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Examining Driving Behavior in Young Adults with High Functioning Autism Spectrum Disorders: A Pilot Study using a Driving Simulation Paradigm

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Abstract: Although it is speculated that impairments associated with Autism Spectrum Disorder (ASD) will adversely affect driving performance, little is known about the actual extent and nature of the presumed deficits. Ten males (18-24 years of age) with a diagnosis of high functioning autism and 10 age matched community controls were recruited for a driving simulation experiment. Driving behavior, skin conductance, heart rate, and eye tracking measurements were collected. The high functioning ASD participants displayed a nominally higher and unvaried heart rate compared to controls. With added cognitive demand, they also showed a gaze pattern suggestive of a diversion of visual attention away from high stimulus areas of the roadway. This pattern deviates from what is presumed to be optimal safe driving behavior and appears worthy of further study.

Keywords: Driving Behavior; High Functioning Autism Spectrum Disorder; Distraction; Cognitive Workload; Driving Simulation

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Introduction

Autism Spectrum Disorders (ASD) comprise a group of lifelong neuropsychiatric disorders that include Autistic Disorder, Asperger's Disorder, and Pervasive Developmental Disorder not otherwise specified (PDD-NOS). ASD is distinguished by difficulties with socialization, communication, and stereotyped or repetitive behaviors. It is estimated that the rate of children diagnosed with ASD in the U.S. has nearly doubled since 2007, from about 1 in 150 children to as high as 1 in 88 children (CDC 2012).

It is estimated that more than a half of individuals with ASD are intellectually competent (CDC 2009; Kogan et al. 2009). Nonetheless, high functioning individuals with ASD (HF-ASD) face difficulties in areas of daily functioning. One such activity is driving (Tantam 2003). A recent survey showed that only 24 percent of adults with autism — many of whom described themselves as “higher functioning” — said they were independent drivers, compared with 75 percent of the population as a whole (O'Neil 2012; Freeley 2010). Considering that driving is a critical step toward attaining independence, for securing and maintaining work and social relationships, a better understanding of the nature of potential driving difficulties in individuals with HF-ASD is of high clinical and public health relevance.

Although it is widely speculated that the range of impairment associated with ASD will adversely affect driving performance, little is known about the extent and nature of the presumed deficits. Sheppard et al. (2010) investigated driving hazard perception by asking participants to view a series of ten video clips containing driving hazards. Compared to controls, adults with HF-ASD identified fewer driving hazards involving a “human figure” and responded slower to driving hazards with and without “human figures”, suggesting attention deficits associated with HF-ASD. More recently, Cox and colleagues (2012) surveyed responses from 123 caregivers of adolescents/young adults with HF-ASD who were attempting, or had previously attempted, to learn to drive. The responses suggested that driving presented a substantial challenge for individuals with HF-ASD, prompting the authors to hypothesize that complex driving demands (e.g., multi-tasking), might be particularly problematic. While these studies suggest driving difficulties in individuals with HF-ASD, no study to date has assessed actual driving behavior in this population.

A better understanding of driving behavior in young drivers with HF-ASD has important clinical implications. Such information will allow individuals, families, clinicians, researchers, engineers, and driving instructors to gain insight as to the nature of driving difficulties in individuals with HF-ASD to help develop specific driving intervention strategies aimed at their amelioration.

Laboratory driving simulation environments provide an excellent method to safely assess driving behaviors in at-risk populations (Adler et al. 1995; Hoffman et al. 2002). Simulators can provide reproducibility, control, efficiency, and ease of use that are lacking in on-road behavior evaluations (Godley et al. 2002). The primary aim of the present pilot study was to explore driving behavior and visual attention in young adult drivers with HF-ASD in comparison with a community sample of non-affected individuals matched for age and sex. This was carried out using a driving simulation that has demonstrated sensitivity in distinguishing differences between ADHD drivers and controls (Reimer et al. 2006; Reimer et al. 2010; Fried et al. 2006; Fried et al. 2009a; Reimer et al. 2007). In studies involving community samples of younger adult drivers, good correspondence has been shown between eye movements recorded across varying in-vehicle demands in the simulator with data collection in the field (Wang et al. 2010). Additionally, Reimer and Mehler (2011) showed that changes in physiological reactivity to increasing levels of cognitive demand were highly consistent between the driving simulator and actual on-road driving. To the best of our knowledge, this is the first driving simulation study to specifically evaluate individuals with HF-ASDs.

Methods

Participants

Subjects were 20 male 18-24 year olds, half HF-ASD and half who were community controls. The HF-ASD group met the DSM-IV criteria for ASD, had IQs of 85 or greater, valid driver's licenses, no major sensorimotor handicaps (e.g. deafness, blindness), and the capability to understand and speak English. HF-ASD participants were recruited from existing outpatients in the Bressler Clinical and Research Program for Autism Spectrum Disorders at the Massachusetts General Hospital (MGH).

Out of the 11 HF-ASD subjects initially enrolled, 10 completed all study procedures. One subject was found ineligible because of low IQ. Community controls were required to have a valid driver's license and be able to understand and speak English. The ten community control cases were selected for comparative purposes from a sample of 75 participants in a concurrent study at the Massachusetts Institute of Technology (MIT). Selection was made based upon sex (male), availability of eye tracking measurements, and age. The community control group was not subject to a psychiatric or cognitive evaluation. Therefore, variables such as IQ were not considered in selection.

The diagnosis of ASD was established by a board-certified psychiatrist experienced in evaluating ASD and comorbid psychiatric disorders. The assessment assured that HF-ASD participants met DSM-IV diagnostic criteria for autistic disorder (n=3), Asperger's disorder (n=4), or PDD-NOS (n=3). The assessment included a detailed psychiatric diagnostic interview that was conducted over two sessions of an hour each with the subject and significant other or caretaker (usually a parent), if available, and also incorporated information from multiple sources when available (e.g., psychiatric records, schools, social services). IQ was either assessed at the time of evaluation through the administration of the Wechsler scales or documented based on recent testing by a licensed psychologist from an outside agency or a treating clinician in the medical record.

The Human Research Committee at MGH and the Committee on the Use of Humans as Experimental Subjects at MIT approved this study. All participants signed an informed consent form from both institutions.

Driving Simulation Paradigm & Data Recording

The study was conducted in a driving simulator consisting of a 2001 Volkswagen Beetle cab situated in front of an 8' by 8' (2.44m by 1.83m), projection screen positioned 76" (1.93m), in front of the mid-point of the windshield. The configuration provided drivers with a near 40-degree view of the virtual roadway, which was displayed at a resolution of 1024 x 768 pixels. Graphical updates were generated at a minimum frame rate of 20 Hz by STISIM Drive version 2.08.02 (Systems Technology, Inc., Hawthorne, CA), based upon the driver's interaction with the steering wheel, brake and accelerator. Force feedback was provided through the steering wheel and auditory feedback consisting of engine noise, cornering sounds and brake noise was played through the vehicle's sound

system. Audio tasks and instructions were also provided through the vehicle sound system. Driving performance data was captured at 10 Hz. A FaceLAB® 5.0 eye tracking system (Seeing Machines, Canberra, Australia), recorded eye tracking data at up to 60 Hz. A MEDAC System/3 physiological monitoring instrument (NeuroDyne Medical Corp., Cambridge, MA) monitored physiological signals at 250 Hz. Heart rate was derived from a modified lead II configuration EKG recording. Skin conductance was measured from low profile dry sensors on the outer segments of the middle fingers.

Procedures

All participants first completed a 6-mile (about 10-minute) adaptation drive to habituate to the driving simulator. The adaptation period began with the speed limit posted at 35 MPH with no on-coming traffic. The speed limit was gradually increased to 55 MPH along with increased visual complexity of roadway and density of on-coming traffic. This gradual increase in visual complexity was designed following guidelines suggested to reduce the likelihood of simulator sickness (Stoner et al. 2011).

Following the adaptation period, participants "stopped" the vehicle and were trained on two tasks, a phone task and an auditory continuous performance task (CPT), that would be employed later during the driving simulation to induce secondary cognitive demand (Mehler et al. 2008; Reimer et al. 2011). Participants then drove a 43-mile virtual roadway that began with a brief accommodation section similar to the initial adaptation period. The scenario's core portion consisted of a period of moderately dense urban driving (stimulating), followed by a straight unpopulated road (initial monotonous) period, a period of low density rural and highway driving (moderate demand), and concluded with a straight unpopulated road (second monotonous period). See Reimer et al. (2010) and Reimer et al. (2006) for a complete description of the driving scenario.

The phone task was presented during a segment of urban driving and the CPT during a segment of the highway driving. During the phone task, subjects were instructed to make a voice based, hands-free call to a ten digit phone

number to schedule a doctor's appointment with "Dr. Jesse for Thursday of next week at 3 pm". Up to three attempts with repeated instructions were allowed for failed attempts to initiate the call. Once initiated, a series of voice prompts required that participants hold the call content in memory before being prompted to leave "your first name, a daytime telephone number, the doctor's last name, as well as the date and time of the appointment you are requesting" (see Reimer et al. 2011 for additional details). During the CPT task, participants listened to a series of letters and were instructed to respond by saying "check" when the letter "A" was preceded by three letters by the letter "Q" (e.g. QrctA). The series of letters contained other Q's and A's as distracters (see Mehler et al. 2008 for additional details). The demanding cognitive activities increase cognitive workload and provide competing attentional demands to driving without directly interfering with sensorimotor control of the vehicle. These tasks have been used in previous research on ADHD drivers (Reimer et al. 2010; Fried et al. 2009b) and in broader investigations of driver distraction (Mehler et al. 2008; Reimer et al. 2011). Upon completion of the simulation, participants completed a post-experimental questionnaire that included the 16-item Kennedy Simulator Sickness Questionnaire (SSQ) (Kennedy et al. 1993).

Participants were compensated for their time and travel involved in clinical and driving simulation assessments. In addition, participants were instructed that they could earn up to an additional \$20 based on task performance. They were also informed that the incentive value would decrease by \$5 for each collision, \$1 for each traffic ticket, and \$2 for each minute over 60 minutes it took them to complete the simulated drive. This incentive was used to encourage a balancing of demands as occurs in real-life such as time constraints, driving safety, and secondary task engagement (Mehler et al. 2009; Reimer et al. 2006). In actuality, all participants received the full incentive regardless of their performance.

Data Analysis

Physiological measures were reduced following procedures in Mehler, Reimer and Coughlin (2012) and eye movement measures according to procedures in Reimer, Mehler, Wang and Coughlin (2012). For continuous random variables, a 2 (environment) x 3 (period) x 2 (HF-ASD status) mixed ANOVA with environment (urban and highway) and period (prior to, during and following a period of secondary cognitive demand) as within-subject

variables and HF-ASD status as a between-subject variable was used. Due to recording difficulties, eye tracking measures from two control participants and one HF-ASD participant were not considered in the analysis.

Results

There were no differences in age between HF-ASD (M 20.20 years; SD 2.04) and community control participants (M 20.70 years; SD 1.89), $F(1,18) = .32, p = .58$. IQ scores in the HF-ASD subjects ranged from 99-126 (M 107.4; SD 5.1). There was a similar distribution of HF-ASD and community control participants (6:6), who reported driving a few days a week or more vs. (3:4), those who reported driving a few days a month or less. One HF-ASD participant did not report the frequency in which he drove a motor vehicle. Four of the HF-ASD participants and six of the community control participants reported driving more than 5000 miles annually. The community controls and HF-ASD groups did not statistically differ in performance on the cellular phone task, CPT, total or subscales of the SSQ.

Driving performance and physiological measures

Two HF-ASD participants and two community control participants were involved in a collision while driving the simulated highway. The difference in speed from the posted limit and standard deviation of lane position did not vary by or interacted with environment, period, or HF-ASD status.

As can be seen in Figure 1, measures of heart rate revealed a significant period and HF-ASD status interaction ($F(2,36) = 3.57, p = .039$), suggesting that while the community control group increased arousal in response to the added cognitive demands, the HF-ASD group did not. Although heart rate was nominally higher in the HF-ASD group by 4.8 beats per minutes than the community controls across the simulation, the differences did not reach statistical significance ($F(1,18) = 1.33, p = .264$), most likely due to limited statistical power. Similarly, skin conductance level (SCL), was nominally but not statistically higher in the HF-ASD group ($F(1,15) = 2.03, p = .175$). The HF-ASD group had a mean SCL of 27.1 micromhos (microsiemens) while the mean value for the community control group was 18.6 micromhos, a difference of 45.7%.

Visual attention

As illustrated in Figure 2, the average vertical position of HF-ASD drivers' gaze was 44% higher than the community control group ($F(1,15) = 6.28, p = .024$), 13.54cm vs. 7.61cm. This main effect of HF-ASD status did not significantly interact with environment or period. Interpreting this observation in terms of driving conditions, the higher vertical gaze position can be viewed as HF-ASD drivers being oriented less often toward objects low in the visual field (i.e. dashboard, lead and directly on-coming vehicles, etc.). In other words, HF-ASD drivers appeared to be spending more time oriented toward the horizon, (e.g. above the active portions of the roadway scene). Across the sample, drivers' focus was 21% higher in the visual scene in the urban environment (where multi-story buildings and controlled intersections were present), as compared to the highway ($F(1,15) = 8.69, p = .010$), 11.95cm vs. 9.43cm.

For horizontal gaze position, a main effect of environment ($F(1,15) = 17.90, p = .001$), period ($F(2,30) = 6.22, p = .005$), and an interaction effect between period and HF-ASD status ($F(2,30) = 3.49, p = .043$), appeared. Overall, drivers focused approximately 1cm (32%), more to the right in the urban environment than the highway environment. This effect seems reasonable given the presence of pedestrians and parked vehicles on the right side of the road in the urban environment. In the highway scene, however, no active stimuli were present to the right of the roadway. In terms of the left side of the roadway, in both conditions on-coming traffic was present. Decomposing the interaction effect illustrated in Figure 3 by HF-ASD status, the effect of environment remained robust across both groups (HF-ASD: $F(1,8) = 9.58, .015$, Control: $F(1,7) = 8.32, p = .023$). A main effect of period appeared for the HF-ASD group ($F(2,16) = 6.73, p = .008$) but not for the control group. While both groups appeared to shift their gaze to the left (lower values), with added cognitive demand, only the HF-ASD group shift reached statistical significance (Figure 3). Within the HF-ASD group, pairwise comparisons with an LSD correction between the period before and during the cognitive load, as well as the period during and after, were significant ($p < .05$). In terms of the HF-ASD group, the nominal difference in gaze positioning more to the left, combined with the main effect of period, suggests a stronger shift in attention away from a vehicle in front and towards on-coming traffic (urban), or the median (highway), as cognitive demand increases.

Discussion

The main objective of this study was to assess the driving behavior of young adults with HF-ASD relative to a community control sample using a driving simulator. In this pilot work, the frequency of simulated crashes was low and comparable between the HF-ASD participants and community controls (two events for each group). Similarly, standard measures of vehicle control, such as the standard deviation of lane position, did not show significant differences in this small sample. However, drivers with HF-ASD exhibited some patterns of behavior that are suggestive of sub-optimal ways, from a driving safety perspective, of responding to increased cognitive demand or stimulation. Specifically, HF-ASD drivers responded to increased cognitive demands (CPT; cell phone task), by shifting visual attention away from the forward roadway and towards a less complex portion of the visual scene. The movement of attentional focus away from the forward roadway with increased cognitive demands suggests, that under these conditions, HF-ASD drivers may place themselves in a position that may impact their ability to respond as promptly to critical events. The ability to timely shift attention to critical events is viewed as an important element of hazard avoidance and safe driving (van der Hulst 1999).

Additionally, of note was the finding that individuals with HF-ASD tended to position their vertical gaze higher and away from nearer objects and more toward the distance than community controls. These findings suggest that individuals with HF-ASD avoid focusing their eyes directly on objects that may provide early indication of rapidly changing situations in the roadway, a key aspect of safe driving.

Also noteworthy is that the HF-ASD group exhibited a nominally elevated, although not statistically significantly higher, heart rate when compared to controls. Moreover, the HF-ASD drivers showed little change in their heart rate in response to the increased cognitive demand period whereas the community controls showed a typical arousal response and recovery (Mehler et al. 2012). Although the reasons for the nominally higher heart rate in individuals with HF-ASD are not entirely clear, elevated heart rate is a frequent concomitant of anxiety states. Increased heart rate could indicate a trend toward higher anxiety in participants with HF-ASD when engaged in a driving simulation, which is consistent with recent survey results (Cox et al. 2012). To the extent that heart rate serves as a measure of arousal, the absence of a heart rate response to the cognitive demand period in the HF-ASD sample is

consistent with a shift in visual attention serving as a behavior for maintaining a consistent level of arousal. If replicated in future studies, these results could suggest that high levels of arousal / anxiety may be one of the reasons why some individuals with HF-ASD choose not to drive. If anxiety is a critical component of driving behavior in individuals with HF-ASD, interventions for reducing anxiety would be a possible solution.

These results show differences in both vertical and horizontal gaze under highly stimulating conditions and are consistent with the literature regarding eye contact in individuals with HF-ASD. In a study investigating the correlation between eye movements and brain activity in subjects with HF-ASD, the amygdala - an emotion center in the brain associated with negative feelings – activated to an abnormal extent during a direct gaze upon a non-threatening face (Dalton et al. 2005). As noted by Kootz et al. (Kootz et al. 1992), individuals with autism appear to be sensitive to heightened stimulation and may use various behavioral strategies to filter and modulate stimulation. Diversion of gaze from high stimulus areas in the driving scene while under elevated cognitive demand may be such a situation.

The current study provides complementary data to previous work on gaze behavior in individuals with HF-ASD and suggests that driving research is an area deserving of further attention in this population. This research provides preliminary indication of the types of challenges that HF-ASD drivers may encounter in the context of the stimulating nature of driving generally, and in the presence of increased cognitive demand in specific. These findings raise the possibility of differences in the allocation of visual attention between individuals with and without HF-ASD. However, whether and the extent to which difference in glance behavior impacts driving safety remains unknown and hence the clinical significance is yet to be determined. Further research is needed to more fully assess the ability of HF-ASD drivers to maintain adequate attentional capacity to respond to rapidly changing driving demands. Such work mapping clinical characteristics of HF-ASD with principles of transportation safety and human factors will better elucidate how the driving environment (pedestrians, vehicles, surrounding buildings, etc.) impact HF-ASD drivers' visual attention, emotion, workload, and other aspects of safe behavior behind the wheel. It may be especially helpful to extend this line of research to include the assessment of persons with ASD who have the capabilities to drive but have not obtained a driver's license, drivers with ASD who have had significant difficulties with the driving task (such as multiple tickets, accidents, or license suspension), and drivers with ASD that tend to

be less frequent drivers to assess the extent to which the patterns observed here may be associated with particular subgroups. Characterizing behaviors along these lines may aid clinicians in better advising patients who are making the complex decision over what accommodations might be necessary to become a successful safe driver.

Limitations

This pilot study has a number of limitations. The sample size was small and as such lacked adequate statistical power to fully assess differences between the groups. A community sample was employed as opposed to a screened control group and an assessment of intellectual functioning or ASD was not obtained. The degree to which outcome measures relate to other covariates such as driving frequency, basal differences in heart rate, SCL, etc. are unknown. As described earlier, the simulator and simulation paradigm used have a level of established validity (Reimer et al. 2010; Fried et al. 2006; Fried et al. 2009a; Reimer et al. 2007; Wang et al. 2010; Reimer and Mehler 2011; Reimer et al. 2006); however, the extent to which these findings can be generalized to the behavior an HF-ASD population under actual driving conditions is unknown (Godley et al. 2002; Reimer et al. 2006; Kaptein et al. 1996). Keeping these considerations in mind, this exploratory driving simulation study found that drivers with HF-ASD exhibited patterns of behavior that are suggestive of sub-optimal ways, from a driving safety perspective, of responding to increased cognitive demand or stimulation. More research is needed to determine if these findings replicate in larger samples and to better assess the impact of these findings on driving safety. It should again be emphasized that while the patterns of visual behavior and physiological activity in response to added cognitive demand while driving raise interesting questions about the HF-ASD sample relative to the reference sample, the results of this pilot study should not be construed as having in any way established whether individuals with ASD are more, less, or equally safe drivers compared to an appropriate non-ASD cohort.

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Figure Captions

Figure 1. Mean heart rate before, during and after the secondary cognitive tasks for the community control and HF-ASD groups. Error bars represent the standard error

Figure 2. Mean vertical gaze for the community control and HF-ASD groups. Error bars represent the standard error

Figure 3. Mean horizontal gaze before, during and after the secondary cognitive tasks for the community control and HF-ASD groups. Error bars represent the standard error



