for Disease Control and Prevention [CDC], 2015a). A survey conducted in 2010 revealed that only 24% of adults with ASD, most of whom described themselves as "high functioning", reported that they were independent drivers (Feeley, 2010). This number is dramatically lower than the 87% of drivers in the general population who consider themselves to be independent drivers (Administration, 2011). A recent pilot study investigating the self-reported driving behaviors of licensed drivers with ASD revealed that, compared to non-ASD drivers, drivers with ASD report significantly lower ratings of their driving abilities, suggesting that they are less confident in their driving abilities than typically developing controls (Daly, Nicholls, Patrick, Brinckman, & Schultheis, 2014). ASD participants in the same study also reported more intentional violations (e.g., speeding or tailgating), driving mistakes (i.e., making a maneuver without checking mirrors, pressing the wrong pedal), and slips or lapses than did typically developing controls. In another survey, the majority (70%) of parents who had adolescents with ASD who were driving or trying to receive their driver's license, reported that their child's autism "moderately" to "extremely" negatively impacted their child's driving abilities (N. B. Cox, Reeve, Cox, & Cox, 2012). These same parents identified multitasking (e.g., merging while maintaining speed), awareness of traffic, use of mirrors and maintaining lane position as the most difficult (rated as "very difficult') skills to teach their son or daughter with ASD (N. B. Cox et al., 2012). Turning, speed control, and braking were also rated as “difficult” tasks when teaching their child to drive. Parent’s also rated the impact of seven characteristics commonly associated with ASD on their adolescent’s driving abilities, and reported that “non-verbal communication” and “unexpected changes in routine” were the most problematic for driving (N. B. Cox et al., 2012). A recent study examining driving skills that were most challenging in the learning to drive period for young drivers with ASD also found that adjusting to unfamiliar situations was one of the most commonly reported problematic skills (Almberg et al., 2015). Qualitative data from this study echo many of the concerns that parents of teens with ASD have expressed in previous research. For example one teen said,

> You have to learn to think, to anticipate that a child may run out on the road from behind a hedge or so . . . yeah, it’s hard. I sort of think I’m in control but my instructor anticipates many more hazards than I do, and brakes before I understand why.

Teens with ASD also self-reported “interacting with other drivers” and “interpreting traffic situations” as some of the most difficult driving skills (Almberg et al., 2015). When these same teens’ driving instructors were questioned about the driving situations that were most challenging for the drivers with ASD they cited the inflexibility and rule following characteristics of ASD as major barriers to driving. The ability to drive is vital for success in achieving the independent lifestyle desired by the majority of those with autism (Gaylord, Abeson, Bosk, Timmons, & Lazarus, 2005). To give those diagnosed with ASD the best chance at a full and happy life, a better understanding of obstacles that drivers with ASD face is important.

Although driving is a difficult task for this specific population, it is also an essential ingredient to the independence and quality of life for adults with ASD. Specialized training efforts have shown success in training individuals with cognitive limitations to pass the learner’s permit portion of the driver’s test (Lanzi, 2005). This simplified approach to teaching individuals with cognitive limitations may also be successful in training individuals with ASD to obtain not only their leaner’s permit, but also their full driver’s license. Driving facilitates mobility, which in turn increases the likelihood of those with ASD will be successfully employed, attend social gatherings and not have to rely as heavily on their parents or caregivers. Although public transportation is frequently used in large cities and urban areas, those with ASD in rural and suburban areas are forced to rely on family and friends for transportation (Gaylord et al., 2005). For individuals with ASD, the ability to drive themselves around would open the door to other opportunities to be independent such as independent living and employment. Renty and Roeyers (2006) found that the more independent adults with ASD feel, the greater the increase in their self-reported quality of life. Improving quality of life for individuals with ASD is extremely important as more and more children are being diagnosed and will later be faced with the challenges of living independently (Zablotsky, Black, Maenner, Schieve, & Blumberg, 2015). Unfortunately, there are several impairments that accompany the diagnosis of ASD, making the complex task of driving especially challenging for these individuals.

ASD is a neurodevelopmental disorder characterized by deficits in social communication and social interaction, as well as the presence of repetitive behaviors and restricted interests, accompanied by a complex combination of diminished, intact and enhanced cognitive abilities (American Psychiatric Association [APA], 2014). There are several different areas of impairment associated with ASD that are particularly relevant to driving, including: (1) deficiencies in executive functioning (Faul, Erdfelder, Lang, & Buchner, 2007; Fournier, Hass, Naik, Lodha, & Cauraugh, 2010; Munoz, Armstrong, Hampton, & Moore, 2003; Rinehart, Bradshaw, Brereton, & Tonge, 2001; Wilde, 1976), (2) reduced attentional capacity (Bradley & Isaacs, 2006; Fan et al., 2012; Romer, Lee, McDonald, & Winston, 2014), (3) poor emotion regulation (Heerey, Keltner, & Capps, 2003; Jahromi, Bryce, & Swanson, 2013; Jahromi, Meek, & Ober-Reynolds, 2012), and (4) an array of social impairments (Centelles, Assaiante, Etchegoyhen, Bouvard, & Schmitz, 2013; Klin, Jones, Schultz, & Volkmar, 2003; Klin, Jones, Schultz, Volkmar, & Cohen, 2002; Zalla, Labruyere, & Georgieff, 2013).

The current study is only the second to examine the impact of these specific impairments on driving performance in adolescents and young adults with ASD, a research topic identified as understudied and greatly needed (S. M. Cox et al., 2015). However, unlike the previously conducted study by Cox and colleagues (2015), the current study recruited participants with ASD and typically developing controls matched on driving experience, a variable identified in previous literature as having a large impact on driving performance (Mayhew, Simpson, & Pak, 2003). Because Cox and colleagues (2015) did not match groups on driving experience, it may be that decrements in driving performance seen in non-licensed individuals with ASD were due to the differences in driving experience in ASD versus fully licensed typically developing controls. This current study addresses this concern by matching groups on driving experience.

Although deficits in executive function and reduced attentional capacity certainly play a large role in driving performance difficulties(Anstey, Wood, Lord, & Walker, 2005) (Munoz et al., 2003; Salvucci, 2006; Tabibi, Borzabadi, Stavrinos, & Mashhadi, 2015), the current study focused specifically on the impact of social deficits seen in ASD on driving performance around hazards which has not been previously been considered in this context. Other cognitive abilities such as processing speed and motor coordination were also explored as possible predictors of poor driving performance. Previous literature suggests that slower speed of processing may affect rapid decision making and lead to negative driving outcomes (Jerome, Segal, & Habinski, 2006; McManus, Cox, Vance, & Stavrinos, 2015). Motor skills (i.e., flexibility, motor response speed) have also been identified as an essential component of safe driving (Anstey et al., 2005), which suggests that impairments in motor skills (such as those seen in ASD) may negatively affect driving performance (Brown, 1986). Along with the hallmark impairments associated ASD, other factors to consider when determining driving capabilities of those with ASD, as well as all drivers, are age and driving experience.

Typically Developing Adolescent drivers

There is a vast literature on driving risks for young, typically developing adolescent drivers. A variety of factors are known to increase driving risks for young, adolescent drivers such increase propensity to engage in risky driving behaviors (i.e., speeding, distracted driving), incomplete development of the prefrontal cortex (a brain area involved in decision-making and other executive functioning skills) and inexperience (Compton & Ellison-Potter, 2008; Shope & Bingham, 2008; Williams, 2003). One of the most salient of these factors is inexperience which contributes to young drivers' difficulty with their anticipation and identification of dangerous situations in the driving environment (McCartt, Mayhew, Braitman, Ferguson, & Simpson, 2009; Sagberg & Bjornskau, 2006). As a result of their inexperience, young drivers often have a hard time identifying dangerous driving situations before they happen (Simons-Morton et al., 2011). In some cases, they may even be aware of a hazard, but may underestimate the severity of the danger (Centers for Disease Control and Prevention [CDC], 2015b). The impairment in identifying dangerous situations in conjunction with the distractions in which young drivers typically engage places them at an increased risk for fatal motor vehicle collisions (MVCs). Older, more experienced drivers can more easily anticipate (Holdnack, Zhou, Larrabee, Millis, & Salthouse, 2011), recognize and avoid hazardous situations possibly due to experience and greater availability of attentional resources. A recent study by Crundall (2016) found that the ability to predict when and where hazardous situations occurred in the driving environment accurately discriminated between novice and experienced drivers, further illustrating the important role driving experience plays in driving safety and mitigation of dangerous driving situations.

Another factor that increases young driver risk is increased willingness to engage in risky driving behaviors compared to other age groups (Centers for Disease Control and Prevention [CDC], 2015b; Lee, McElheny, & Gibbons, 2007). Driving late at night, driving with multiple passengers in the car and driving while using a cell phone are a few of the most common risky driving behaviors reported by young drivers (Goodwin, Foss, Harrell, & O'Brien, 2012; Olsen, Shults, & Eaton, 2013; Simons-Morton et al., 2011). Performing secondary tasks (such as text messaging on a cell phone) in these risky situations (e.g., low visibility, around driving hazards), where cognitive and attentional resources are already being taxed for driving, proves to be an extremely dangerous combination (Burge & Chaparro, 2012; Stavrinos et al., 2015). The inexperience and increased propensity to engage in risky driving commonly seen in typically developing adolescent drivers in combination with the impairments specific to individuals with ASD (i.e., impairments in executive functioning, motor coordination, social skills) may make young drivers with ASD an especially vulnerable and high risk population of drivers.

Social Impairments

Although each individual is in his or her own vehicle, the network of drivers on the roadway is an undeniably social environment (N. Benson, Hulac, & Kranzler, 2010; Kulp & Sortor, 2003). The existence of this vast social ecosystem is contingent on the successful interactions of hundreds of drivers running smoothly. Not only does this ecosystem include drivers, but also other road users including cyclists and pedestrians. The often sudden and sometimes subtle exchanges between drivers and other road users can be the difference between life and death. Gueguen and colleagues (2016) recently examined this complex social exchange by evaluating how a pedestrian's smile may influence the behavior of oncoming drivers. Findings suggested that oncoming drivers were more likely to stop for and drove more slowly approaching a pedestrian who was smiling compared to one who was not (Guéguena et al., 2016). These results suggest that non-verbal communication - even something as subtle as a smile - can alter the relationship between road users.

The use of body language as a form of non-verbal communication is usually automatic in typically developing drivers, but this automatic understanding can be affected and even absent in those with ASD. Numerous studies have revealed significant deficits in the interpretation of body language as a form a communication for ASD groups compared to typically developing controls (Centelles et al., 2013; Klin et al., 2003; Zalla et al., 2013). These deficits are less apparent when ASD participants are specifically asked to identify the meaning of body cues in a laboratory setting, but when placed in naturalistic settings the impairments become much more distinct (Zalla et al., 2013). The interpretation of body language comes into play for drivers most when encountering other road users (e.g., pedestrians or cyclists). Reading and anticipating the actions of pedestrians and cyclists is an essential skill for drivers to possess to maintain safety.

The hallmark social profile of someone with ASD includes, first and foremost, a profound impairment in the interpretation of actions based upon the verbal and non-verbal communication of others (Centelles et al., 2013). Many of the social deficits in those with ASD are related to deficits in the theory of mind (Frith, 1994). Theory of mind is the ability to interpret and understand the mental states of others (Zelazo, Jacques, Burack, & Frye, 2002). Theory of mind impairments are consistently attributed to people with ASD, in part, because of their inability to interpret social situations and their diminished capacity for social interactions with others (Kleinman, Marciano, & Ault, 2001). Without the successful use of theory of mind to anticipate and interpret the actions of other drivers, getting around in the environment, especially the driving environment may be exceedingly more challenging for ASD drivers.

Another important facet of social skills is social orienting, the natural tendency of people to orient their attention to social rather than non-social stimuli. This tendency has been shown to be somewhat automatic in typically developing humans and even monkeys

(Deaner & Platt, 2003; Hill et al., 2010). An exception to this reflex is in the case of those diagnosed with ASD. Previous research has demonstrated that this automatic tendency to allocate attention to social information is impaired and in some cases, absent in those with ASD (Dawson, Meltzoff, Osterling, Rinaldi, & Brown, 1998). Dawson and colleagues (1998) examined this phenomenon by comparing the visual social orienting abilities of children with autism as compared to another group of children with similar developmental delays without the known social impairments of ASD: children with Down syndrome. Both groups of children were presented with two social (child's name being called and hand clapping) and two non-social (sound of rattle and music from a toy) stimuli. They found that compared to those with Down syndrome, children with ASD more frequently failed to visually orient to social stimuli, and if they did, it took children with ASD significantly longer to do so (Dawson et al., 1998). Another study by Wright and colleagues (1987) examined the preferential, visual orienting of children with ASD using point-light displays of biological and mechanical motion. They discovered that children with ASD failed to show the preference to biological motion that was observed in typically developing children (Quimby et al., 1987). The presence and speed of social orienting is vital to identify and react to social stimuli. Pedestrians in a roadway environment provide a real-world example of social stimuli, and the natural tendency of typical drivers to orient their attention to them makes it easier to avoid pedestrian related driving hazards (e.g., a person steps out into the street or a child crosses the street unattended). Because the natural social orienting reflex is impaired in those with ASD, it stands to reason that ASD drivers would be at a disadvantage in identifying and avoiding hazards that are social in nature. In an online survey, adult drivers with ASD reported being involved in significantly more car crashes where they hit another driver or pedestrian than their non-ASD counterparts (Daly et al., 2014). Little research has sought to understand how the social impairments associated with ASD affect driving performance in general, and the perception of hazards in particular (Sheppard, Ropar, Underwood, & Van Loon, 2010).

Hazard Perception

Hazard perception is a driver’s ability to foresee potentially dangerous driving situations, and has been identified as a driving ability that has serious implications for roadway safety and avoiding motor vehicle collisions (McKenna & Horswell, 1999). In typical drivers, hazard perception is largely based on visual attention and eye fixation patterns; put simply, it is based on what grabs the driver’s eye gaze and the path that gaze follows throughout the drive (Doshi & Trivedi, 2009; Hardiess, Hansmann-Roth, & Mallot, 2013; Pradhan et al., 2005; Smith, Shah, & Lobo, 2003; Underwood, Phelps, Wright, Van Loon, & Galpin, 2005). Typically developing, experienced drivers tend to focus their visual attention on important, safety-relevant aspects of the driving environment (e. g., the cars in front of them, pedestrian crosswalks, traffic lights and road signs) (Almberg et al., 2015; Borowsky, Shinar, & Oron-Gilad, 2010). A study by Crundall (2015) found that hazard prediction was less effortful for experienced drivers compared to novice drivers and this difference was even greater when the driving hazard was less obvious (e.g., a car pulling out of a hidden drive). Experienced drivers’ increased attention to important areas of the driving environment and their ability to quickly scan the scene for hazards provides them with adequate information to drive safely and allows them to react more quickly to avoid these hazardous situations

(Almberg et al., 2015; Borowsky et al., 2010). This visual scanning ability has shown to be impaired not only in novice drivers, but also in individuals with ASD (Corbett, Constantine, Hendren, Rocke, & Ozonoff, 2009; Yi et al., 2012). In an eye tracking study by Yi and colleagues (2012) children with ASD performed significantly worse than age matched, typically developing controls on the visual scanning aspect of the Dimensional Change Card Sorting Task. More specifically, the ASD group spent a significantly longer time looking at an incorrect response card (i.e., any card that was not the correct card) when compared to typically developing controls. In the driving environment, the inability to rapidly visually scan an environment and identify important, target items (e.g., traffic lights, other cars, pedestrians, stop signs, etc.) could result in involvement in motor vehicle collisions but scanning has not been previously considered in this at-risk population.

Deficits in hazard perception may be more evident for drivers with ASD if the hazard is social, human or biological in nature (e.g., a pedestrian crossing the street rather than a car stopped in the roadway). The social deficits of ASD in the areas of body language, adherence to social norms and social cues are well documented in previous literature, specifically in the context of observing and identifying conventional social (e.g., two people shaking hands, waving goodbye or hugging) and emotional (e.g., people crying and being comforted or sharing happiness) situations (Centelles et al., 2013; Klin et al., 2002; Pierce, Glad, & Schreibman, 1997). Those with ASD are less skilled than typically developing controls at distinguishing motion for biological or living organism from mechanical movement (Centelles et al., 2013). Previous eye tracking research has also shown that adults with ASD, when asked to view a social scene and report any oddities, were unable to immediately recognize social violations (V. Benson, Castelhano, Howard, Latif, & Rayner, 2015). Unlike typically developing individuals who immediately looked at and reported social violations in the scene, adults with ASD often fixated on social violations but only reported the violation after looking elsewhere and coming back to the social violation (V. Benson et al., 2015). Delays in social recognition could lead to problems in real world situations such as conversation with others, where there is no chance to return to a moment and recover missed social cues. Although it has not been studied explicitly in the context of a driving environment, it stands to reason that these social impairments would affect social aspects of driving such as reading the body language of pedestrians (Zalla et al., 2013) or following the common social courtesies of driving (Guéguena et al., 2016). Failure to perceive driving hazards may result in slower reaction times and further increase risk of motor vehicle collisions. This is an especially important area of research as social hazards (i.e., pedestrians and cyclists) have the highest rates of injury and fatality when involved in a MVC (Moudon, Lin, Jiao, Hurvitz, & Reeves, 2011). The detection of hazards, whether social or non-social in nature, provide a driver with information to assess the risk associated with a particular situation and allows them to quickly identify their ability to deal with that hazard appropriately (Deery, 1999).

Previous Autism and Driving Research

Although much research has been conducted on ASD and daily living skills, little research has examined the effects of having ASD on driving performance. Reimer and colleagues (2013) were one of the first to test the driving capabilities of individuals with ASD using a driving simulator. Findings indicated that compared to matched, typically developing controls; drivers with ASD had significantly slower reaction times when identifying hazards with a response button. This is important when considering that delayed reaction time is a significant predictor of motor vehicle collision-related injury or death (Elander, West, & French, 1993). Eye tracking results in Reimer's study (2013) further revealed that drivers with ASD focused their eye gaze more on low stimulus areas of the driving environment (e.g., looking up towards the horizon where there are fewer cars) than high stimulus areas of the driving environment (e.g., directly at the car in front of them, at pedestrians walking to their right or left) (Reimer et al., 2013). This is particularly dangerous in a real-world driving environment, because high stimulus areas such as city streets and suburban streets are where hazards often occur for various reasons (e.g., more pedestrian crossings and intersections) (Moudon et al., 2011). Although Reimer and colleagues (2013) examined the vulnerable group of drivers with ASD compared to typically developing controls, they did not examine ASD driving behavior compared to a clinical control population of drivers. Clinical control groups in research may aid in differentiating explanations for poorer driving performance in adolescents and young adults with ASD. One clinical population that shares some of the impairments seen in ASD is Attention-Deficit/Hyperactivity Disorder (ADHD).

ADHD is a behavioral disorder with inattention and/or hyperactivity-impulsivity (American Psychiatric Association [APA], 2014) and affects over 13% of the population in Alabama (Centers for Disease Control and Prevention [CDC], 2014). The Combined Type of ADHD (ADHD-C), however, is a subtype of ADHD that presents with at least six symptoms of each inattention and hyperactivity-impulsivity characteristics (American Psychiatric Association [APA], 2014), as well as deficits in executive functioning

(Barkley, 1997). Several of these symptoms of ADHD, such as inattention and executive function deficits (Gioia, Isquith, Kenworthy, & Barton, 2010), are shared with those diagnosed with ASD (Ronald, Simonoff, Kuntsi, Asherson, & Plomin, 2008), however, those with ADHD do not display the same type of social impairments seen in ASD (American Psychiatric Association [APA], 2014). The social skills deficits seen in individuals with ADHD are most commonly due to social isolation due to inappropriate, hyperactive behaviors and inability to sustain attention in social conversations, whereas the social skills deficits seen in individuals with ASD are due to an inability to understand and respond to social cues in the environment (de Boo & Prins, 2007; Klin et al., 2002). Because the current study's focus was on the effects of social information processing on driving and this impairment is one of the distinguishing characteristics of ASD and ADHD, drivers with ADHD seemed to be an appropriate clinical control group to isolate the effects of social impairment on driving performance.

Classen and colleagues (2013) examined the driving characteristics of non-driving adolescents with ASD compared to ADHD as well as individuals with a combined diagnosis of ASD and ADHD. Findings suggested that those with ASD+ADHD experienced deficits in selective attention, visuo-motor integration and motor performance, which resulted in a poorer driving performance in the areas of visual scanning, speed regulation, lane maintenance, adjustment to stimuli (i.e., adjusting the width of a turn to accommodate another vehicle in an adjacent lane) and total number of driving errors. Although this study examined the effects of a combined diagnosis of ASD and ADHD in the context of a simulated driving environment, previous work has not considered the effects of social versus non-social hazards on driving performance in drivers with ASD as compared to typically developing controls. This is an important aspect of driving to consider as social orienting and processing of social information is a known impairment for those with ASD (Klin et al., 2002).

Cox and colleagues (2015) conducted the most recent driving simulator study in a population of individuals with ASD who had received their learner's permit. The goal of the study was to examine the role of executive function and basic motor skill in tactical driving performance in 17 individuals with ASD who were not yet fully licensed but had obtained a driver's permit compared to 27 typically developing controls who had just received their full driver's license. Results indicated that the ASD group exhibited poorer driving performance (i.e., increased swerving, increased lane changes) and decrements were further compounded with the addition of a working memory task. Findings of the study also suggested that the ASD group had significantly slower hand/arm reaction times (i.e., swerving) when compared to typically developing controls (S. M. Cox et al., 2015). The study did not take into account the differences in driving experience, a factor shown by previous literature to have a large impact on driving performance (Almberg et al., 2015; Mayhew et al., 2003). Not only did the ASD and typically developing groups have inherent differences in driving experience (i.e., the ASD group had only permits while the typically developing group had obtained a full unrestricted license), but they also did not consider within group variability in driving experience. The impact of hazard typology (i.e., social vs. non-social) on driving performance was also not taken into account in this study. The type of hazard that a driver is encountering is an important topic of study as pedestrian and cyclists are 1.5 times more likely to be involved in a fatal collision than other motor vehicles (Moudon et al., 2011), and little research has been done to examine differences in social and non-social hazard perception.

Sheppard and colleagues (2010) sought to answer the question of social and non-social hazard perception by examining the ability of adults with ASD (average age = 23 years), who were regular car passengers but not licensed drivers, to identify social (e.g., a visible pedestrian or cyclist) versus non-social (e.g., car where driver was not visible) hazards. Previous studies have indicated that drivers perceive cars and other motor vehicles where the person is not visible as non-social, but become social when the source of the hazards is a visible human (Walker, 2005). Participants were asked to watch a video clip from the perspective of a passenger in a car (as none of the participants were current drivers but all were regular car passengers), and press a response key as soon as they recognized a hazard in the clip. This response paused the clip, at which point participants were asked to tell the experimenter if the clip was social or non-social in nature. Across experimental groups (ASD and controls) participants exhibited slower reaction times when presented with hazards that were social rather than non-social in nature. Adults with ASD had significantly longer reaction times in identifying all hazards than matched controls, and also identified fewer social hazards (Sheppard et al., 2010). These findings suggest that the identification of social hazards may be impaired in drivers with ASD. However, as previously noted, the nature of these social impairments has not been clearly explained, and few, if any, studies have examined the abilities of drivers with ASD to identify and avoid social and non-social hazards in a driving environment.

The Current Study

Although significant differences were previously found in identification of hazards from the perspective of a car passenger (Sheppard et al., 2010), the ability of an individual to identify hazards should be tested when they are the driver of the vehicle, as car passengers do not have the added motor, cognitive and attention demands that the complex task of driving requires (Salvucci, 2006). A driving simulator provides a safe, validated and accurate means of studying how a deficit in identification of social hazards may affect the driving performance of individuals with ASD (Godley, Triggs, & Fildes, 2002; Kaptein, Theeuwes, & Van Der Horst, 1996; Mullen, Charlton, Devlin, & Bedard, 2011; Underwood, Crundall, & Chapman, 2011). The current study is one of only a few such studies in a small body of research examining the driving behaviors of individuals with Autism Spectrum Disorder through the use of a driving simulator (Classen, Monahan, & Hernandez, 2013; S. M. Cox et al., 2015; Reimer et al., 2013)

Pedestrians and cyclists are the most common forms of social hazards in urban areas and in 2012, nearly 5,000 of them were killed in crashes involving motor vehicle collisions, accounting for 14% of all traffic fatalities (National Highway Traffic Safety Administration [NHTSA], 2013). Considering the high prevalence of social hazards on the roadway and safety risks that accompany them, it is essential to better understand the abilities of drivers with ASD to perceive and avoid these social hazards that account for such a significant portion of motor vehicle related fatalities.

Specific Aims

The current study was among the first to evaluate the perception of social and non-social driving hazards in ASD drivers in a simulated driving environment. Unlike previous studies that have examined the driving behavior of adolescents and adults with ASD (Classen et al., 2013; S. M. Cox et al., 2015; Reimer et al., 2013), the current study was the first to include a clinical comparison group of drivers with ADHD as well as a typically developing control group. It was also the first study to match these clinical and typically developing controls to drivers with ASD on driving experience, a variable that has a significant impact on driving performance (Mayhew et al., 2003). The inclusion of clinical and typically developing controls matched on driving experience allowed for isolation of impairments associated with ASD that may affect driving performance by controlling for the effects of experience and accounting for similar impairments also found in ADHD (i.e., executive function impairments, attentional impairments) (Clark, Feehan, Tinline, & Vostanis, 1999; Corbett et al., 2009). The overall aim was to evaluate driving performance among adolescents and young adults with ASD as compared to drivers with ADHD and typically developing controls, and further driving performance around hazardous driving situations of varying type (i.e., social or non-social). The following specific aims were tested:

AIM 1: Evaluate the driving performance of drivers diagnosed with Autism Spectrum Disorder in a simulated driving environment as compared to a clinical control group of drivers with ADHD and typically developing controls.

Driving performance was measured using six driving indicators collected by the driving simulator: (1) root mean square (RMS) or standard deviation of lane position, (2) reaction time, (3) standard deviation of speed, (4) average driving speed, (5) motor vehicle collisions (MVCs) and (6) number of speed exceedances. Differences between diagnostic groups (ASD, ADHD, and Control) on continuous measures of driving performance (RMS, reaction time, standard deviation of speed and average driving speed) were tested using Analysis of Covariance (ANCOVA), controlling for any significant demographic differences found among the groups. Due to the rare nature of the count variables (i.e., MVCs and number of speed exceedances), a Generalized Estimation Equation (GEE) Poisson model was used to examine the effect of diagnostic group, while controlling for any demographic variables that may differ between groups. Significant differences among the groups were followed up with Tukey's post hoc pairwise comparisons.

Hypothesis 1. Based on previous work indicating that individuals with ASD exhibit increased driving errors, poorer lane maintenance, and poorer driving performance (Classen et al., 2013; S. M. Cox et al., 2015; Reimer et al., 2013), it was expected that drivers with ASD would have poorer driving performance (greater deviation in lane position [RMS], slower reaction times, greater variability in speed, more MVCs and more speed exceedances) compared to the clinical control (ADHD) and typically developing control group. No specific hypothesis was made for differences in average driving speed, as there was no previous literature to consult on this topic.

AIM 2: Assess the ability of those with ASD to respond to and avoid social and non-social hazards compared to drivers with ADHD and typically developing controls.

Avoidance of social and non-social hazards was assessed based on the driver's reaction time to the presentation of the hazard (e.g., how quickly the driver reacted to avoid a pedestrian or oncoming vehicle) and success in avoiding a MVC with the hazard.

The effects of hazard type on driving performance were analyzed using a Generalized Linear Model (GLM) for continuous measures (reaction time and average driving speed) and GEE Poisson for count variables (MVCs and speed exceedances).

Next, to analyze the interaction effects of group and hazard type on continuous driving performance outcomes (reaction time and average driving speed) a GLM with a mixed model approach was used. GEE Poisson analysis was utilized to analyze the interaction effects of group and hazard type on count, driving performance variables (MVCs and speed exceedances), controlling for significant differences among the group on any demographic variables. Tukey's post hoc pairwise comparisons were used to further analyze significant differences among the groups.

Hypothesis 2a. Based on the findings of Sheppard and colleagues (2010) which revealed slower reaction times to social hazards in individuals both with and without ASD, it was expected that regardless of diagnostic group, poorer driving performance would occur surrounding social hazard condition (i.e., pedestrians and cyclists) when compared to the non-social hazard condition (i.e., other cars or objects in the roadway).

Hypothesis 2b. Based on the preliminary video-based findings of Sheppard and colleagues (2010) indicating that drivers with ASD identified significantly fewer social hazards than those without ASD, it was expected that individuals with ASD would identify significantly fewer social hazards as compared to typically developing controls and individuals with ADHD in a simulated driving environment. The ability to identify and avoid hazards by individuals with ASD was measured using their driving performance as they navigated through a scenario in a driving simulator. Indicators of poor driving performance (reaction time, MVCs and speed exceedances) around the hazards embedded in the scenario provided a measure of the driver's ability to identify and avoid them. Due to social impairments (Centers for Disease Control and Prevention [CDC], 2015a), it was expected that drivers in the ASD group would have significantly poorer driving performance surrounding social compared to non-social driving hazards.

AIM 3: To identify significant predictors of poorer driving performance in drivers with ASD.

Many of the impairments associated with ASD such as motor coordination, visual scanning and attention have been implicated as potential culprits behind the impairments in driving performance noted in drivers with ASD (Classen et al., 2013; S. M. Cox et al., 2015; Reimer et al., 2013). Few studies however have examined the effects of the social skills deficits in ASD on driving performance, and no study has examined effects of these deficits in a simulated driving environment. Previous work has not considered how these skills relate to driving performance in drivers with ASD.

Potential predictors of driving performance for ASD drivers included: ASD symptoms; ADHD symptoms; processing speed; motor coordination; as well as social skill impairment. Predictors were tested using a series of four step hierarchical multiple regressions to predict continuous driving performance outcomes (RMS, reaction time, average driving speed and standard deviation of speed) and GEE Poisson regressions to predict count driving performance outcomes (MVCs and speed exceedances). The first step included demographic variables (age, gender, driving experience), step two included diagnostic variables (ASD and ADHD symptoms), step three included cognitive abilities (processing speed and motor coordination) and the final step included social skill impairment.

Hypothesis 3a. Based on the pilot data collected by Classen and colleagues (2013) suggesting that participants with ASD had poorer driving performance along with the self-reported decreased driving capabilities of drivers with ASD from the online survey study (Daly et al., 2014), it was expected that presence of ASD symptoms (as measured by their score on the AQ) would significantly predict poorer driving performance for all driving performance indicators (RMS, reaction time, standard deviation of speed, average driving speed, MVCs and speed exceedances) over and above demographic factors.

Hypothesis 3b. It was also expected, based on previous ADHD and driving research (Barkley & Cox, 2007), that ADHD symptoms (as defined by the inattentive and impulsivity scores on the DBRS) would significantly predict poorer driving performance over and above demographic factors in individuals with ASD.

Hypothesis 3c. The deficits of drivers with ASD in the areas of motor coordination and processing speed shown in previous studies (Classen et al., 2013; Monahan, Classen, & Helsel, 2013; Reimer et al., 2013), lead us to expect motor coordination (as measured by the Beery Motor Coordination subscale of the Beery Visual-Motor Integration test) and processing speed (as measured by Processing Speed Index subscale of the WAIS-IV) to emerge as significant predictors of poorer driving performance for all driving performance indicators over and above demographic and diagnostic predictors.

Hypothesis 3d. Based on the findings of Sheppard and colleagues (2010) it was also expected that greater social skill impairment would significantly predict slower reaction times, more MVCs and more speed exceedances over and above all other predictors.

METHOD

Participants

The total sample consisted of 47 young adults (16 to 30 years old): 16 with a clinical diagnosis of ASD, 15 with a clinical diagnosis of ADHD, and 16 typically developing controls. The majority of the sample was male (approximately 94%) as expected given the distribution of ASD prevalence in the general population, with ASD being five times more common in males than females (Centers for Disease Control and Prevention [CDC], 2015a). As ASD occurs equally in all racial and ethnic groups, ethnic distributions were that of the general population (approximately 75% Caucasian) (Centers for Disease Control and Prevention [CDC], 2015a). To ensure equality among the groups, ADHD and control participants were recruited according to the gender distributions of ASD participants. Typically developing controls and participants with ADHD were also matched to participants with ASD based on driving experience (as measured by months since driving permit was received) to account for its effect on driving performance (Almberg et al., 2015; Crundall, 2016).

Participants with ASD were recruited from flyers, advertisements on social networks, and also from several organizations designed to address the needs of individuals with neurodevelopmental disabilities. Participants with ADHD were recruited from flyers, advertisements on social networks and also from several local health clinics. Control participants were recruited using advertisements on social networks and flyers around the community. These methods have proven effective for recruitment of young drivers with and without neurodevelopmental disabilities in previous studies (Stavrinos et al., 2013; Stavrinos et al., 2015).

General Study Inclusion/Exclusion Criteria

Exclusion criteria for the study included: (1) diagnosis of any severe psychiatric conditions (e.g., bipolar disorder) and (2) presence of severe physical disabilities (e.g., need for a wheelchair) which would prohibit full participation in the experimental protocol. Inclusion criteria included (1) age at least 16 and no older than 30 years of age; (2) acquisition of a full driver's license (i.e., not permit); (3) and the ability to read, write and comprehend English. ASD is commonly accompanied by other neurodevelopmental disabilities, with co-occurrence of one or more non-ASD neurodevelopmental diagnoses occurring in 83% of those diagnosed with ASD (Centers for Disease Control and Prevention [CDC], 2015a). For this reason, participants with a co-occurring developmental disability were not excluded from the study; however in order to maintain group separation, individuals with a dual diagnosis of ASD and ADHD were excluded.

ASD Group

To be assigned to the ASD group participants had to have a previous diagnosis of Autistic disorder, Asperger's syndrome, Pervasive Developmental disorder not otherwise specified or Autism Spectrum Disorder. ASD symptom counts were collected using the Autism-Spectrum Quotient (AQ) (Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001; Volkmar, Rogers, Paul, & Pelphrey, 2014), which was administered in a pre-visit telephone screener. Participants in the group with ASD had significantly more ASD symptoms (higher AQ scores) than ADHD and typically developing controls (See Table 1).

Clinical Control Group

Participants assigned to the clinical control group had a previous diagnosis of ADHD. The Disruptive Behavior Rating Scale (DBRS) was used to further confirm diagnosis, and the group with ADHD endorsed significantly more ADHD inattentive and impulsive items compared to ASD and typically developing participants (See Table 1).

Typically Developing Control Group

To be assigned to the typically developing controls, participants had to have no previous diagnosis of ASD or ADHD. Participants in the control group also endorsed significantly fewer ADHD symptom scores (as measured by the DBRS) than the group with ADHD, and significantly fewer ASD symptoms (as measured by the AQ) than the group with ASD (See Table 1).

Measures

Driving Simulator

Study participants engaged in a computerized driving simulation task to measure performance under specified conditions of interest (STISIM Drive, Systems Technology Inc., Hawthorne, CA). The simulation was displayed on three, 20" LCD computer monitors. The simulator provided a view of the roadway and dashboard instruments, including a speedometer, rpm gauge and a letter indicating the vehicle's gear. The vehicle was controlled by moving a steering wheel in a typical driving manner while depressing the accelerator and brake pedals accordingly. An on-board stereo sound system provided naturalistic engine sounds, external road noise, and sounds of passing traffic.

Driving Scenarios. The driving scenario featured a two-lane, bi-directional road enhanced by daytime suburban scenery. The scenario was standardized by distance (5 miles) and varied in posted speed limit, so participants could differ in the time it took them to complete the drive (on average approximately 10 to 15 minutes). During the scenarios, participants navigated through an environment containing a total of eight hazards: 4 social (e.g., a pedestrian darted into the street, a cyclist swerved into the participant's lane, etc.) and 4 non-social hazards (e.g., a lead vehicle braked suddenly, a truck pulled out in front of the participant from a hidden drive, etc.) that required an immediate response (See Figure 7 for examples). Hazardous events were defined as unexpected events that required the driver to brake, speed up or make some type of evasive maneuver to avoid a collision. These were modeled after previous research efforts (Sheppard et al., 2010). Events were triggered when the driver was a certain distance (determined by simulator software) away from the hazard.

Driving Performance. The simulator provided six indicators of driving performance:

(1) RMS indicated the deviation of lane position and provided a sensitive measure of driving precision (Marcotte et al., 2003). RMS served as an indicator of the degree of adjustment the driver implemented to maintain a desired position within the lane. Greater within-lane deviation indicated poorer driving precision.

(2) Reaction time reflected the amount of time in seconds that elapsed from the time of the event triggered to the first of five possible reactions: a 10% increase in accelerator pressure (i.e., the driver began to depress the accelerator to speed up), a 10% decrease in accelerator pressure (i.e., the driver began to release the accelerator to slow down), an accelerator position equal to 0 (i.e., the driver's foot was removed from the accelerator) (Rakauskas, Gugerty, & Ward, 2004), an increase of at least 1 pound of pressure to the brake pedal (i.e., driver began to press the brake to slow the vehicle), or a

5-degree change in steering wheel angle (i.e., the driver swerved to avoid the hazardous event).

(3) Standard deviation of speed was also collected and served as a measure of deviation in average driving speed, which provided a measure of compensatory slowing and speeding up (Stavrinos et al., 2013). Greater standard deviation of speed indicated poorer driving performance.

(4) Average driving speed was collected and defined as the driver's average speed across the entire driving scenario in miles per hour (mph).

(5) Total number of motor vehicle collisions (MVCs) was computed across each driving scenario as anytime the participant ran off the road or struck another vehicle, pedestrian, cyclist or object (Narad et al., 2013).

(6) Number of speed exceedances was defined as the number of times the participant exceeded the speed limit greater than or equal to 8 miles per hour while driving through the scenario.

Demographics.

Participants were asked via telephone screening to provide basic demographic information including age, gender, race, the highest level of education completed, months since permit was received (indicator of driving experience), average days driven per week, marital status, employment status and living status (residential setting, group home or living independently).

Possible Predictors

Diagnosis Confirmation. *Autism-Spectrum Disorder.* The Autism-Spectrum Quotient (AQ) questionnaire was used to assess the presence of autistic symptoms

(Baron-Cohen, Hoekstra, Knickmeyer, & Wheelwright, 2006). The AQ is a 50 item questionnaire comprised of 5 sets of 10 questions that assessed five different areas of ASD symptomology: social skill, attention switching, attention to detail, communication and imagination, with higher scores indicating a greater presence of autistic characteristics (Baron-Cohen et al., 2001). Previous research suggests that the average score for typically developing controls is approximately 16.4, and a score of 32 or greater indicates "clinically significant levels of autistic traits" (Baron-Cohen et al., 2001). Discriminative power tests of the AQ revealed a successful differentiation rate of 80% (Naito, Matsui, Maeda, & Tanaka, 2010). The Cronbach's α for the current study was .48. AQ score was used as a predictor of driving performance.

Attention Deficit/Hyperactivity Disorder. The self-report version of the Disruptive Behavior Rating Scale (DBRS) was used to assess the presence of ADHD symptoms (Erford, 1993). This 18 item questionnaire assessed the frequency of ADHD inattentive and impulsivity symptoms. The inattentive subscale was composed of 9 items addressing inattention (e.g. "I am easily distracted") while the second impulsivity subscale was composed of 9 items dealing with hyperactivity/impulsivity symptoms (e.g., "I have difficulty awaiting my turn"). Each item, or behavior, was rated on a 4-point Likert scale from 0 (*never* or *rarely*) to 3 (*very often*). If the participant answered either 2 (*often*) or 3 (*very often*) on an item (consistent with experiencing that ADHD symptom), they were given a score of 1 for that question. A summed symptom count was computed for each subscale ranging from 0 to 9 for Inattentive (Cronbach's α = .98) and Hyperactive/Impulsive (Cronbach's α = .98). Total ADHD symptom scores were collected by summing the Inattention and Hyperactivity/Impulsivity scales, yielding a score from 0-18 (Cronbach's α = .99). DBRS symptom scores were used as a predictor of driving performance.

Processing Speed. *Symbol Search and Coding.* The processing speed subtests of the Wechsler Adult Intelligence Scale – Fourth Edition (WAIS-IV): Symbol Search and Coding were used to assess ability to quickly scan and discriminate visual information (Wechsler, 2008). The combined scores of these two subtests provided a Processing Speed Index (PSI) score, which also measured short-term memory, attention and visual-motor coordination. The Symbol Search task required participants to scan a search group of symbols and indicate if one of the symbols in the target group matches one of the symbols in the search group. Scores on the Symbol Search typically range from 0 to 60 and indicate the number of correctly identified symbols in a 120 second time frame. The Coding task required participants to copy symbols paired with numbers using a symbol/number legend at the top of the page. Scores on the Coding task typically range from 0 to 135 and indicate the number of correctly coded items in a 120 second time frame. The raw scores were then scaled to account for the differences in age among participants. The scaled scores of these two tests were combined to provide a Processing Speed Index (PSI) score (Nelson, Canivez, & Watkins, 2013). PSI score was used as a measure of processing speed and was also used to predict driving performance outcomes. The ability to quickly scan and search for specific items has been shown by previous research to be impaired in adolescents with ASD and ADHD, and impaired performance on these types of tasks have shown to be a significant predictor of poorer driving performance in ASD and ADHD drivers when compared to control drivers (Monahan et al., 2013). The WAIS-IV PSI has high reliability (*r* = .89) and high consistency, with test-retest reliability of .89 (Wechsler, 2008).

Motor Functioning. *Beery Visual-Motor Integration: Fifth Edition (Beery VMI).* The standard score of the Motor Coordination Subtest of the Beery VMI was used to assess participant's ability to control fine motor movements, an ability commonly referred to as "eye-hand coordination" (Beery, Buktenica, & Beery, 2010). This 30-item task required the participant to draw a series of geometric forms with pencil and paper by connecting dots and staying within increasingly confined areas, with a raw score of 30 indicating adequate age-based motor functioning (Kulp & Sortor, 2003). The Beery VMI has shown strong reliability with an overall reliability score of .92 (inter-scorer reliability: *r* = .92, internal consistency: *r* =.96 and test-retest reliability: *r* = .89). Previous research has found that adolescents with ADHD and ASD show an impairment on this task when compared to typically developing controls (Monahan et al., 2013). As driving is a largely visual motor task (Salvucci, 2006), it is expected that impairments in this domain would predict deficits in driving performance.

Social Skill. *Social Responsiveness Scale: Second Edition (SRS-2).* The adult self-report form of the SRS-2 was used as a measure of social skill impairment for all participants aged 19 and older (Constantino & Gruber, 2012). The SRS-2 was a 65-item questionnaire measuring social skill impairment (e.g., "I think or talk about the same thing over and over"). It is comprised of five subscales: social awareness, social cognition, social communication, social interactions and restricted interests and repetitive behavior, with higher scores indicating greater social skill impairment. The SRS-2 has good internal consistency in the current sample (Cronbach's $\alpha = .91$) and is best used to assess severity of difficulties in social interaction and behavior (Volkmar et al., 2014). As would be expected based on the review of literature above, those with ASD exhibit significant deficits in the area of social skills and, not surprisingly, SRS scores when compared to a typically developing individuals (Volkmar et al., 1987). SRS-2 scores were as a possible predictor for deficits in identifying and avoiding social hazards in the simulated driving environment.

Social Skills Rating System (SSRS). Participants aged 16 to 18 completed the student self-report form of the SSRS as a measure of social skill (Gresham & Elliott, 1990). The SSRS consists of 39 self-report social behavior items (e.g., “I make friends easily”) rated on a 3-point scale (0 = Never, 1 =Sometimes, 2= Very Often), with higher scores indicating better social skills. To provide consistency and accuracy when using social skill score as a predictor of driving performance outcomes, the items on the SSRS were reverse scored such that higher scores now indicted poorer social skills to matching the SRS-2. By reversing the scores of the SSRS, both measures of social skill are now on the same scale with higher scores indicating greater social skill impairment. The SSRS showed good internal consistency (Cronbach’s $\alpha = .89$).

Procedure

A team of 12 trained graduate and undergraduate research assistants in the Translational Research for Injury Prevention (TRIP) Laboratory administered telephone screenings and a team of 2 trained graduate students administered tasks and questionnaires to all participants. Standardized experimental protocols were followed in all testing sessions. Participant eligibility for the study was based on information acquired during a pre-visit telephone screening process conducted by a trained research assistant.

Telephone screenings for ASD participants were used to collect basic demographic information (e.g., age, gender, and years of education) as well as driving experience (e.g., months since driving permit was received). For ADHD and control participants, telephone screenings were conducted to collect basic demographic information as well as match participants on age, gender and driving experience to ASD participants. Participants meeting eligibility for the study were scheduled for a study visit and mailed a packet including consent form, instructions for the visit, directions to the lab, and a series of questionnaires to complete. Prior to study participation, upon arrival, each participant provided written informed consent, and parents provided consent for participants under the age of 18.

Upon arrival, participants received instruction in the operation and use of the driving simulator during a calibration session prior to actual data collection. Participants drove a brief (1 mile), standardized simulator scenario until they achieved stable driving performance (no collisions and fewer than 2 speed warnings). Participants received verbal warnings if they drove too far below or above the posted speed limit. To complete the calibration drive, participants had to have less than 2 verbal speed warnings and drive through the scenario without crashing. Participants were offered three attempts to complete the calibration drive. Participants who were unable to complete the calibration drive were deemed unfit for participation and did not proceed any further with the study. However, all study participants were able to demonstrate this minimum standard of proficiency and went on to complete the actual scenario drive.

Participants then engaged in the experimental driving task consisting of a five mile driving scenario with the following conditions presented throughout the scenario: (a) no hazard condition, during which participants drove through a baseline driving scenario that included common driving skills (i.e., turning, stopping at stop signs); (b) a social hazard condition, where participants encountered driving hazards involving either a pedestrian or cyclist (i.e., cyclist crosses the road directly in front of the driver, pedestrian walks out unexpectedly from behind parked cars on the street); and, (c) a non-social hazard condition, where each participant encountered driving hazards involving other cars (i.e., a car quickly reversing out of a driveway in front of the driver) (Sheppard et al., 2010). The driving scenario lasted approximately 15 minutes when driven at the posted speed limit. Social and non-social hazards were randomly presented throughout the driving scenario. Subsequently, each participant completed a series of questionnaires and tasks assessing social skills, cognitive abilities and motor proficiency. At the conclusion of the session, participants were compensated $25.00 for their time.

DATA ANALYSIS

Preliminary Analyses

Means and standard deviations of all variables were examined using descriptive statistics analyses in SPSS version 23 (IBM, 2015).

Distributions of variables were inspected and tests of normality, missingness, skewness and kurtosis were conducted. Missing data were handled appropriately according to the type of missingness pattern observed. Outliers were identified as observations that exceeded three standard deviations from the mean. All values exceeding three standard deviations were examined. Non-normal distributions were adjusted or transformed accordingly. *P*-values less than .05 were considered significant for all analyses.

Primary Analyses

AIM 1: Evaluate the driving performance of drivers diagnosed with an Autism Spectrum Disorder in a simulated driving environment as compared to a clinical control group of drivers with ADHD and typically developing controls.

Differences among the groups on continuous measures of driving performance (RMS, reaction time, standard deviation of speed, and average driving speed) were tested using Analysis of Covariance (ANCOVA), controlling for any significant differences among the groups in demographic variables. Significant differences among the groups for driving outcome variables were followed up with Tukey's post hoc pairwise comparisons. Due to the rare nature of the count variables (MVCs and number of speed exceedances), a Generalized Estimation Equation (GEE) Poisson model was used to examine the differences among diagnostic groups while controlling for differences among the groups in demographic variables.

AIM 2: Assess the ability of individuals with ASD to identify and avoid social and non-social hazards compared to drivers with ADHD and typically developing controls.

First, Generalized Linear Models (GLM) were used to analyze the effect of hazard condition (social hazard or non-social hazard) on continuous measures of driving performance with the exception of RMS and standard deviation of speed. The driving outcomes RMS (standard deviation of lane position) and standard deviation of speed could not be calculated separately for social and non-social hazards because drivers' behavior around hazards affected the accuracy of these variables (e.g. swerving to avoid a hazard would appear as poor lane maintenance and slowing to avoid a hazard would appear as greater variability in speed). For this reason, these two driving performance outcomes were not used in analyses including the effect of hazard type. GEE Poisson models were used to test the differences in hazard condition for driving performance measures of a count nature (MVCs and speed exceedances).

Second, the interaction of group (ASD, ADHD and Controls) and hazard type (social and non-social) was tested using GLM with a mixed model approach for all continuous driving performance outcomes measures with the exception of RMS and standard deviation of speed, and GEE Poisson models were used to test the differences among the groups in each hazard condition for driving performance measures of a count nature (MVCs and speed exceedances).

AIM 3: Identify specific predictors of poorer driving performance in drivers with ASD.

A series of four stage hierarchical multiple regressions were conducted in SPSS to examine the prediction of driving performance outcomes for participants with ASD (RMS, reaction time, standard deviation of speed, MVCs and number of speed exceedances), first on the basis of demographic factors (age, gender, race and driving experience); second, with the addition of symptom count (AQ and DBRS inattentive score and DBRS impulsivity score); third with the addition of the motor and cognitive predictors motor coordination score (Beery Motor Coordination) and processing speed (PSI); and lastly, with the addition of social skill impairment (SSRS or SRS-2 Standard

Score). Demographic predictors were age, gender (male or female), race (Caucasian or Minority) and driving experience (months since drivers permit was received). Symptom count predictors were AQ score (ASD symptom count from 0 – 50), DBRS inattentive score (ADHD inattentive symptom count from 0 – 9) and DBRS impulsivity score (ADHD impulsivity symptoms count from 0 – 9). Motor and cognitive predictors included Beery Motor Coordination standard score and WAIS-IV or WISC-IV (depending upon participant age) Processing Speed Index Score. Finally, the social skill predictor was defined as SSRS or SRS-2 standard score (depending upon participant's age).

RESULTS

Demographics

Data from 47 participants were collected with participants having an average age of 23.30 years (*SD* = 3.85), 94% being male and 74.5% reported Caucasian Race. Participants reported driving an average of 5.32 days per week (*SD* = 2.20) and had an average of 92.77 months (or about 7.7 years) of driving experience (*SD* = 47.47). There were marginally significant differences among the groups for number of comorbid diagnoses ($F(2,44) = 3.194$, $p=.051$) with the ASD group having a greater number of comorbidities ($M = 1.44$, $SD = 2.66$) as compared to typically developing controls (no reported psychological diagnoses). ADHD participants reported an average of 0.80 comorbidities ($SD = 0.78$). The most commonly reported comorbidities for ASD and ADHD participants included Generalized Anxiety Disorder, Depression and Obsessive Compulsive Disorder. All participants were able to demonstrate adequate proficiency in the simulator with 64% of participants passing on the first attempt, 32% of participants passing on the second attempt and only 4% of participants needing the third attempt to meet the minimum level of proficiency. These rates were not significantly different across group, with no group needing significantly more attempts to pass the calibration drive than any other group ($\chi^2(4) = 1.57$, $p = .82$). No significant differences were found between the groups on matching variables (age, gender and driving experience). There were, differences among the groups for Race, with significantly more Caucasian participants in both the ASD and ADHD groups, $\chi^2(2) = 8.23$, $p = .02$. However, previous research has not suggested a relationship between race and driving performance, therefore analyses proceeded without Race included as a covariate. The ASD group (M = 4.31, SD = 2.75) also drove significantly fewer days per week than the control group (M = 6.19, SD = 1.52), $F(2,44) = 3.25$, $p = .048$. Given the importance of driving experience to driving performance, days per week driven was included as a covariate in all analyses examining differences among diagnostic groups. See Table 1 for descriptive statistics of participant characteristics by group.

Missing Data

Data from 47 individuals was available for analysis and inspection of frequencies revealed no missing data for the independent variables or driving performance outcomes (RMS, reaction time, standard deviation of speed, average driving speed, MVCs and speed exceedances).

Assumptions

The outcomes variable speed exceedances had an overdispersed distribution (i.e., the variance was larger than the mean). MVCs had a variance that was slightly smaller than the mean and violated the Shapiro Wilks test for normality ($p < .001$) for all groups (ASD, ADHD, Controls). RMS, reaction time, standard deviation of speed, and average driving speed were all normally distributed. All outcome and predictor variables were within the acceptable ranges for skewness and kurtosis, with the exception of standard deviation of speed (kurtosis = 9.96), DBRS inattentive score (kurtosis = 4.55) and DBRS impulsivity (kurtosis = 6.06). There was 1 outlier (greater than ±3 standard deviations from the mean) for standard deviation of speed (Z = 4.54). Analyses were run with and without this outlier to determine how the data were affected and no significant differences were found. For this reason and to provide a more complete dataset, all results provided include this outlier. There were three outliers for the following predictor variables: Social Skill standard score ($Z = 3.12$), DBRS Inattentive score ($Z = -3.97$) and DBRS Impulsivity score ($Z = -4.11$). However, upon examination, all of these values fell within the appropriate score range of the measure and were therefore kept in all analyses. Leven's Test for homogeneity of variances revealed no violations. Table 2 provides descriptive statistics for all predictor and driving outcome variables. Because there were only two levels of the within-subject independent variable (hazard type) the Levene's test was used to test homogeneity of variances and indicated no violations ($p = .643$).

DBRS inattentive and impulsivity scores were significantly correlated ($r = 0.782$, $p < .0001$), therefore a composite (total) ADHD symptom count (DBRS inattentive + DBRS impulsivity) was used in all analyses. Age and months since learner's permit was received were also significantly correlated (*r* = 0.932, *p* < .0001) indicating multicollinearity. For this reason, a composite score for age and driving experience was created by converting both variables into standard (*Z*) scores and then combining them into one age/experience variable. This variable was used for all further analyses. Although other significant correlations emerged, they did not approach levels of concern for multicollinearity (i.e., *r* < .70), and therefore analyses proceeded as planned. Table 3 displays intercorrelations among all variables used in analyses.

AIM 1: Evaluate the driving performance of drivers diagnosed with Autism Spectrum Disorder in a simulated driving environment as compared to a clinical control group of drivers with ADHD and typically developing controls.

Analyses of Covariance (ANCOVA), controlling for days per week driven, revealed a significant difference among groups on average driving speed $F(2,43) = 4.58$, $p = .02$; partial $\eta^2 = .18$. Post hoc pairwise comparisons revealed that drivers with ADHD drove significantly faster (*M* = 35.57, *SD* = 3.67) as compared to drivers with ASD (*M* = 30.99, *SD* = 4.46), however the driving speeds of the groups with ADHD or ASD were not significantly different from typically developing controls (See Figure 1). A significant difference between groups also emerged for standard deviation of speed, $F(2,43) = 3.28$, $p=.047$; partial $\eta^2 = .13$. Post hoc comparisons indicated that the ASD group (*M* = 11.82, *SD* = 1.61) exhibited significantly less standard deviation of speed than the ADHD group (*M* = 13.48, *SD* = 2.54) (See Figure 2). No significant differences were seen among the groups for RMS or reaction time. GEE Poisson analyses covarying for days per week driven indicated that group was not a significant predictor of either MVCs or speed exceedances.

AIM 2: Assess the ability of individuals with ASD to identify and avoid social and non-social hazards compared to drivers with ADHD and typically developing controls.

Results from a GLM examining the main effect of hazard type revealed a significant effect of hazard condition for reaction time ($\chi^2(1) = 11.13$, $p < .01$), with all participants responding more quickly to social hazards ($M = .94$, $SD = .41$) than to non-social hazards ($M = 1.13$, $SD = .36$) (See Figure 3). Across groups, participants also drove significantly slower around social hazards ($M = 22.45$, $SD = 7.44$) as compared to non-social hazards ($M = 28.34$, $SD = 10.83$), $\chi^2(1) = 27.97$, $p < .001$ (See Figure 4). Table 4 provides descriptive statistics for driving outcomes by hazard type (social and non-social).

The effect of hazard type on non-normally distributed, count variables revealed hazard type to be a significant predictor of the driving performance outcome MVCs ($\chi^2(1) = 15.63$, $p < .001$) (See Figure 5). Participants had 94% fewer simulated MVCs around social hazards compared to non-social hazards (Exp(β) = .06; 95% C.I. = .009 to .420).

Results from a mixed model GLM indicated no significant group by hazard type interaction for reaction time. Further, ANCOVAs controlling for days per week driven were also conducted to examine the differences among the groups in social hazard reaction time, and although drivers with ASD had the slowest reaction time ($M = 1.05$, $SD = .37$) when compared to ADHD ($M = .92$, $SD = .47$) and control drivers ($M = .84$, $SD = .41$), no significant differences emerged. Similarly, there was no significant difference among the groups for average non-social hazard reaction time. However, the pattern of means suggested differences in reaction time to social compared to non-social hazards only in the ADHD and Control groups. To further investigate this pattern, paired samples t-tests were conducted within each group to compare driving performance outcomes in the presence of social versus non-social hazards. Significant differences emerged for reaction time to social (M = .838, SD = .41) versus non-social hazards (M = 1.13, SD = .28) in the control group, $t(15) = -3.63$, $p < .01$, and marginally significant differences emerged for the ADHD group (Social: M = .92, SD = .47; Non-social: M = 1.16, SD = .40), $t(14) = -2.02$, $p = .06$, with both groups reacting more quickly to social hazards. However, no significant difference was found in reaction time to social (M = 1.05, SD = .36) versus non-social hazards (M = 1.10, SD = .41) for the ASD group (See Figure 6).

GEE Poisson analysis (controlling for days per week driven) for count measures of driving performance (MVCs and speed exceedances) indicated that the Group x Hazard Type interaction was not a significant predictor of either MVCs or speed exceedances.

AIM 3: To identify specific predictors of poorer driving performance in drivers with ASD.

GEE Poisson regression analysis indicated that for drivers with ASD, the age/ experience and ASD symptom variables both emerged as significant predictors of total MVCs such that an increase in age and experience predicted a 30% decrease in simulated MVCs and each additional ASD symptom predicted a 9% increase in simulated MVCs. Gender also emerged as a significant predictor of speed exceedances such that being female was associated with a 60% decrease in simulated speed exceedance. Motor coordination and social skill impairment were also marginally significant predictors of simulated speed exceedances, with a one point increase in motor coordination score predicting a 1% increase in simulated speed exceedances and each point increase in social skill impairment predicting a 1% increase in simulated speed exceedances. Table 6 provides coefficients and 95% Confidence Intervals (CIs) resulting from this analysis. Results from the four step hierarchical regression in ASD drivers revealed no significant predictors for any of the continuous measures of driving performance (RMS, reaction time and standard deviation of speed).

DISCUSSION

The current study investigated the driving performance of drivers with ASD compared to both a clinical control population of ADHD drivers as well as a healthy control group of drivers with typical development. The presence of hazards, whether social or non-social in nature, was proposed to negatively impact driving performance, and driving performance was expected to be poorest in the presence of social hazards (Sheppard et al., 2010). It was also expected that drivers with ASD would have the poorest driving performance around social hazards as compared to drivers with ADHD and drivers with typical development. The current study was among the first to examine the simulated driving performance of young drivers with ASD, and was the first to include a clinical control group of young drivers with ADHD. This study was also the first to evaluate the perception of social and non-social driving hazards in drivers with ASD in a simulated driving environment.

Effects of Diagnostic group on Driving Performance

Findings indicated that drivers with ASD drove significantly slower than drivers with ADHD and exhibited marginally less variability in speed (as measured by standard deviation of speed) compared to their counterparts with ADHD. The combination of significantly slower driving speed and marginally less speed variability in participants with ASD may suggest that drivers with ASD compensate for poor self-perceived driving ability (Daly et al., 2014) and known areas of impairment by maintaining a steady, slow driving speed. However as drivers with ASD and ADHD differed significantly only from each other and not from typically developing controls, it is more likely that there may be differences in driving behaviors across different neurodevelopmental disabilities rather than in drivers in general. Drivers with ADHD drove significantly faster than drivers with ASD, and previous studies have shown that faster speeds increase crash rate on minor roads (i.e., low speed roads), indicating that compared to drivers with ASD, drivers with ADHD may be at an increased risk of being involved in a MVC (Aarts & van Schagen, 2006). Previous literature has demonstrated that drivers with ADHD exhibit more risk taking behavior while driving (e.g., speeding and distracted driving), are involved in more MVCs and incur more violations (e.g., speeding tickets) than typically developing controls (Barkley, 2004; Barkley, Guevremont, Anastopolous, DuPaul, & Shelton, 1993; Stavrinos et al., 2015). The findings of the current study suggest that drivers with ASD may exhibit more cautionary driving behavior (i.e., slower and more consistent speed) as compared to their ADHD counterparts. The current study added a unique perspective to the current body of knowledge on ASD and driving by including drivers with ADHD as a clinical control group. Because individuals with ADHD share similar cognitive deficits as individuals with ASD with the exception of social skill impairment, their inclusion allowed the current study to isolate social impairment as a factor that may negatively impact driving performance and hazard perception in drivers with ASD. However, more research is needed to investigate the differences in driving behavior across neurodevelopmental disabilities and how these differences may affect crash risk and overall driving safety in this vulnerable population of drivers.

Effect of Hazard Type on Driving Performance

Contrary to the previous findings of Sheppard and colleagues which suggested slower reaction times to social versus non-social hazards (2010), the current findings indicated participants reacted more slowly to non-social hazards (e.g., other cars) compared to social hazards (e.g., pedestrians and cyclists), regardless of diagnosis. Sheppard and colleagues were the first to test the effects of this novel approach to hazard typology (social and non-social) on hazard response time, but this was examined in a population of non-drivers using video clips of hazardous situations (Sheppard et al., 2010) which may have limited the external validity of the study's findings. The current study's methodological approach (i.e., utilization of driving simulator technology in a population of current drivers) may provide results that are more representative of real-world driving behavior and explain the discrepant findings. Previous literature on social orienting indicates that typically developing individuals naturally orient their visual attention to social aspects of an environment. This lends support to the findings of this study suggesting that participants reacted more quickly to social hazards (Hill et al., 2010). If a driver's visual attention is automatically and unconsciously directed towards social stimuli in an environment, it stands to reason that it would take less time for that driver to identify and subsequently react to a hazard that is social in nature (Hill et al., 2010). Automatic orientation and subsequently faster reaction times to social hazards likely explain the finding that across groups, all participants had fewer MVCs around social hazards compared to non-social hazards. The slower driving speeds all participants exhibited around social hazards may also suggest that all drivers drove more carefully around social hazards due to the increased likelihood of injury and fatality for the pedestrian or cyclist (Moudon et al., 2011).

Effect of Hazard Type and Group on Driving Performance

Contrary to expected findings, the effect of hazard type on driving performance did not vary significantly by diagnostic group. However a closer examination of the data revealed that drivers with ADHD and typically developing controls reacted more quickly to social hazards as compared to non-social hazards. In other words, they had faster reaction times to, and therefore lower likelihood of having a simulated MVC with (Quimby et al., 1987) pedestrians and cyclists compared to other vehicles. This difference was however absent in drivers with ASD, who showed no difference in reaction time to pedestrians and cyclists compared to other vehicles. It is suspected that the natural tendency of typically developing controls and drivers with ADHD (individuals with typical social information processing) to orient their attention to social aspects of the driving environment (i.e., social orienting) (Hill et al., 2010) may explain their quickened reaction time to social versus non-social hazards. It is also suspected that the impairment in or lack of social orienting seen in individuals with ASD (Dawson et al., 1998) may explain the fact that they showed no difference in reaction to social versus non-social hazards. This finding suggests that drivers with ASD may be at a greater safety risk, and more likely to be involved in a MVC when encountering hazards that are social in nature (i.e., pedestrians and cyclists). However, as no significant differences emerged between the groups for social hazard reaction time, this finding is provisionary and should be more thoroughly researched before firm conclusions can be met.

Predictors of Driving Performance for Drivers with ASD

Consistent with previous literature done in typically developing controls, age and driving experience emerged as a significant predictor of driving performance with greater age and driving experience predicting a significant decrease in simulated MVCs (30%) for drivers with ASD. As expected based on the few studies that have examined the impact of ASD on driving performance, the findings of this study suggest that higher ASD symptom counts significantly predicted an increase in simulated MVCs (9%). As is the case with most neurodevelopmental disabilities including ASD and ADHD, greater symptom counts are commonly associated with greater impairment in everyday function and increased severity of the disorder (Shattuck et al., 2007; Volk, Todorov, Hay, & Todd, 2009). These findings suggest that increased symptoms of ASD may have a negative impact on driving performance and increase individuals with ASD's risk for MVCs.

The current findings also suggested that being a female driver with ASD predicted a significant decrease in simulated speed exceedances (60%) as compared to males with ASD. This is consistent with previous research in typically developing controls indicating that female drivers exhibit less risky driving behavior and have a lower citation rate than male drivers (McCartt, Shabanovaq, & Leaf, 2003). However it should also be noted that due to the high prevalence of ASD in males (1 in 42 in males compared in 1 in 189 in females), the study only contained one female driver with ASD (Centers for Disease Control and Prevention [CDC], 2015a). For this reason, these findings regarding gender should be interpreted with caution and more research is needed to further examine the impact of gender on driving performance in drivers with ASD. Social skill impairment also emerged as a marginally significant predictor of simulated speed exceedances. Consistent with the hypotheses of this study and with the little research that has been done on the social nature of some driving hazards, it was found that greater social skill impairment predicted a slight increase in simulated speed exceedances (1%). The driving environment is one full of unspoken social courtesies and social interactions with other drivers, so it stands to reason that impairments in social skill might negatively impact how effectively one can successfully navigate the driving environment. Google recently released a statement regarding the effectiveness and safety of their innovative autonomous vehicles (i.e., driverless cars or cars that drive themselves) after its first crash. They indicated that self-driving cars need social skills to better interact and anticipate the actions of other human drivers ("Self-driving cars need social skills," 2016). This study was among the first to examine how social skill impairment may affect driving performance, and much more research is needed to further investigate this fascinating aspect of driving. Contrary to previous literature implicating impairments in motor coordination as a factor negatively impacting driving performance in individuals with ASD, the current study’s findings suggest that an increase in motor coordination ability was a marginally significant predictor of a slight increase in simulated speed exceedances (1%). One possible explanation for this unexpected finding may be that greater motor coordination skill in drivers with ASD lead to increased confidence in driving performance and faster driving speed. However, as social skill impairment and motor coordination were only marginally significant predictors of simulated speed exceedances, interpretations of these two predictors should be taken with caution.

It should also be noted that although social skill impairment and motor coordination emerged as marginally significant predictors of simulated speed exceedances, a post hoc power index analysis revealed low power (.48) and effect sizes were found to be quite small for these two variables (.04 and .03) (Faul et al., 2007). In light of the lack of power and small effect sizes, it is likely that these increased rates of predicted simulated speed exceedances may not be meaningful and therefore may not translate into real-world increases. The small sample size of the study may also have affected the ability to detect any other significant predictors of driving performance. This study was the first, to examine the unexplored research area of possible predictors of driving performance in drivers with ASD.

Limitations

As is the case with many other studies examining clinical populations, recruiting individuals with ASD who also had a driver's license proved to be quite challenging and limited the sample size of the current study. However, the current study's sample size was comparable, and in some cases larger, than previous investigations of ASD and driving (Classen et al., 2013; S. M. Cox et al., 2015; Reimer et al., 2013; Sheppard et al., 2010). Future research should expound on these study findings in a larger sample of drivers with ASD and drivers with ADHD.

ASD symptoms, ADHD symptoms and social skill measures were all gathered via self-report, which may have introduced biases into results. A previous research study investigating the validity of the adult self-report form of the AQ (measuring ASD symptoms) found that adults with ASD tended to self-report fewer ASD symptoms than their parent or caregiver reported them having (Baron-Cohen et al., 2001). It should also be noted that the Cronbach's alpha for the AQ in the current study's sample was unusually low (.48), especially compared to the Cronbach's alpha previous documented in studies assessing the measure's psychometric properties in both typically developing (.75) and ASD populations (.84) (Broadbent, Galic, & Stokes, 2013). It is unclear why such a low Cronbach's alpha was observed in this population. It is possible that the telephone administration of the AQ (as opposed to in-person administration methods used in previous studies (Baron-Cohen et al., 2006)) may have resulted in participant confusion when answering questions asked in a negative format (e.g., "It does not upset me if my daily routine is disturbed" – a positive answer, "strongly agree" would indicate that the participant was not upset by changes in routine). An in-person administration method might provide participants greater opportunity to see and re-read questions for clarification if needed. In light of the low internal consistency of the AQ in this sample, its usefulness as a predictor of MVCs should be interpreted with caution. The underreporting of symptoms seen in ASD populations has also been shown in individuals with ADHD, suggesting that adults with ADHD may underreport symptoms (Millstein, Wilens, Biederman, & Spencer, 1997). This suggests that these self-reported symptom counts may be conservative estimates of the number ASD and ADHD symptom present in participants. It is also expected that participants may have overestimated their social skills due to self-enhancement biases (Brown, 1986), so future studies may consider also obtaining social skill evaluations from the individual's family members, spouse or friends for a more comprehensive assessment of social skill impairment.

Motor coordination and processing speed assessments were collected using well-validated, accurate measures; however these skills were not measured in the context of a driving environment, a limitation present in many previous research studies examining cognitive predictors of driving performance (Ball, Owsley, Sloane, Roenker, & Bruni, 1993; Edwards et al., 2008). This may explain why processing speed did not emerge as a significant predictor of driving performance and why motor coordination had only a small effect in the opposite direction as would be expected, even though they were both skills reported as barriers to driving by individuals with ASD and their families and driving instructors (Almberg et al., 2015). For example, slower processing speed on a pen and paper task may not necessarily translate into slower processing of information in a driving environment. Further, fine motor skill (i.e., the skills participants needed to complete the Beery VMI Motor Coordination subtest) may not have translated into the complex skill of driving as it may only require gross motor coordination or may be more related to visual-motor integration skill. More research is needed to identify specific maneuvers and manual driving skills that pose the greatest challenge to drivers with ASD.

As is the challenge when conducting any research that examines the topic of injury prevention, this study was faced with the challenge of examining how people react in dangerous situations. The driving simulator provided a validated way to assess how vulnerable drivers react to dangerous driving situations (Godley et al., 2002; Underwood et al., 2011). Although the simulator and driving scenarios were designed to imitate the real world driving environment and situations, it is always difficult to translate simulated driving behavior into real-world driving behavior. For this reason, naturalistic driving studies (i.e., in-car camera and data collection devices) may provide a more objective depiction of how drivers with ASD react to different driving situations.

Due to the innovative nature of this research project and the lack of previous research on the topic of hazard perception and driving performance in individuals with ASD, the attempt to identify significant predictors of driving performance in drivers with ASD, although based on a theoretical framework, was exploratory in nature. Much more research is needed to identify the specific needs and challenges of this vulnerable and under-studied population of drivers.

Future Directions

As ASD is growing increasingly more prevalent and there are now more transitioning adults with ASD than ever before, additional research on the topic of ASD and driving is expected to emerge over the next decade to meet the growing need. The current study examined the driving abilities of adults with ASD who had already attained a driver’s license, however future research would benefit from looking rather to teens with ASD who are still in the learning to drive phase (i.e., are trying to or have already attained a learner’s permit). Current research on teens with ASD who are learning to drive and the specific barriers they face is limited to survey data alone (Almberg et al., 2015). Incorporating individuals with ASD who are still learning to drive into driving simulator research will allow us to better understand the impact that driving experience and age play in the impairments in driving performance previously exhibited by individuals with ASD (Classen et al., 2013; Reimer et al., 2013). By more closely examining pre-drivers with ASD (i.e., those with only a learner’s permit), and the cognitive, social and manual skills required for safe driving that they may be lacking, empirically-based, targeted driving training programs could be developed to aid in their learning process and improve their driving safety.

The current study findings suggested differences in the response time to social and non-social hazards for drivers with ADHD and typical development, but not for drivers with ASD. The significantly faster reaction times to pedestrians and cyclists versus other cars observed in drivers with ADHD and typically developing controls suggests that drivers without social skill impairment may automatically orient their attention to these social hazards more quickly than to non-social hazards (Hill et al., 2010). This quickened visual orienting in ADHD and typically developing drivers led to faster reaction times, which further resulted in fewer MVCs with these social hazards. The faster a driver is able to identify and react to a hazard in the environment, the less likely the driver is to collide with that hazard (Crundall, 2016). These quicken reaction times to social hazards in typically developing drivers and drivers with ADHD are promising as MVCs involving pedestrians and cyclists (i.e., social hazards) are far more likely to result in an injury or fatality (Moudon et al., 2011). Why the quickened response to social hazards was not present in drivers with ASD is a question that requires further investigation. It is possible that drivers with ASD are visually attending to these hazards, but do not process social hazards as quickly as typically developing controls; however it may also be that drivers with ASD are taking longer to orient their visual attention to these social hazards compared to typically developing controls due to impairments in social orienting (Dawson et al., 1998). Future research should utilize eye-tracking technology in the context of a driving simulator to monitor visual attention and gaze patterns of drivers with ASD compared to typically developing controls. This would provide information to help explain the differences seen in social and non-social hazard response time in drivers with ASD compared to clinical and typically developing controls. Further, if social information processing (rather than social orienting) is found to be a predictor of slower social hazard response time in individuals in ASD, social skills training programs (i.e., computerized or group-based training) should be examined as a possible intervention strategies to improve social information processing in the context of a driving environment. If social orienting and visual attention are found to be significant predictors of slower social hazard reaction times, driving hazard anticipation and avoidance training programs may prove to be a more effective intervention strategy for individuals with ASD.

Identifying the factors contributing to differences found in social and non-social hazard perception would also aid in the development and implementation of hazard training programs. Hazard training programs that teach drivers how to anticipate hazardous driving situations have proven successful in improving hazard perception and response time for other vulnerable populations of drivers including novice, teen drivers (Fisher, Pollatsek, & Pradhan, 2006). The majority of these training programs are computer-based and take drivers through a variety of hazardous scenarios. In each of these scenarios the driver is taught where hazards are likely to emerge and are provided feedback when attending to the incorrect area of the driving environment (Taylor et al., 2011). Future studies should examine the effectiveness of these training programs in the vulnerable population of drivers with ASD.

Conclusions

This study is among the first to examine the driving performance of individuals with ASD compared to typically developing control drivers and a clinical control group of drivers with ADHD, adding to the much needed body of knowledge on ASD and driving. More research is desperately needed to improve quality of life, ensure successful transition to adulthood and address the transportation safety needs of individuals with developmental disabilities such as ASD. Not only will this research have a positive impact on the community of individuals with developmental disabilities, it will also aim to improve the driving safety and MVC rate of the general population, a major public safety concern.

Table 1

Demographic Descriptive Statistics for Participants

	ASD (n=16)			ADHD (n=15)			Controls (n=16)			
Variables	*M (SD)*	*n* (%)	Range	*M (SD)*	*n* (%)	Range	*M (SD)*	*n* (%)	Range	*F* or χ^2
Demographic variables										
Age (Years)	23.88 (3.70)	-	17-30	23.07 (3.75)	-	16-29	22.94 (4.25)	-	16-30	$F(2,44) = .27, p=.76$
Gender (Male)	-	15 (94%)	-	-	14 (93%)	-	-	15 (94%)	-	$\chi^2(2) = .003, p=.99$
Race (Caucasian)	-	13 (81%)	-	-	14 (93%)	-	-	8 (50%)	-	$\boldsymbol{\chi^2(2) = 8.23, p= .02}$
Education (Years)	13.13 (1.59)	-	10-16	12.93 (1.49)	-	10-16	13.50 (2.25)	-	9-17	$F(2,44) = .39, p=.68$
Marital Status (Single)	-	16 (100%)	-	-	15 (100%)	-	-	13 (81%)	-	$\boldsymbol{\chi^2(2) = 6.21, p= .045}$
Employed (Yes)	-	7 (44%)	-	-	10 (67%)	-	-	13 (81%)	-	$\chi^2(2) = 4.95, p= .08^{\dagger}$
Months since learner's permit	95.50 (5.09)	-	11-187	91.40 (42.18)	-	8-147	91.31 (51.28)	-	14-184	$F(2,44) = .04, p=.96$
Days per week driven	4.31 (2.75)	-	0-7	5.47 (1.81)	-	2-7	6.19 (1.52)	-	2-7	$\boldsymbol{F(2,44) = 3.25, p=.048}$
Diagnostic variables										
AQ Total Score	33.19 (5.60)	-	22-43	17.87 (6.05)	-	10-34	14.69 (3.65)	-	10-23	$\boldsymbol{F(2,44) = 57.89, p< .001}$
DBRS Total Score	4.38 (3.54)	-	0-11	8.67 (3.37)	-	2-14	2.06 (1.61)	-	0-5	$\boldsymbol{F(2,44) = 19.71, p< .001}$
DBRS Inattentive Score	0.94 (3.17)	-	0-4	3.93 (2.31)	-	0-8	0.63 (0.96)	-	0-3	$\boldsymbol{F(2,44) = 9.39, p< .001}$
DBRS Impulsivity Score	1.63 (3.38)	-	0-6	4.73 (1.83)	-	2-8	1.44 (1.03)	-	0-3	$\boldsymbol{F(2,44) = 9.85, p< .001}$

Note: M = Mean, SD = Standard Deviation, AQ = Autism Spectrum Quotient, DBRS= Disruptive Behavior Rating Scale. **Bold** = p < .05,
† = Marginal significance ($p < .10$).

Table 2

Predictor and Driving Performance Outcomes Descriptive Statistics by Group

	ASD (n=16)		ADHD (n=15)		Controls (n=16)		
Variables	*M (SD)*	Range	*M (SD)*	Range	*M (SD)*	Range	F or χ^2
Predictor variables							
Motor Coordination (standard score)	74.81 (17.91)	45-102	89.87 (9.03)	71-107	78.06 (20.52)	45-107	**$F(2,44) = 3.45$, $p = .04$**
PSI (standard score)	90.13 (14.79)	71-124	98.93 (9.19)	84-117	98.25 (11.39)	79-129	$F(2,44) = 2.60$, $p = .09^{\dagger}$
Social Skill Impairment (standard score)	72.81 (12.19)	48-102	57.00 (11.84)	37-84	52.25 (6.53)	37-63	**$F(2,44) = 16.82$, $p < .01$**
Driving Outcome variables							
RMS (SD)	0.55 (0.18)	0.24-0.83	0.53 (0.16)	.31-.82	0.58 (.16)	0.41-0.91	$F(2,43) = .514$, $p = .60$
Reaction Time (seconds)	1.07 (0.32)	0.65-1.61	1.04 (0.37)	0.41-1.65	0.98 (.31)	0.63-1.73	$F(2,43) = .230$, $p = .79$
Standard Deviation of Speed	11.82 (1.61)	8.16-14.21	13.48 (2.54)	10.99-21.87	12.86 (1.22)	10.45-15.35	**$F(2,43) = 3.28$, $p = .047$**
Average Speed (miles per hour)	30.99 (4.46)	23.86-39.35	35.57 (3.67)	29.53-41.52	32.36(5.42)	22.59-41.49	**$F(2,43) = 4.58$, $p = .02$**
Speeding Exceedances (count)	9.63 (3.54)	3-14	9.47 (3.85)	4-16	8.50 (4.34)	2-14	$\chi^2(2) = .259$, $p = .88$
MVCs (count)	1.63 (0.89)	0-3	1.13 (0.83)	0-3	1.44 (0.73)	1-3	$\chi^2(2) = 2.00$, $p = .37$

Note: M = Mean, SD = Standard Deviation, RMS = Root Mean Square (standard deviation) of lane position, MVCs = Motor Vehicle Collisions. **Bold** = $p < .05$. † = Marginal significance ($p < .10$). Reaction Time = Average reaction time across all 8 hazards. Days per week driven was included as a covariate for analyses of driving outcome variables.

Table 3

Intercorrelations among Variables Used in Analyses

	1	2	3	4	5	6	7	8	9	10	11	12
1. Age/Experience	1	.227	-.053	.208	.060	-.004	-.097	-.006	.219	.111	-.213	.083
2. AQ Score		1	.013	-.087	**-.288***	**.683****	-.048	.114	-.230	-.040	.164	-.188
3. DBRS Total Score			1	.196	.050	.168	-.236	-.006	.085	.095	-.285	.277
4. Motor Coordination (SS)				1	.256	-.099	**-.305***	.269	**.423****	.144	-.147	.199
5. PSI Score (SS)					1	-.144	-.064	-.166	**.369***	.019	-.001	.219
6. Social Skill Impairment (SS)						1	.070	.021	-.194	-.011	.229	-.232
7. RMS (SD)							1	**-.421***	-.161	.151	.028	-.028
8. Reaction Time (Seconds)								1	-.093	-.094	-.017	.020
9. SD of Speed (SD)									1	.165	.033	**.443****
10. Speeding Exceedances (count)										1	-.181	**.471****
11. MVCs (count)											1	-.097
12. Average Speed (mph)												1

Note: Age/Experience = Composite score of age and months since permit was received, SS = Standard Score), SD of Speed = Standard Deviation of Speed, MVCs = Motor Vehicle Collisions, RMS = Root Mean Square (standard deviation) of lane position, Reaction Time = Average reaction time across all 8 hazards, *** *p*<.05, ** *p*<.01, *** *p*<.001.**

Table 4

Driving Performance Outcome Descriptive Statistics by Hazard Type

	Social (4 Hazards)	Non-social (4 Hazards)	
Driving Outcome variables	*M (SD)*	*M (SD)*	χ^2
Reaction Time (seconds)	.94 (.41)	1.13 (.36)	**$\chi^2(1) = 11.13, p < .01$**
Average Speed (miles per hour)	22.45 (7.44)	28.34 (10.83)	**$\chi^2(1) = 27.97, p < .001$**
Speeding Exceedances (count)	.51 (.62)	.70 (.66)	$\chi^2(1) = 2.33, p = .13$
MVCs (count)	.021 (.14)	.85 (.51)	**$\chi^2(1) = 13.90, p < .001$**

Note: M = Mean, SD = Standard Deviation, Reaction Time = Average reaction time across 4 hazards (social or non-social), MVCs = Motor Vehicle Collisions. The variables RMS and Standard Deviation of Speed were not calculated between hazard types. **Bold** = $p < .05$.

Table 5

Summary of GEE Poisson Regression for Significant Count Variables

	MVCs				
Predictors	B	CI 95%		Exp(B)	*p*
Age/Experience	-.356	-.660	-.052	.70	**.022**
ASD Symptoms	.083	.004	.163	1.09	**.040***
	Speed Exceedances				
Gender (Female)	-.913	-1.25	-.578	.40	**>.001****
Motor Coordination	.014	.000	.028	1.01	.053†
Social Skill Impairment	.011	-.007	.022	1.01	.052†

Note. ***p** **< .05, **p < .01**, † = Marginal significance ($p < .10$)

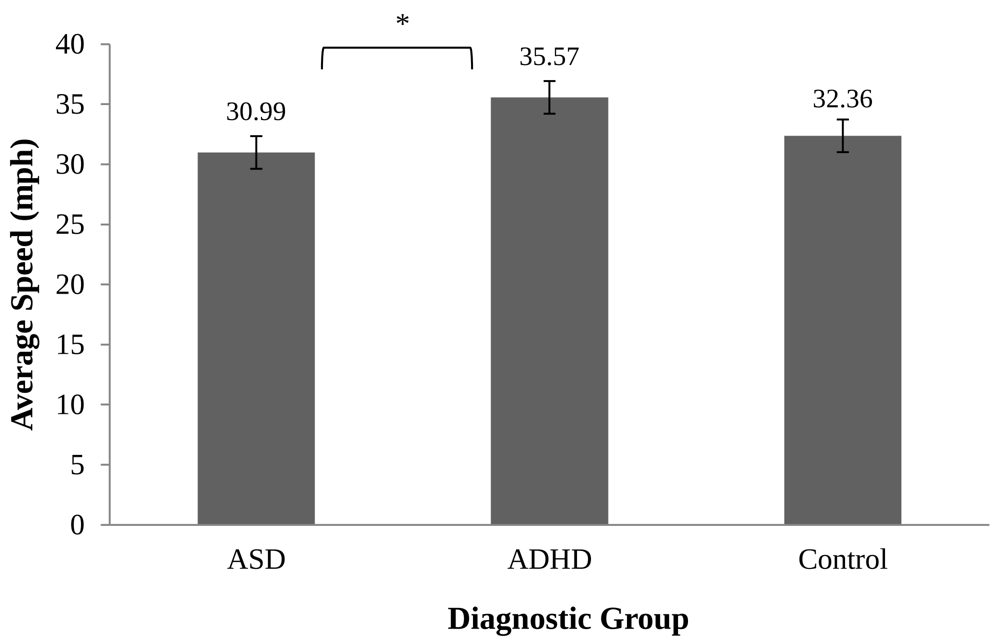

Figure 1. Differences in average driving speed across diagnostic group. Asterick indicates *p*-value < .05. ASD participants had significantly slower driving speed as compared to their ADHD counterparts. Neither the ASD nor ADHD group's average driving speed was significantly different from typically develoing controls.

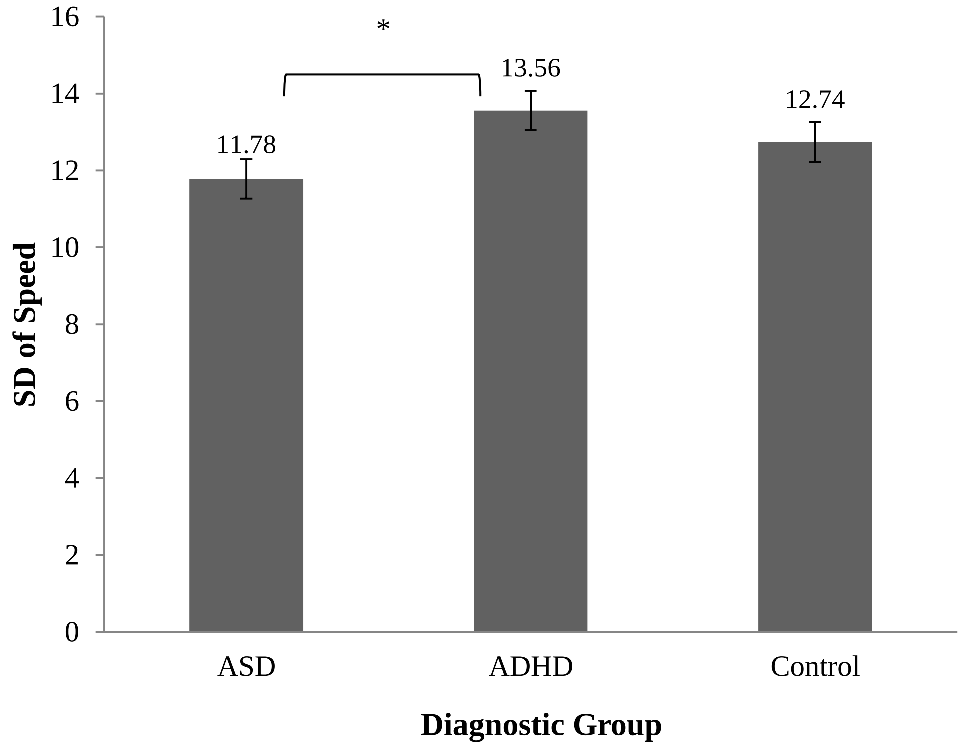

Figure 2. Differences in standard deviation of speed across diagnostic group. Asterick indicates *p*-value < .05. ASD participants had significantly less varibaility in speed as compared to their ADHD counterparts. Neither the ASD or ADHD group's standard deviation of speed was significantly different from typically develoing controls.

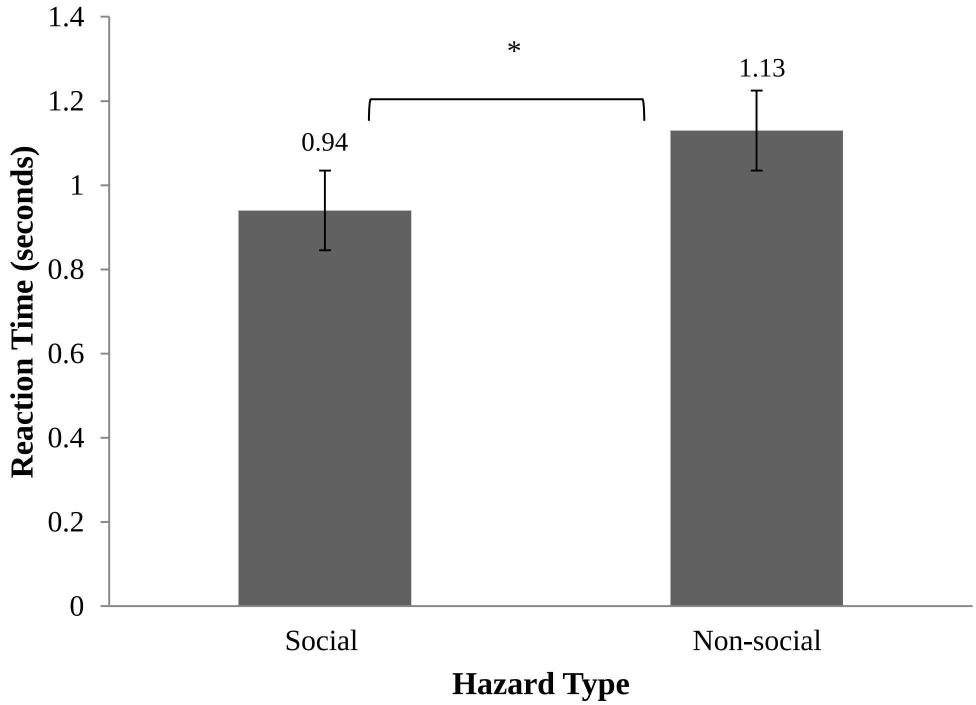

Figure 3. Effect of hazard type on reaction time. Asterick indicates *p*-value < .05. All participants, regardless of diagnostic group, reacted significantly faster to social as compared to non-social hazards.

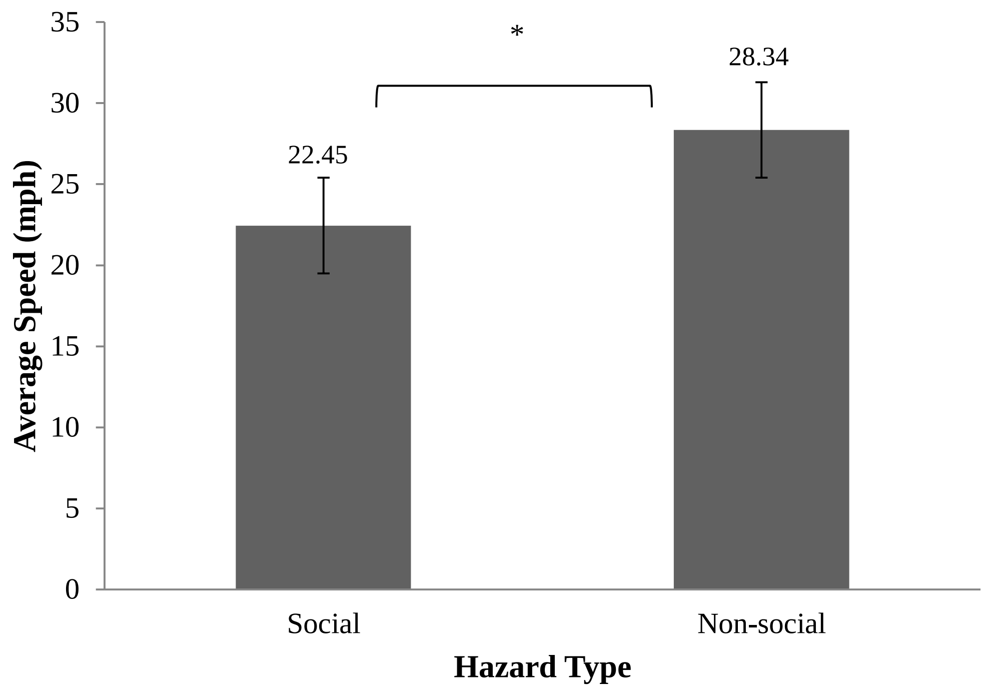

Figure 4. Effect of hazard type on driving speed. Asterick indicates *p*-value < .05. All participants, regardless of group, drove significantly slower around social as compared to non-social driving hazards.

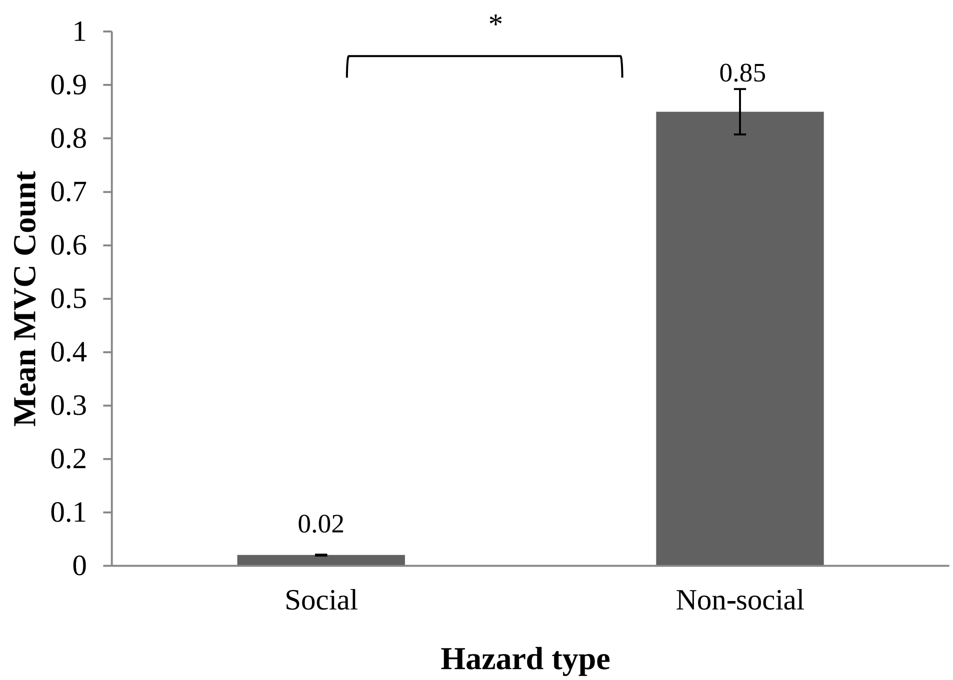

Figure 5. Effect of hazard type on simulated MVCs. Asterick indicates *p*-value < .05. All participants, regardless of group, had significantly fewer simulated MVCs around social compared to non-social driving hazards.

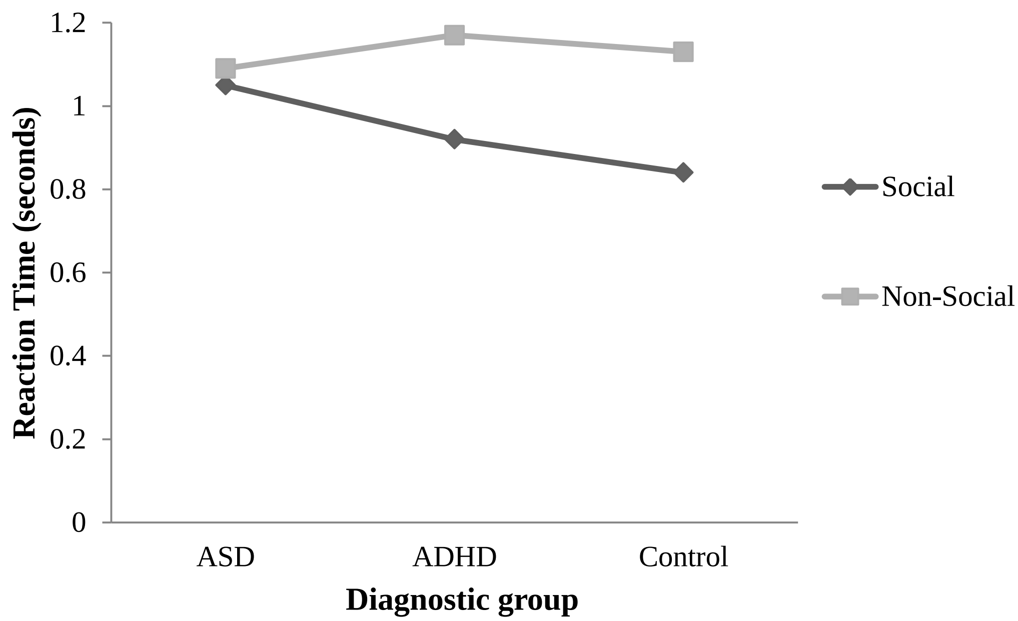

Figure 6. Interaction of diagnostic group and hazard type on reaction time. Although the group by hazard interaction did not reach statistical significance (*p* = .16), ADHD and control drivers reacted significantly more quickly to social as compared non non-social hazards. This difference was not found in the ASD group.

A B

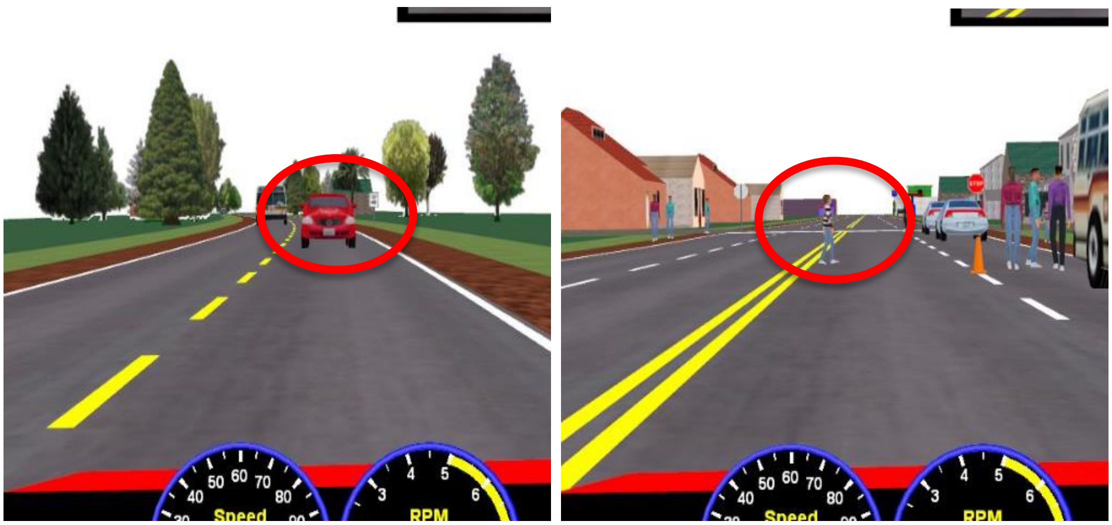

Figure 7. Social and Non-social driving hazard examples. Example A depicts one of the non-social hazards participants encountered (i.e., a vehicle approaching head on), while example B depicts one of the four social hazards encountered in the driving scenario (i.e., a pedestrian crossing the street outside of a crosswalk).

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APPENDIX A

IRB APPROVAL

THE UNIVERSITY OF ALABAMA AT BIRMINGHAM
Institutional Review Board for Human Use

Form 4: IRB Approval Form
Identification and Certification of Research
Projects Involving Human Subjects

UAB's Institutional Review Boards for Human Use (IRBs) have an approved Federalwide Assurance with the Office for Human Research Protections (OHRP). The Assurance number is FWA00005960 and it expires on January 24, 2017. The UAB IRBs are also in compliance with 21 CFR Parts 50 and 56.

Principal Investigator:	STAVRINOS, DESPINA
Co-Investigator(s):	JOHNSON, HALEY D
Protocol Number:	**X140820006**
Protocol Title:	*ROADS - Research On Autism and Driving Study (Understanding and Preventing Motor Vehicle Crashes Around Social and Non-Social Hazards Among Adolescent Drivers with Autism Spectrum Disorders)*

The IRB reviewed and approved the above named project on 8-12-15. The review was conducted in accordance with UAB's Assurance of Compliance approved by the Department of Health and Human Services. This Project will be subject to Annual continuing review as provided in that Assurance.

This project received EXPEDITED review.

IRB Approval Date: 8-12-15

Date IRB Approval Issued: 8-12-15

IRB Approval No Longer Valid On: 8-12-16

HIPAA Waiver Approved?: N/A

Marilyn Doss
Member - Institutional Review Board for Human Use (IRB)

Investigators please note:

The IRB approved consent form used in the study must contain the IRB approval date and expiration date.

IRB approval is given for one year unless otherwise noted. For projects subject to annual review research activities may not continue past the one year anniversary of the IRB approval date.

Any modifications in the study methodology, protocol and/or consent form must be submitted for review and approval to the IRB prior to implementation.

Adverse Events and/or unanticipated risks to subjects or others at UAB or other participating institutions must be reported promptly to the IRB.

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