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A pilot study assessing performance and visual attention of teenagers with ASD in a novel adaptive driving simulator

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Abstract

Individuals with ASD, compared to typically-developed peers, may demonstrate behaviors that are counter to safe driving. The current work examines the use of a novel simulator in two separate studies. Study 1 demonstrates statistically significant performance differences between individuals with (N = 7) and without ASD (N = 7) with regards to the number of turning-related driving errors ($p < .01$). Study 2 shows that both the performance-based feedback group (N = 9) and combined performance- and gaze-sensitive feedback group (N = 8) achieved statistically significant reductions in driving errors following training ($p < .05$). These studies are the first to present results of fine-grained measures of visual attention of drivers and an adaptive driving intervention for individuals with ASD.

Keywords

autism spectrum disorders; driving simulation; driving intervention; gaze-sensitive

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Author Contributions: JW implemented large portions of the software used in the driving simulator, oversaw all experiments, conducted all data analyses, and drafted the technical portions of the manuscript. NS and ZW conceived of the study, crafted the experimental design, and revised the manuscript. LZ and DB provided major software modules for eye tracking and physiological data acquisition, respectively, and also aided in conducting experiments. MS provided consultations regarding software engineering, 3D-modeling, and algorithm design. AW, NB, and AS provided major design considerations for the driving simulator from a clinical perspective, managed recruitment of participants, drafted portions of the manuscript, and aided in several rounds of editing and revision. All authors read and approved the final manuscript.

Compliance with Ethical Standards
All procedures performed in studies involving human subjects were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Informed consent/assent was obtained from all individual participants included in the study.

Introduction

Autism Spectrum Disorder (ASD) refers to a common (1 in 68), complex neurodevelopmental disorder characterized by impairments in social interaction and communication as well as restricted, repetitive patterns of behavior and interest (American Psychiatric Association, 2013; Christensen et al. 2016). Although ASD is considered a lifelong diagnosis, much of the current literature regarding assessment and intervention for ASD focuses on early childhood (Lord & Bishop, 2010; Weitlauf et al. 2014). Given discouraging evidence regarding adaptive, educational, and employment outcomes for many adolescents and young adults with ASD (Howlin et al. 2004; Lawrence et al. 2010; Shattuck et al. 2012), there is a strong need for effective evaluation and intervention services that optimize lifespan outcomes while efficiently utilizing available resources (Lord & Bishop, 2010). The current work examines the use of a technological system that evaluates performance and attention in real time and provides feedback and assessment regarding an often critical task for adaptive independence in young adulthood: driving.

Independent transportation can enhance quality of life by increasing vocational and social opportunities and by reducing dependence upon caregivers. Supporting such enhancements is important, given that existing research suggests that only a minority (23%) of adults with ASD achieve “good” to “very good outcomes,” such as paid employment, friendships, and some independence, whereas most (58%) achieved “poor” to “very poor” outcomes and remained highly dependent on their families and social services (Howlin et al. 2004). Similarly,Shattuck et al. (2012) reported that more than 50% of individuals with ASD do not access education or employment in the two years following high school. Although the causes of these deficits are multifaceted, a targeted intervention that promotes driving independence may provide an avenue for some adolescents and adults with ASD to more easily achieve their educational and vocational goals.

Although some individuals with ASD can and do drive, research focusing on this population of drivers has advanced only in the last few years (Classen & Monahan, 2013). Recent estimates suggest that roughly one third of individuals with ASD currently drive (Curry et al. 2017), although Cox et al. (2012) found that 48% of surveyed parents of a child with ASD reported that their child had successfully attained a driver’s license. Huang et al (2012) found that 30% of age-eligible individuals with ASD do drive, and another 34% plan to do so. Respondents were more likely to drive if they were placed in a full-time regular education setting, operating under an Individualized Education Plan that included driving goals, had experience with paid employment outside of the home, and were taught to drive by parents with prior experience teaching others to drive. Parent respondents to the Cox et al. (2012) survey suggested that teaching basic driving skills was not difficult, but that teaching their children how to simultaneously perform multiple skills, particularly while maintaining awareness of other drivers, proved more challenging. Moreover, the majority of these parents (70%) suggested that the characteristics associated with ASD exerted a moderately to extremely negative influence on their child’s ability to drive safely.

The anecdotal experiences of these parents are supported by the extant literature, which suggests that ASD symptoms may compromise one’s ability to learn to drive and do so safely (Classen et al. 2013; Cox et al. 2016; Daly et al. 2014; Reimer et al. 2013; Chee et al. 2017). However, the empirical evidence is limited regarding the nature and extent of the influence that these features have on driving skills. Daly et al. (2014) surveyed licensed driving adults with and without ASD about their driving histories. They found that individuals with ASD reported being older at the age of licensure, spending less time driving, feeling less confident about their driving abilities, and experiencing greater numbers of traffic violations than TD peers. To date, only one study has investigated behind-the-wheel performance of drivers with ASD using on-road evaluation. Chee et al. (2017) conducted on-road evaluations of drivers with and without ASD driving their own vehicle along a standardized course. The researchers reported that drivers with ASD actually outperformed TD drivers on some tasks (e.g., navigating roundabouts and traffic lights), but performed more poorly on tasks related to maneuvering the vehicle at intersections (i.e., turning left or right and responding properly at pedestrian crossings).

Reimer et al. (2013) expanded the use of technology in driving evaluation further than previous studies by using eye tracking and physiological signal measurement tools to collect attentional and emotional information from participants during a simulated driving task. Regarding eye gaze, they found that individuals with ASD tended to fixate higher along the vertical axis of the scene than TD participants. When presented with increased cognitive load or demands (e.g., making a phone call while driving), individuals with ASD shifted their gaze to less visually complex and less driving-relevant areas of the simulator screen, which may increase reaction time to hazards and impede safe driving behaviors. Classen et al. (2013) also used a driving simulator to observe behavioral distinctions between individuals with and without ASD. They found that, compared to controls, the ASD group demonstrated significantly more driving errors (e.g., lane-maintenance and speed-regulation). Cox et al. (2016) also showed that drivers with ASD demonstrated significantly more errors than their TD counterparts in a driving simulator with respect to collisions, changing lanes without using a turn signal, and exceeding the speed limit, to list only a few.

Collectively, these findings suggest that technological platforms, particularly driving simulators, can provide preliminary information regarding factors related to differences in driving performance across ASD and TD populations that may represent targets for intervention. Cox et al. (2017) conducted a rigorous study designed to assess the utility of simulated driving as a tool for driving training in individuals with ASD. This work also considered the impact of expert trainer feedback based on patterns of drivers’ visual attention by first collecting data from an eye tracker and then conducting post-training reviews to explore ways to improve attention. The researchers found that drivers with ASD performed more poorly than TD drivers on tasks related to general tactical driving and working memory (Cox et al. 2017). The researchers also urge readers, rightly, not to generalize such negative results across all individuals with ASD because the condition’s heterogeneity, in some cases, may actually manifest itself in positive ways (e.g., higher-than-typical levels of caution and rule-following)—a point that has also been raised by other investigators (Huang et al. 2012; Chee et al. 2017).

Although the availability of commercial driving simulation software is both plentiful and diverse, to our knowledge, there is not a simulated driving system that can simultaneously incorporate information from a variety of sensory input modalities in real time to assess driver affect, monitor driver gaze processing of dynamical objects, or adaptively modify the driving experience to accommodate different drivers. Such a system would potentially be able to address driving issues related to processing *and* performance deficits, rather than focusing only on performance. For example, a drivers' eye gaze information could be utilized in real time to adaptively respond to inappropriate gaze patterns, such as detecting the driver's failure to notice a pedestrian and instantly providing remedial feedback. The first step towards designing such a system would require an accurate, robust mechanism for monitoring eye gaze that can reliably detect the focus of a driver's attention. The only other researchers to collect measures of gaze from individuals with ASD in a driving simulator reported only the proportions of gaze in different axes of the screen space (Reimer et al. 2013) or used the collected data strictly offline (Cox et al. 2017), and did not report fixation durations on specific objects or other regions of interest. The authors of this paper have developed such a system, and the studies presented here aim to demonstrate its sensitivity to different populations of users as well as its potential utility as an intelligent tool for driving intervention.

Two separate studies are presented. The first is a preliminary investigation into the application of a novel driving simulator system capable of capturing gaze patterns to better understand driving performance. In this study, adolescents with and without ASD perform driving tasks using the novel system and the two groups are compared with respect to both performance and attentional metrics. Based upon the extant literature, we hypothesized that group differences would arise with respect to attention (measurable via eye gaze) and ability to complete driving-related tasks, including turns, stops, and obeying speed limits. The second study concerns the use of the driving simulator as an intervention tool. In this study, two intervention strategies are evaluated on two groups of adolescents with ASD. With the first strategy, only performance is tested, while with the second strategy, gaze-contingent criteria must be met in addition to proper performance. Both of these intervention sub-systems are described in detail in the next section. For this second study, we hypothesized that the strictly performance-based intervention strategy would result in improved performance post-training, while the gaze-contingent strategy would result in improved performance as well as changes in attentional patterns. To the best of our knowledge, this is the first study to measure gaze fixation of individuals with ASD on dynamical objects in a virtual driving environment. Differences in how people with ASD attend to such information could have important implications for safety and learning within a driving environment.

Methods

System Overview

A novel driving simulator was used to carry out the presented studies. The authors thoroughly described the technical design of this system in an earlier paper (Wade et al. 2016). Thus, we limit our description of the system here to the most important information. Creating a novel system was necessary as none available commercially could be used to administer driving interventions that incorporated multimodal input (e.g., eye gaze and physiology) for the purpose of providing individualized intervention for people with ASD.

Apparatus

The Virtual Reality Driving Intervention Architecture (VADIA) is made up of a virtual driving environment and a range of input and sensory peripherals. The virtual environment is a model of downtown Philadelphia with regions added to expand and diversify the scene, including residential, arboreal, and industrial regions. Users interact with the system via a Logitech G27 controller, which features a steering wheel, pedal board, and gear shifter, although this last item was not utilized in the presented studies. The G27 controller mounts conveniently onto a car-like bucket seat that is positioned in front of a flat panel LCD monitor displaying the driving environment. A remote eye tracker was used to collect real-time gaze information, and a range of wireless sensors were used to collect physiological and electroencephalography (EEG) data.

The monitor and eye tracker were both fixed on a specialized mounting device, which was attached to an adjustable-height table that could be raised or lowered to accommodate participants of varying heights. The bucket seat was placed in such a way that the approximate distance from the participant's eyes to the eye tracker was 70 cm in accordance with the manufacturer's recommendations (Tobii Technology, 2011). At this distance, the 24" monitor (resolution 1920 × 1080 offered participants a horizontal viewing angle of approximately 41.5 degrees.

Gaze information was acquired using a Tobii X120. While the X120 is reported to demonstrate an error of only .5 degrees under ideal conditions (Tobii Technology, 2011), in practice the observed error was .88 degrees (Wade et al. 2016). Given the distance between the monitor and where participants are seated, this translates to approximately 1 cm on the screen. The X120 has the ability to collect measures of gaze position (both eyes independently), saccade path length, pupil diameter, and blink rate. In addition, by combining information about gaze position with the known locations of objects in the virtual environment, measures of fixation duration (FD) may be obtained with respect to salient objects, such as traffic lights, passing vehicles, pedestrians, and side view mirrors. The novel system was also fully integrated with physiological and EEG data capture sub-systems for use in the development of complex affective modeling procedures. Such modeling is not connected to the primary hypotheses of the current work and is presented elsewhere (Zhang et al. 2017).

Virtual Driving Environment Design

A range of driving tasks, or *assignments*, were designed within the virtual environment to challenge drivers on a range of specific skills. In each of these assignments, drivers were to navigate a specified route while engaging in a sequence of scenarios referred to as *trials*. Trials were designed to test a set of driving skills from one of four categories: turning, merging, speed-maintenance, and adherence to road laws. Examples of trials from each of these categories include driving cautiously in construction zones (speed-maintenance), stopping appropriately at stop signs (road laws), safely changing lanes on the highway (merging), and making left turns at intersections (turning). Assignments consisted of eight trials, which drivers were to complete one after the other in the order presented. Drivers experienced assignments as an unbroken route, but the route was divided up in both space and time according to the trial being performed. For instance, a trial involving a turn at an intersection is demarcated in space by the boundaries of the intersection, while a trial requiring the driver to pass another vehicle can occur at many different locations but must occur during a time-bounded interval.

For the successful completion of trials, drivers are rewarded with virtual money, which also serves to provide drivers with an indication of their performance. The successful completion of an entire assignment is met with pre-recorded, congratulatory audio feedback to encourage good performance. *Trial errors* occur when drivers do anything that is considered unsafe or improper. VADIA monitors drivers' actions and considers the following to be errors: failing to stop at stop signs or appropriately designated intersections, failing to stop at pedestrian crossings or for unloading school buses, running red lights, turning right at no-turn-on-red intersections, making wrong turns, driving in the wrong lane, exceeding the posted speed limit, colliding with other vehicles or pedestrians, colliding with other roadway objects (e.g., traffic cones), driving onto sidewalks or curbs, veering off course, stopping in intersections, blocking or failing to stop for emergency vehicles, and failing to pass vehicles in applicable trials. Note that the use of turn signals is not enforced, but it is a functionality that is available. Furthermore, the gaze-contingent feature of VADIA monitors in real time drivers' gaze patterns and reports trial errors when drivers fail to look at key regions of interest while driving.

VADIA includes six levels of difficulty, each consisting of three assignments for a total of 18 unique assignments. Difficulty in VADIA is determined by several parameters including the number and speed of other vehicles on the road, weather conditions, and responsiveness of the driving controls. Difficulty level one is marked by few dynamical objects (e.g., pedestrians and other drivers) in bright and sunny weather, while difficulty level six contains many such dynamical objects as well as poorer weather conditions that impede drivers' control (i.e., simulating slippery road conditions). For a full delineation of VADIA's difficulty parameters, please see our prior description (Wade et al. 2016).

Driving Environment Conditions

Two versions of VADIA are assessed in this paper: the performance-based version and the gaze-contingent version. With the performance-based version, drivers maneuver through diverse driving assignments in which their progress depends solely on their performance (i.e., seeking to minimize trial errors). The gaze-contingent version enforces the same rules as the performance-based version, but additionally requires that drivers' gaze fall on predetermined regions of interest in the virtual environment in order to progress through trials. Failing to look at these key regions results in trial errors referred to as *gaze errors*, as opposed to *performance errors*. Importantly, when one of these key regions is not observed, on subsequent attempts the object becomes highlighted as in Fig. 1 to draw the attention of the driver. A sufficient number of errors in either version results in an *assignment failure*, and an assignment—once failed—cannot be attempted again.

Experiments

Two studies using the VADIA system were conducted. The first study was a preliminary investigation to determine the acceptability of the novel system and to assess differences between drivers with ASD and their TD peers. In the second study, VADIA was pilot tested as a tool for targeted driving intervention with regards to both performance-based and gaze-contingent modalities. The reader should note that some metrics are not directly comparable between the two studies (e.g., number of trial errors) due to differences in the tasks selected for both studies (e.g., number of assignments and task difficulty).

Study 1: Preliminary Investigation

The aim of the first study was twofold: to gauge the initial acceptability of the novel simulation system within the target population and to assess the performance and processing differences between drivers in the ASD and TD populations. Note that this study uses the performance-based version of VADIA exclusively.

Participants—Fourteen participants were recruited for a study designed to assess differences between individuals with ASD (N = 7) and TD controls (N = 7). Participants were matched pairwise with respect to both age and gender, and all participants were of approximate driving age (16 years) in the state where the study was conducted. However, participants had different levels of experience across groups with regards to licensure or learner’s permit status. See Table 1 for full participant data.

Participants in the ASD group were recruited through an existing clinical registry. The registry includes individuals who received a clinical diagnosis of ASD from a licensed clinical psychologist and scored at or above the clinical cutoff on the Autism Diagnostic Observation Schedule (ADOS; Lord et al. 2000) or Autism Diagnostic Observation Schedule, Second Edition (ADOS-2; Lord et al. 2012). Estimates of cognitive functioning for those in the ASD group (IQ M=114.3) were available from the registry [tested abilities from either the Differential Ability Scales (Hale, 2008) or the Wechsler Intelligence Scales for Children, Fourth Edition (Wechsler, 2003)].

Participants in the TD group were recruited through an electronic recruitment registry accessible to community families. The clinical battery for the TD group included the Wechsler Abbreviated Scale of Intelligence, Second Edition (WASI-II; Wechsler, 2011) to quantify cognitive functioning (IQ M=104.9). To screen for autism risk in the TD group, parents in both groups completed the Social Responsiveness Scale, Second Edition (SRS-2; Constantino & Gruber, 2012) and the Social Communication Questionnaire, Lifetime Version (SCQ; Rutter et al. 2003). None of the participants in the TD group scored in the at-risk or clinical range on either assessment.

Because all of the participants were minors, informed consent and assent were collected from the parents and participants, respectively. The study was approved by the university Institutional Review Board (IRB). Participants received a gift card as compensation for their time.

Procedures—All participants attended a single session lasting approximately 90 minutes including consent, sensor application, and driving (about 70 minutes spent driving). At the start of the visit, participants were shown a tutorial explaining the system controls and task objectives. Following the tutorial, the eye tracking device was calibrated to the participants' eyes using a nine-point calibration procedure. After calibration, participants began a three-minute, unrestricted practice drive. This practice period excluded pedestrians and other vehicles, allowing participants to focus their attention on habituating to the simulator.

After practicing, participants began the first of six consecutive assignments—two assignments each from levels four, five, and six. Assignments were presented in order of increasing difficulty and participants could attempt each assignment only once, but progression through the levels was not contingent upon successful completion of the previous level. When trials were failed, the system generated feedback based on the context of the driving error. For example, if the error was due to driving too quickly through an active school zone, then the system advised, "Did you notice you were in a school zone? Always watch for speed limit signs when entering a school zone." Participants were required to acknowledge feedback messages by pressing down twice on the accelerator pedal.

At the end of every assignment, participants completed a brief self-report survey that was integrated directly into VADIA (see Table 2). The survey prompted participants to rate their affective levels (i.e., engagement, enjoyment, frustration, and boredom) on a 5-Likert scale, where a value of one indicates low intensity. Additional questions in the survey pertained to perceived system quality (e.g., graphics, instructional clarity, etc.). Upon completion of the six assignments and corresponding surveys, the session was complete.

Measures and Data Analysis—A variety of performance and gaze metrics were collected in order to gauge preliminary differences in performance and attention between ASD and TD drivers in the novel simulator. The number of trial errors was used to characterize driving performance. Periodic surveys were built directly into VADIA and provide insight into the experiences of drivers using the novel system (the survey questions and response results are given in Table 2).

Measures of fixation duration on various categories of regions of interest (ROI) were used to assess attentional differences between both groups. The metric fixation duration captures the proportion of time that drivers spend looking at salient objects, such as street signs, pedestrians, and other vehicles. Fixation duration was computed for three non-exclusive categories of ROI: dynamic, static, and social. Dynamic ROI are those that do not have a fixed position in the virtual environment (e.g., pedestrians, other vehicles, etc.). Static ROI, on the other hand, have a fixed position in the virtual environment (e.g., side-view mirrors, speedometer, and the navigation system). Social ROI consisted of pedestrians and cyclists, following the earlier designation by Sheppard et al. (2010), which has also been adopted in recent related work (Bishop et al. 2017; Sheppard et al. 2017).

Due to the small sample sizes being compared, descriptive statistics are presented, including mean, standard deviation, and median. Appropriate inferential test statistics are also presented. Because the sample variables being assessed are non-normally distributed, Mann-

Whitney ranked sum tests are used to make group comparisons. For inferential tests, medians, test statistics (both Z and p), and effect size approximations (Cohen's d) are reported. Note that the cutoffs for small, median, and large effect sizes are set at 0.3, 0.5, and 0.8, respectively (Cohen, 1988). In an attempt to control for the heterogeneity of driving experience in the samples, post hoc analyses were conducted using a two-way ANOVA with the factors *group* (i.e., ASD and TD) and *experience level* (i.e., none and permit or license). Age was not evaluated as a separate covariate because age is closely associated with experience level and the experience levels across the two groups were equally split (i.e., four experienced and three inexperienced participants in each group).

Results—Participants in the ASD group demonstrated a greater number of trial errors (*Median* = 11) than their TD counterparts (*Med* = 8), although the difference was not statistically significant ($Z = 1.86$, $p = .058$, $d = 1.08$). Participants in the ASD group had a combined total of 85 trial errors resulting in 11 failed assignments, whereas the TD group had 55 trial errors and only one failed assignment. The ASD group failed trials involving turning at a significantly higher rate than TD participants (see Table 3). Participants with ASD failed twice as many turning-related trials (*Med* = 6) as TD participants (*Med* = 3, $Z = 2.92$, $p < .01$, $d = 2.49$). A post hoc two-way ANOVA of turning-related trial incidences revealed a significant effect of group ($F(1,10) = 16.38$, $p = .002$), but not of experience level ($F(1,10) = .01$, $p = .913$) or interaction of group and experience level ($F(1,10) = 1.82$, $p = .207$). Note, however, that the four highest-performing participants in the TD group were all licensed drivers. Of the total trial errors experienced by the ASD group, 48.2% were related to turning compared to 34.5% in the TD group. No significant differences between the two groups emerged with respect to the other three categories (i.e., merging, laws, and speed-maintenance). VADIA recorded not only the types of trial errors that occurred, but the causes of the errors as well. A wide range of causes led to errors in turning-related trials, including failing to stop at red lights or stop signs, colliding with other vehicles mid-turn, driving onto sidewalks/curbs, and making wrong turns (e.g., turning left instead of right).

Fixation durations were examined for the aforementioned categories of ROI. Fixation durations were computed as the ratio of time that a participant spent looking at a particular category of ROI during an assignment to the total duration of the assignment (expressed as a percentage). Interestingly, although no statistically significant group differences arose, participants in the ASD group showed nominally larger fixation durations than TD peers for all categories of ROI. Table 4 presents detailed fixation durations by ROI category for these two groups.

The median vertical gaze position of participants with ASD was 2.39% higher than that of the TD participants, and slightly more to the right along the horizontal axis by .05%. Although these vertical and horizontal position differences were statistically significant, the effect sizes were not substantially large ($p < .001$, $d = .11$ and $p < .001$, $d = .02$, respectively). Despite the small differences in position, the direction of the shifted gaze position from the TD group to the ASD group appears to agree with a key finding of a previous study (Reimer et al. 2013).

Participants in the ASD group reported significantly lower levels of enjoyment ($Z = 2.11$, $p < .05$, $d = 1.33$) and nominally higher levels of frustration ($Z = 1.87$, $p = .061$, $d = 1.41$) using the system compared to participants in the TD group (see Table 2 for details). Overall, participants in the ASD group reported a generally more negative view of their experience interacting with the system than the TD group. Specifically, the ASD group, in comparison to the TD group, reported lower ratings pertaining to ease of operating the vehicle, less clarity in understanding the instructions, a decreased sense of the relevance of the task objectives, and lower satisfaction with the quality of the virtual environment.

Study 2: Intervention Design

The second study presented in this paper was concerned with the effectiveness of VADIA as a tool for driving intervention. Twenty adolescents with ASD were recruited and randomly assigned to one of two groups: a group using the performance-based version of VADIA or a group using the gaze-contingent version. The purpose of this study was to assess changes in performance and processing after training with the novel system, as well as to compare the effectiveness of the two modalities (i.e., with a sensitivity to gaze or not).

Participants—Twenty participants with ASD, ranging in age from 13 to 18 years (M=15.4, SD=1.62), were recruited for a driving intervention study. This relatively wide range in age was selected in part as a convenience sample. Although the lower bound of 13 years of age is too young to attain a learner's permit in the state where the research was conducted (i.e., 15 years or 14 years in cases of hardship), opening enrollment to younger subjects is not uncharacteristic of the ASD/driving literature (e.g., Classen et al. 2013; Brooks et al. 2016). Furthermore, early and extended exposure to driving training may be desirable for children with ASD who are approaching age-eligibility. Following randomized group assignment (via a balanced, randomly generated sequence of binary digits), all participants were assigned to either a performance-based group (N = 10) or gaze-contingent group (N = 10). Table 5 gives detailed participant data for both of these groups. Participants were recruited from the same clinical registry as Study 1, and all received a diagnosis of ASD from a licensed clinical psychologist. Three of the participants recruited had previously participated in Study 1 as well; through random assignment, two were placed in the performance-based group while the third was placed in the gaze-contingent group. Despite our best efforts to recruit participants from both sexes, only one female participant was enrolled due to the greater prevalence of ASD in males than in females. Appropriate consent/assent was collected from all participants, and this study was approved by the university IRB. As in the previous study, participants were compensated for their time with a gift card.

Procedures—Recruited participants were enrolled in a series of six sessions. On the initial visit only, participants were shown a tutorial on the use of the system and then completed a three-minute practice drive to acclimate to the simulator before beginning the major driving tasks. A pre-test/training/post-test style design was used to compare training effects of the novel driving simulator. The pre- and post-test sessions—sessions one and six, respectively—consisted of assignments from difficulty levels two and five so that performance could be assessed across a range of task difficulties. The training sessions—sessions two through five

—consisted of assignments from difficulty levels one, three, four, and six, respectively. Each session was made up of three assignments lasting approximately 60 minutes (about 30 minutes of drive time and about 30 minutes of preparation and sensor application/removal).

Participants in the performance-based group completed tasks using the same non-adaptive (i.e., without gaze-sensitivity) version of VADIA as in Study 1. In the performance-based version, drivers are permitted a maximum of three trial errors per assignment. A fourth trial error results in the failure of the assignment, which cannot be re-attempted. Participants in the gaze-contingent group completed tasks using the adaptive version of VADIA. In this version, trial errors are classified as either performance errors or gaze errors, and drivers must follow the rules of the performance-based system while also paying attention to salient aspects of the driving environment. Drivers who fail to look at any one of these important objects during trials (e.g., oncoming vehicles, traffic lights, etc.) receive a gaze error. A maximum of three gaze errors and/or three performance errors are permitted in the gaze-contingent system, but a fourth error in either category results in an assignment failure.

Measures and Data Analysis—Performance and gaze metrics were again collected in the second study, but no periodic surveys were conducted. The number of trial errors metric was used to track performance across sessions and to gauge training effects from pre- to post-test. Similarly, fixation duration metrics provided a means to compare attentional differences pre- and post-training. Computed fixation durations for categories of ROI were the same as in the first study (i.e., dynamic, static, and social).

Although the samples sizes were slightly larger than those in the first study, conservative statistical methods were used to evaluate training effects and to compare variables across groups. For pre- and post-test assessments, Wilcoxon signed rank tests are used, given the paired-sample design and non-normality of the variables. For these analyses, medians, test statistics (both Z and p), and effect sizes (Cohen's d) are reported. Additionally, an ANCOVA design was used in post hoc analysis to control for effects of age. Age, rather than experience level, was selected as a controlling factor due the low number of experienced drivers in both groups (i.e., there were only two experienced drivers in each group).

Results—Once enrolled, none of the 20 participants dropped out of the study. However, data were excluded from analyses for participants who were unable to achieve a baseline level of performance sufficient for analysis of training effects. This data exclusion criterion was defined such that a participant must successfully complete at least one assignment during the course of the entire experiment. Data from two participants in the gaze-contingent group and one participant in the performance-based group were excluded from data analyses. The data exclusion from the two participants in the gaze-contingent group was due to both of these individuals preferring to test the boundaries of the system (i.e., repeatedly and intentionally creating accidents because they enjoyed doing so). Data from one participant in the performance-based group were excluded because, despite our best efforts, we were unable to collect usable eye tracking data from this participant. Therefore, presented group statistics are based on N = 9 participants in the performance-based group and N = 8 participants in the gaze-contingent group.

Participants in the performance-based group showed a significant reduction in trial errors from pre-test (*Med* = 7) to post-test (*Med* = 3), with large effect ($Z = 2.38$, $p < .05$, $d = 1.43$). Table 6 breaks down these trial errors by category. Trials in the law category showed a particularly large reduction in rate of errors from pre-test (*Med* = 3) to post-test (*Med* = 0), with large effect ($Z = 2.69$, $p < .01$, $d = 2.30$). With regards to fixation durations, participants in the performance-based group displayed nominal increases in fixation durations across all categories from pre-test to post-test, though none of these changes were statistically significant (see Table 8).

It is extremely important to note that the gaze-contingent version of VADIA detects trial errors due to both gaze and performance, and thus the number of trial errors will often be higher for this group than for participants using the performance-based system. Essentially the number of opportunities for failure is more than doubled in this condition. Participants in the gaze-contingent group also showed a significant reduction in trial errors from pre-test (*Med* = 10) to post-test (*Med* = 5.5), with large effect ($Z = 2.37$, $p < .05$, $d = 1.36$). Given that the two systems cannot be directly compared with respect to numbers of driving errors, it may be instructive to instead consider the metric *change in number of trial errors* from pre-test to post-test. Using this metric as the response variable for a one-way ANCOVA design controlling for age with a group factor (i.e., gaze-contingent and performance-based), we found no significant effect on error reduction due to group ($F(1,13) = .0$, $p = .988$), age ($F(1,13) = .02$, $p = .897$), or interaction between group and age ($F(1,13) = .34$, $p = .569$). This suggests that participant age did not significantly influence gains in performance and that both groups showed performance gains of equivalent magnitude.

Table 7 presents gaze-contingent group trial errors by trial category. Again, trial errors in the law category showed a nominal, though non-significant, reduction post-training, and trial errors in the turn category showed a significant reduction from pre-test (*Med* = 5) to post-test (*Med* = 2), with large effect ($Z = 2.23$, $p < .05$, $d = 1.45$). No significant changes in fixation duration were found for the gaze-contingent group, but the reader should note the differences in magnitude between both the initial and final fixation durations for all ROI across both groups, which appear to move in opposite directions (see Table 9).

Discussion

These two studies are the first attempt to measure gaze fixation of individuals with ASD on dynamical objects in real time in a virtual driving environment. We found differences in the types of trial errors that individuals with ASD made compared to TD controls. We expanded upon our initial work to compare performance within gaze- versus performance-based feedback and found significant reductions in trial errors post-training. These preliminary findings warrant future work using VADIA to both assess and intervene on driving-related attention in individuals with ASD.

Concerning the first study conducted, compared to TD controls, participants with ASD demonstrated more driving errors. This result is in line with the reported outcomes of previous studies investigating driving in individuals with ASD (Classen et al. 2013; Cox et al. 2016; Daly et al. 2014; Cox et al. 2017). Notably, the majority of the observed trial errors occurred during driving tasks that involved turning the vehicle. Participants in both the ASD and TD groups demonstrated comparable performance for the other trial types (i.e., merging, speed-maintenance, and adherence to road laws), suggesting that turning may be a particularly problematic skill for individuals with ASD. In fact, this result has recently been observed in real-world driving among individuals with ASD (Chee et al. 2017). In our study, participants experienced turning-related errors for a variety of reasons including collisions with other vehicles, running red lights or stop signs, and driving onto sidewalks. A post hoc analysis suggests that experience level does not appear to significantly affect these rates of turning-related errors. It is possible that motor coordination difficulties as well as attentional differences both contributed to error rates, as recent investigations of motor coordination differences between drivers with and without ASD have shown that drivers with ASD require significantly more time than controls to perform steering-related tasks (Cox et al. 2016; Brooks et al. 2016).

Individuals with ASD may demonstrate additional challenges as the cognitive and attentional demands of performance increase in driving scenarios despite being able to perform smaller skill components with success. This highlights the need for systems that can provide feedback and support during such loaded challenges in order to realize more powerful impact and generalization to real-world skill deployment. While no statistically significant differences were detected between the two groups on measures of fixation duration, median fixation durations in the ASD group were nominally of greater length across all ROI categories. Early work comparing fixation durations of novice and experienced drivers provides evidence that novice drivers demonstrate longer fixations than more experienced drivers, which would suggest a greater need for time to process unfamiliar or complex situations (Crundall & Underwood, 1998).

Although the difference was slight, compared to TD peers, participants in the ASD group showed a median gaze position on the display monitor that was both higher vertically and towards the right horizontally. The directions of these shifts mirror results reported in an earlier study that looked at young drivers with ASD in a driving simulator (Reimer et al. 2013). Reimer et al. speculated that the gaze position differences may have been due to individuals with ASD attempting to shift their attention away from more complex regions of the environment (i.e., away from the developing roadway) in order to modulate potentially aversive emotional reactions (e.g., anxiety) in response to challenging information. In light of this, it might be important for future iterations of gaze detection work to also collect subjective and physiological ratings of anxiety states as well as the other affective domains similar to those that we measured.

We gathered self-reported affective data to gauge user enjoyment, engagement, boredom, and frustration regarding our novel VR system. We found that participants in the ASD group reported a more negative experience overall compared to the TD participants. Participants with ASD reported lower levels of enjoyment and engagement, and higher levels of frustration when using the system compared to TD participants. Compared to the TD group, participants with ASD also reported greater difficulty operating the vehicle, poorer reception of the virtual environment, a lower sense of the practical relevance of task objectives, more difficulty grasping the task instructions, and greater overall difficulty in completing tasks.

This important information will not only inform our future work with VADIA related to engaging participants, but it may also reflect a general lack of confidence in one's own ability to drive that has been observed in individuals with ASD (Daly et al. 2014).

Building upon our first work, the second study sought to assess the utility of the novel simulator as a tool for driving intervention. Both of the tested intervention modalities (i.e., the performance-based and gaze-contingent modalities) showed statistically significant reductions in trial errors post-training. However, the reader is reminded that this is pilot work and the apparent improvements in performance that were observed cannot yet be confirmed as not arising from practice effects. Even so, these promising preliminary results warrant further investigation into the use of VADIA as an intervention tool, including determining whether training effects of the simulator translate to improvements in on-road tests. Indeed, the researchers plan to conduct this investigation as part of ongoing research with VADIA.

In both the performance-based and gaze-contingent groups, there were no significant differences in fixation duration patterns from pre- to post-test. However, the gaze-contingent group did show nominally greater fixation durations at pre-test evaluation than participants in the performance-based group, which seems intuitive given that participants in the gaze-contingent group were required to look at ROI in order to progress through driving tasks. Furthermore, the trends in both groups' length of fixation duration appear to diverge: the performance-based group trends towards longer fixations while the gaze-contingent group trends towards shorter fixations. While we are unable characterize these trends with statistical certainty, these findings call to mind the differences in fixation patterns between novice and experienced drivers. That is, experienced drivers demonstrate shorter fixations than novice drivers (Crundall & Underwood, 1998).

Despite the potential that our system demonstrates, the studies presented here are preliminary in nature and possess a few critical limitations. First, the small sample sizes, although characteristic of exploratory studies in general, limit the statistical power of the analyses and subsequently the generalizability of the results. Second, while we attempted to balance the number of participants with driving experience in both studies across respective groups, the effects of neither age nor driving experience are sufficiently controlled for in the presented studies. Post hoc analyses using ANOVA and ANCOVA were conducted in an attempt to address this issue, but the assumptions of these models (e.g., normality) are not necessarily met with the current small sample. In light of this, the reader is cautioned to consider presented results in the context of such imbalanced initial capabilities. Future work should assess groups of either experienced or inexperienced drivers separately, rather than a mixture of both, in order to prevent pollution of the results. Third, the preliminary analyses do not control for the co-occurrence of potential conditions such as Attention Deficit/Hyperactivity Disorder (ADHD) that can have a clear and negative impact upon driving performance and patterns of visual attention (Jerome et al. 2006). With regards to driving in the ASD population, the literature contains only one study that attempted to analytically control for the effects of ADHD on study results (Huang et al. 2012). Huang et al. (2012) reported that a majority (51.1%) of children with ASD of driving age also had ADHD; however, this factor did not significantly affect whether or not the child drove a vehicle.

Brooks et al. (2016) reported that 9 of 10 participants in a group of individuals with ASD were also diagnosed with ADHD compared to only 4 of 31 having ADHD in the control group. Thus, future work is needed to understand the potential impact of ADHD on driving simulation performance for individual with ASD.

Lastly, the validity of the system has not yet been proven. A study designed to assess such validity is planned as future work and will be conducted in collaboration with Certified Driving Rehabilitation Specialists in both clinical and on-road settings. We aim to evaluate two groups—a group receiving training using the gaze-contingent simulator and a control group receiving standard clinical training—and we will assess changes in performance based on best practice clinical and on-road evaluation metrics.

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References

American Psychiatric Association. Diagnostic and statistical manual of mental disorders. 5. Arlington, VA: American Psychiatric Publishing; 2013.

Bishop HJ, Biasini FJ, Stavrinos D. Social and non-social hazard response in drivers with autism spectrum disorder. Journal of Autism and Developmental Disorders. 2017; 47(4):905–917. [PubMed: 28070791]

Brooks J, Kellett J, Seeanner J, Jenkins C, Buchanan C, Kinsman A, Desmond K, Pierce S. Training the motor aspects of pre-driving skills of young adults with and without autism spectrum disorder. Journal of Autism and Developmental Disorders. 2016; 46(7):2408–2426. [PubMed: 27055416]

Chee DY, Lee HC, Patomella AH, Falkmer T. Driving Behavior Profile of Drivers with Autism Spectrum Disorder (ASD). Journal of Autism and Developmental Disorders. 2017; :1–13. DOI: 10.1007/s10803-017-3178-1 [PubMed: 27696184]

Christensen DL, Baio J, Braun KV, Bilder D, Charles J, Constantino JN, Yeargin-Allsopp M. Prevalence and characteristics of autism spectrum disorder among children aged 8 years - autism and developmental disabilities monitoring network, 11 sites, United States, 2012. Morbidity And Mortality Weekly Report. Surveillance Summaries (Washington, D.C.: 2002). 2016; 65(3):1–23.

Classen S, Monahan M. Evidence-based review on interventions and determinants of driving performance in teens with attention deficit hyperactivity disorder or autism spectrum disorder. Traffic Injury Prevention. 2013; 14(2):188–193. [PubMed: 23343028]

Classen S, Monahan M, Hernandez S. Indicators of simulated driving skills in adolescents with autism spectrum disorder. The Open Journal of Occupational Therapy. 2013; 1(4) Article 2.

Cohen, J. Statistical power analysis for the behavioral sciences. 2. Hillsdale, NJ: Lawrence Erlbaum Associates; 1988.

Constantino, JN., Gruber, CP. Social responsiveness scale. 2. Los Angeles, CA: Western Pyschological Services; 2012.

Cox DJ, Brown T, Ross V, Moncrief M, Schmitt R, Gaffney G, Reeve R. Can Youth with Autism Spectrum Disorder Use Virtual Reality Driving Simulation Training to Evaluate and Improve Driving Performance? An Exploratory Study. Journal of Autism and Developmental Disorders. 2017; :1–12. DOI: 10.1007/s10803-017-3164-7 [PubMed: 27696184]

Cox NB, Reeve RE, Cox SM, Cox DJ. Brief report: driving and young adults with ASD: Parent's experiences. Journal of Autism and Developmental Disorders. 2012; 42(10):2257–2262. [PubMed: 22359179]

Cox SM, Cox DJ, Kofler MJ, Moncrief MA, Johnson RJ, Lambert AE, Reeve RE. Driving simulator performance in novice drivers with autism spectrum disorder: The role of executive functions and basic motor skills. Journal of Autism and Developmental Disorders. 2016; 46(4):1379–1391. [PubMed: 26676628]

Crundall DE, Underwood G. Effects of experience and processing demands on visual information acquisition in drivers. Ergonomics. 1998; 41(4):448–458.

Curry AE, Yerys BE, Huang P, Metzger KB. Longitudinal study of driver licensing rates among adolescents and young adults with autism spectrum disorder. Autism. 2017; :1–10. DOI: 10.1177/1362361317699586

Daly BP, Nicholls EG, Patrick KE, Brinckman DD, Schultheis MT. Driving behaviors in adults with autism spectrum disorders. Journal of Autism and Developmental Disorders. 2014; 44(12):3119–3128. [PubMed: 24925544]

Hale JB, Fiorello CA, Dumon R, Willis JO, Rackley C, Elliott C. Differential ability scales — second edition (neuro)psychological predictors of math performance for typical children and children with math disabilities. Psychology in the Schools. 2008; 45(9):838–858.

Howlin P, Goode S, Hutton J, Rutter M. Adult outcome for children with autism. Journal of Child Psychology and Psychiatry. 2004; 45(2):212–229. [PubMed: 14982237]

Huang P, Kao T, Curry AE, Durbin DR. Factors associated with driving in teens with autism spectrum disorders. Journal of Developmental & Behavioral Pediatrics. 2012; 33(1):70–74. [PubMed: 22157351]

Jerome L, Segal A, Habinski L. What we know about ADHD and driving risk: a literature review, meta-analysis and critique. Journal of the Canadian Academy of Child and Adolscent Psychiatry. 2006; 15(3):105–125.

Lawrence DH, Alleckson DA, Bjorklund P. Beyond the roadblocks: transitioning to adulthood with asperger's disorder. Archives of Psychiatric Nursing. 2010; 24(4):227–238. [PubMed: 20650368]

Lord C, Bishop SL. Autism spectrum disorders: Diagnosis, prevalence, and services for children and families. Social Policy Report. 2010; 24(2):1–26. Retrieved from www.srcd.org/spr.html.

Lord, C., Rutter, M., DiLavore, PC., Risi, S. Autism diagnostic observation schedule. Torrance, CA: Western Psychological Services; 2000.

Lord, C., Rutter, M., DiLavore, PC., Risi, S., Gotham, K., Bishop, SL. Autism diagnostic observation schedule. 2. Torrance, CA: Western Psychological Services; 2012.

Reimer B, Fried R, Mehler B, Joshi G, Bolfek A, Godfrey KM, Biederman J. Brief report: Examining driving behavior in young adults with high functioning autism spectrum disorders: A pilot study using a driving simulation paradigm. Journal of Autism and Developmental Disorders. 2013; 43(9):2211–2217. [PubMed: 23338532]

Rutter, M., Bailey, A., Lord, C. Social communication questionnaire (SCQ). Los Angeles, CA: Western Psychological Services; 2003.

Shattuck PT, Narendorf SC, Cooper B, Sterzing PR, Wagner M, Taylor JL. Postsecondary education and employment among youth with an autism spectrum disorder. Pediatrics. 2012; 129(6):1042–1049. [PubMed: 22585766]

Sheppard E, Ropar D, Underwood G, van Loon E. Brief report: Driving hazard perception in autism. Journal of Autism and Developmental Disorders. 2010; 40(4):504–508. [PubMed: 19890705]

Sheppard E, Van Loon E, Underwood G, Ropar D. Attentional differences in a driving hazard perception task in adults with autism spectrum disorders. Journal of Autism and Developmental Disorders. 2017; 47(2):405–414. [PubMed: 27866348]

Tobii Technology. Accuracy and precision test method for remote eye trackers. Tobii Technology. 2011; AB 2.1.1:1–28.

Wade J, Zhang L, Bian D, Fan J, Swanson A, Weitlauf A, Sarkar M, Warren Z, Sarkar N. A Gaze-contingent adaptive virtual reality driving environment for intervention in individuals with autism spectrum disorders. ACM Transactions on Interactive Intelligent Systems (TiiS). 2016; 6(1) Article 3.

Wechsler, D. Wechsler intelligence scale for children-fourth edition (WISC-IV) administration and scoring manual. San Antonio, TX: Pearson Education, Inc; 2003.

Wechsler, D. Wechsler abbreviated scale of intelligence. 2. San Antonio, TX: Pearson Education, Inc; 2011.

Weitlauf AS, McPheeters ML, Peters B, Sathe N, Travis R, Aiello R, Warren Z. Therapies for children with autism spectrum disorder: Behavioral interventions update. Comparative Effectiveness Review. 2014; (137)

Zhang L, Wade J, Bian D, Fan J, Swanson A, Weitlauf A, Warren Z, Sarkar N. Cognitive load measurement in a virtual reality-based driving system for autism intervention. IEEE Transactions on Affective Computing. 2017; 8(2):176–189. [PubMed: 28966730]

Figure 1.

Driver perspective with object highlighting in the gaze-contingent version of [NAME REMOVED FOR BLINDED REVIEW]. In this scene, the driver failed to look at one or both of the key regions of interest in the trial (i.e., the speedometer and road-work sign), thus those objects are highlighted during subsequent attempts of the trial.

Table 1

Study 1 Participant Characteristics

Group M (SD)		
	ASD (N=7)	**TD (N=7)**
Gender (% male)	86%	86%
Chronological age	16.3 (0.98)	16.01 (1.14)
IQ	114.3 (10.42)	104.9 (19.02)
SRS-2 total raw score	95.3 (22.22)	9.17 (5.34)
SCQ total score	13.9 (7.86)	0.67 (0.82)
Permit holders (%)	42.86%	0%
License-holders (%)	14.29%	57.14%

Note: SCQ = Social Communication Questionnaire; SRS-2 = Social Responsiveness Scale, Second Edition;

IQ = composite score: Differential Ability

Scales (General Conceptual Ability) or Wechsler Intelligence Scale for Children (Full Scale IQ).

Table 2

Study 1 Post-Assignment Survey Responses

	ASD (N=7)	TD (N=7)			
Survey Item	**Med (M ± SD)**	**Med (M ± SD)**	***Z***	***p***	***d***
Which best describes your experience of operating the vehicle?[a]	3.67 (3.1±0.97)	4 (3.86±0.56)	1.80	.071	.96
How would you rate the visual quality of the objects?[a]	2 (2.36±0.96)	4 (3.45±1.22)	1.67	.094	.99
Which best describes how you felt about the objectives of the trials?[a]	2.83 (2.9±0.71)	4 (3.95±0.21)	2.54	.011 *	2.01
How would you describe the clarity of the instructions given?[a]	2.83 (3.07±0.8)	4.17 (4.14±0.63)	2.25	.025 *	1.48
Which describes how you felt about the difficulty?[a]	3.17 (2.95±0.87)	3.67 (3.81±0.3)	2.32	.021 *	1.32
As best you can, rank your level of…enjoyment when completing the assignment.[b]	3 (3.02±0.97)	4 (4.1±0.6)	2.11	.035 *	1.33
…engagement[b]	3.5 (3.67±1.12)	4.17 (4.24±0.6)	.84	.400	.70
…frustration[b]	2.83 (2.69±0.98)	1.82 (1.67±0.3)	1.87	.061	1.41
…boredom[b]	1.5 (1.76±1.02)	1.83 (1.69±0.75)	0	1	.08

[a] Larger values correspond to a more positive experience.

[b] Larger values correspond to higher intensity.

[*] $p < .05$;

[**] $p < .01$;

[***] $p < .001$

Table 3

Study 1 Trial Errors

Trial Errors by Category—Total Based on 6 Assignments

	ASD (N=7)	**TD (N=7)**	**Mann-Whitney *U*-test Statistics**		
Trial Type	**Med (M ± SD)**	**Med (M ± SD)**	***Z***	***p***	***d***
Laws	2 (2.43±2.64)	2 (1.86±1.35)	0	.991	.30
Turns	6 (5.86±1.35)	3 (2.71±1.38)	2.92	.002 **	2.49
Merging	0 (1±1.53)	0 (0.57±0.79)	.21	.878	.38
Speed-maintenance	3 (2.86±1.95)	3 (2.71±0.76)	.20	.823	.10
All	11 (12.14±5.27)	8 (7.86±2.97)	1.86	.058	1.08

[*] $p < .05$;

[**] $p < .01$;

[***] $p < .001$

Table 4

Study 1 Fixation Durations

Fixation Durations by ROI Type (%)					
	ASD (N=7)	TD (N=7)	Mann-Whitney *U*-test Statistics		
Trial Type	**Med (M ± SD)**	**Med (M ± SD)**	***Z***	***p***	***d***
Social	3.73 (3.35±1.54)	1.81 (2.3±1.27)	1.28	.209	.74
Static	10.65 (10.76±10.86)	10.6 (13.44±7.67)	.51	.620	.29
Dynamic	9.25 (9.58±4.84)	5.16 (6.15±2.55)	1.28	.209	.89
All ROI	19.97 (22.58±14.97)	16.9 (18.32±11.49)	.38	.710	.32

[*] $p < .05$;

[**] $p < .01$;

[***] $p < .001$

Table 5

Study 2 Participant Characteristics

Group M (SD)	PB (N=10)	GC (N=10)
Gender (% male)	100%	90%
Chronological age	15.1 (1.58)	15.48 (1.78)
SRS-2 total raw score	96.1 (31.66)	99.6 (22.94)
SCQ total score	20.8 (11.5)	20.5 (5.84)
Permit holders (%)	20%	10%
License-holders (%)	0%	10%

Note: SCQ = Social Communication Questionnaire; SRS-2 = Social Responsiveness Scale, Second Edition

Table 6

Study 2 Performance-based Group Trial Errors

Performance-based Group (N=9)—Totals Based on 3 Assignments

	Pre-test	Post-test	Wilcoxon Signed Rank Statistics		
Trial Type	**Med (M ± SD)**	**Med (M ± SD)**	***Z***	***p***	***d***
Laws	3 (2.89±1.05)	0 (.67±.87)	2.69	.007[**]	2.30
Turns	3 (2.33±1.87)	1 (1.44±1.42)	.86	.388	.54
Merging	1 (1.11±1.45)	1 (.89±1.05)	.29	.774	.17
Speed-maintenance	2 (2±1.22)	1 (.89±1.27)	2.27	.023[*]	.89
All	7 (8.33±2.18)	3 (3.89±3.82)	2.38	.018[*]	1.43

[*] $p < .05$;

[**] $p < .01$;

[***] $p < .001$

Table 7

Study 2 Gaze-contingent Group Trial Errors

Gaze-contingent Group (N=8)—Totals Based on 3 Assignments					
	Pre-test	**Post-test**	**Wilcoxon Signed Rank Statistics**		
Trial Type	**Med (M ± SD)**	**Med (M ± SD)**	***Z***	***p***	***d***
Laws	1.5 (1.5±1.2)	.5 (.63±.74)	1.82	.068	.87
Turns	5 (4.38±2.2)	2 (2±.76)	2.23	.026*	1.45
Merging	2.5 (2.63±1.51)	1.5 (1.63±1.06)	1.73	.085	.77
Speed-maintenance	2 (2±1.41)	1 (1.75±2.71)	.78	.438	.12
All	10 (10.5±2.88)	5.5 (6±3.7)	2.37	.018*	1.36

*$p < .05$;

**$p < .01$;

***$p < .001$

Table 8

Study 2 Performance-based Group Fixation Durations

Performance-based Group (N=9) Fixation Durations by ROI Type (%)					
	Pre-test	**Post-test**	**Wilcoxon Signed Rank Statistics**		
Trial Type	**Med (M ± SD)**	**Med (M ± SD)**	***Z***	***p***	***d***
Social	6.42 (5.88±5.56)	8.14 (8.13±4.03)	1.11	.267	.46
Static	5.56 (5.24±3.23)	7.77 (5.17±4.57)	.35	.724	.02
Dynamic	2.69 (3.18±2.77)	3.05 (3.48±2.35)	.4	.691	.12
All ROI	3.4 (4±2.47)	5.13 (4.15±2.68)	.18	.859	.06

[*] $p < .05$;

[**] $p < .01$;

[***] $p < .001$

Table 9

Study 2 Gaze-contingent Group Fixation Durations

Gaze-contingent Group (N=8) Fixation Durations by ROI Type (%)					
	Pre-test	**Post-test**	**Wilcoxon Signed Rank Statistics**		
Trial Type	**Med (M ± SD)**	**Med (M ± SD)**	***Z***	***p***	***d***
Social	13.7 (13.39±6.59)	10.4 (10.67±5.38)	1.1	.27	.45
Static	7.17 (6.77±3.9)	6.44 (7.48±3.55)	.16	.875	.19
Dynamic	4.68 (5.35±2.24)	4.89 (4.9±1.68)	.16	.875	.23
All ROI	5.71 (5.86±2.08)	5.57 (5.93±1.22)	.00	1	.04

[*] $p < .05$;

[**] $p < .01$;

[***] $p < .001$