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14. ABSTRACT ***Objective***: This study evaluated whether Virtual Reality Driving Simulation Training (VRDST) could improve VRDS performance, psychological comfort with driving, and on-road driving performance of young drivers with Autism Spectrum Disorder (ASD) holding a learner's permit.
Procedure: This multi-center study (U.Va. and U.I.) consented 73 young drivers (age range= 15-24, μ age= 17.96, 78% male). Participants completed an assessment at time 0 and 3 months, which included parents completing questionnaires (Social Responsiveness Scale-Second Edition [SRS-2] and the Scale of Apprehensive Driving [SAD]) and drivers completing driving simulator-based assessments of executive functioning and tactical driving skills. Following baseline assessment, drivers were randomized to one of four groups: (1) Routine Training (RT) following the Department of Motor Vehicles (DMV) guidelines, (2) Standard VRDS training (Standard) where performance feedback was provided by a human trainer, (3) Automated VRDS training (Automated), where the simulator provided real-time audio feedback (e.g. "too fast, too slow, swerving, across midline" etc.), or (4) Standard+Eye-Tracking (Eye-Tracking), where drivers additionally viewed video feedback from eye-tracking technology informing where the driver was looking when executing different driving maneuvers, such as turning, going through intersections, etc. For the next two months, all drivers and parents were instructed to follow the DMV guidelines for behind-the-wheel training necessary for a full driver's license. Subjects assigned to groups 2-4 additionally received 10-12 one hour-long VRDST training sessions. Post assessment also included an on-road assessment administered by a certified driving instructor who was unaware of subjects' previous group assignment and training experience.
Results: (1) Compared to a normative group, driving performance of novice drivers with ASD were significant worse on tactical but not executive function driving parameters at baseline. (2) After the training phase, while controlling for baseline, it was found that both Standard and Automated training significantly improved VRDS driving performance when compared to RT. (3) Although executive functioning improved pre-post, no difference was found between groups. (4) SAD scores showed that attitudes concerning contemplation about and preparation to drive did not differ between the groups at post-assessment. However, attitudes concerning actual driving did significantly improve for the VRDS groups at post-assessment compared to RT. (5) Analyses showed that the groups did not differ in terms of passing an on-road assessment or (6) securing an independent driver's license over the subsequent six months, though for both on-road assessment and licensure, Eye-Tracking had the highest success rate.
Conclusion: VRDST holds significant promise to aid individuals with ASD in improving driving performance and comfort, but further research needs to focus on how best to generalize VRDST skills to real world driving.

15. SUBJECT TERMS Autism, Asperger, driving, virtual reality, driving simulation, driving safety					
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- **INTRODUCTION:** There are no standardized or validated means of assessing an ASD individual's ability to safely drive a motor vehicle, nor to train such individuals on how to safely drive a vehicle. This multi-center project (University of Virginia and University of Iowa) investigated whether we could: (1) identify individuals with a learner's permit who would eventually go on to earn an independent driver's license, and (2) use Virtual Reality Driving Simulation (VRDS) training to aid individuals with ASD to safely operate a motor vehicle. This effort was successful in both regards.

- **KEYWORDS:** Autism Spectrum Disorder, driving safety, driving simulation, virtual reality, licensure

- **ACCOMPLISHMENTS:**
  - **What were the major goals of the project?**

    1. Develop, administer and evaluate a psychometric test that assesses novice drivers' enthusiasm/apprehension concerning driving a motor vehicle.
    2. Determine if classic symptoms of ASD, Scale of Apprehensive Driving (SAD) scores, and/or VRDS performance predict on-road driving performance.
    3. Determine if VRDS training could improve driving performance over Routine Training (**RT**) as required by the Department of Motor Vehicles (**DMV**).
    4. Determine whether VRDS training delivered by a human (standard) could be enhanced by incorporating:
       - Real-time automated computer feedback from the simulator (e.g., "driving too fast, driving across midline, wide turn"
       - Eye-tracking feedback where drivers could be informed where they were and were not looking while driving through a virtual world
    5. Compared to RT, determine if VRDS training could increase the likelihood of ASD individuals acquiring an independent driver's license during the 6 months following training.

  - **What was accomplished under these goals?** (See Appendix 2 and 3 for relevant manuscripts)

    1. The Scale for Apprehensive Driving (SAD) was developed to address the first goal above (see Appendix 1). It assesses both positive and negative cognitions, physical arousal, and behaviors that relate to contemplating driving, preparing to drive, and actual driving, consistent with the Readiness to Change theoretical model. The positive items are reverse coded and then all of the item responses are summed. Results from our analyses demonstrate that (1) novice drivers with ASD are generally less

enthusiastic and more apprehensive about driving a vehicle than novice neuro-typical drivers, (2) experience with driving significantly reduces this apprehension, and (3) VRDS training further reduces driving apprehension by a significant amount.

2. When employing a logistic regression, we determined that the ability to obtain a license within six months could be predicted based on social awareness, emotional control, ability to self-monitor, enthusiasm about driving, and level of agitation when discussing driving (see Appendix 2).
3. Standard VRDS training significantly improved performance on VRDS assessment of driving competency and led to a significant reduction in apprehensive driving. In terms of post-assessment, employing automated feedback or eye-tracking did not further enhance the efficacy of standard VRDS training. No form of VRDS training significantly increased the likelihood of ASD novice drivers passing our post-assessment on-road driving exam. However, while the RT pass rate was 30%, the pass rate with eye-tracking was 50%(see Appendix 3).
4. The addition of VRDS training to RT did not significantly increase the likelihood of passing the DMV licensure exam. However, only 30% of the RT subjects passed both the on-road and the DMV exams, while VRDS training incorporating eye-tracking that trained where to look while driving improved the pass rate to 50% on both on-road exams, although this was not statistically different from RT (see Appendix 3).
5. ASD drivers differed most significantly from neuro-typical novice drivers in their driving skills (negotiating a simulated vehicle through a virtual world) but not in terms of driving-relevant measures of executive functioning (see Appendix 4).

- **What opportunities for training and professional development has the project provided?**

We mentored 6 undergraduate and 6 graduate students in the process of executing this project. These trainees include:

1. Undergraduates:
    a. Sarah Cain, psychology student, UVA
    b. Addison Walker, psychology major, UVA
    c. Richard Johnson, psychology major, UVA
    d. Matthew Moncrief, psychology major, UVA
    e. Erin Thiemann, psychology major, UI
    f. Trevor Johnson, B.A., UI
2. Graduates:
    a. Paula Aduen, clinical psychology student, UVA
    b. Stephany Cox, clinical psychology student, UVA
    c. Veerle Ross, PhD student in driving safety at Hasselt University, Belgium

d. Rachel Dyke, PharmD candidate, College of Pharmacy, UI
e. Paul Barnard, MAT candidate, College of Education, UI
f. Kristin Lucas, PhD student in Special Education, UI

- **How were the results disseminated to communities of interest?**
- At UVA, we have made presentations to:
  - Gatherings of parents with adolescents diagnosed with ASD seeking driving privileges
  - YouthNEX academic weekly lectures
  - Public forums for parents with graduating teens with special needs
- At UI we:
  - Will be presenting at the Association for the Advancement of Automotive Medicine in October 2015.
  - Attended the Corridor Autism Resource Expo at the Cedar Rapids Library (Iowa) in June 2014 to inform attendees of our study and objectives.

- **What do you plan to do during the next reporting period to accomplish the goals?**
  - This past year we submitted an application in response to a DoD RFA for a Randomized Clinical Trial (see Appendix 5) which was not funded. In the next year, we hope to submit a revision of this proposal.
  - During the next year, we anticipate publishing our manuscripts that appear in the Appendices.

- **IMPACT:**
  - **What was the impact on the development of the principal discipline(s) of the project?**
    - NA until after we publish our manuscripts.
  - **What was the impact on other disciplines?**
    - NA until after we publish our manuscripts.
  - **What was the impact on technology transfer?**
    - NA until after we publish our manuscripts.
  - **What was the impact on society beyond science and technology?**
    - NA until after we publish our manuscripts.

- **CHANGES/PROBLEMS:**
  - **Changes in approach and reasons for change**
    - NA

- **Actual or anticipated problems or delays and actions or plans to resolve them**
  - We encountered delays securing modifications to our simulator software, which was eventually resolved and we concluded our study.

- **Changes that had a significant impact on expenditures**
  - None
- **Significant changes in use or care of human subjects, vertebrate animals, biohazards, and/or select agents**
  - NA
- **Significant changes in use or care of human subjects**
  - NA
- **Significant changes in use or care of vertebrate animals.**
  - NA
- **Significant changes in use of biohazards and/or select agents**
  - NA

- **PRODUCTS:**
  - **Publications, conference papers, and presentations**
    See Appendices 2, 3, and 4.
  - **Website(s) or other Internet site(s)**
    NA
  - **Technologies or techniques**
    NA
  - **Inventions, patent applications, and/or licenses**
    Copyright: Scale of Apprehensive Driving (SAD).
  - **Other Products**
    NA
- **PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS**
  - **What individuals have worked on the project?**

University of Virginia

- Name: **Daniel J. Cox**
  - Project Role: Principle Investigator
  - Person month:4
  - Contribution: Oversaw the entire project and UVA staff and wrote manuscripts
  - Funding Support: DoD ASD grant
- Name: **Ron Reeve**
  - Project Role: Co-Investigator
  - Person month: 2
  - Contribution: Oversaw confirmatory diagnoses and all psychometric utilization
  - Funding Support: DoD ASD grant
- Name: **Tom Banton**
  - Project Role: Research Coordinator

    - Person month:4
    - Contribution: Managed budgeting, all reports and manuscript presentations
    - Funding Support: DoD ASD grant
- Name: **Matthew Moncrief**
    - Project Role: Research Assistant
    - Person month: 8
    - Contribution: trained all ASD subjects and managed/analyzed data
    - Funding Support:
- Name: **Sarah Cain**
    - Project Role:: Undergraduate Research Assistant
    - Person month: 8
    - Contribution: Oversaw subject recruitment, data tracking and subject assessment
    - Funding Support:
- Name: **Stephanie Cox**
    - Project Role: Graduate Research Assistant
    - Person month: 1
    - Contribution: Data analyses, wrote one manuscript, and conducted professional meeting presentations
    - Funding Support: DoD ASD grant
- Name: **Paula Aduen**
    - Project Role: Graduate Research Assistant
    - Person month: 1
    - Contribution: Data analyses and manuscript preparation for the SAD
    - Funding Support: None
- Name: **Veerle Ross**
    - Project Role: Graduate Research Assistant
    - Person month: 1
    - Contribution: Statistical analysis and assisted in the manuscript preparation
    - Funding Support: None
- Name: **Addison Walker**
    - Project Role: Research Assistant
    - Person month: 8
    - Contribution: Oversaw data collection and on-road assessments, and performed VRDS assessments
    - Funding Support: DoD ASD grant

<u>University of Iowa</u>

- Name: **Tim Brown**
    - Project Role: Co-PI
    - Person month: 4.39 months
    - Contribution: Dr Brown led the research conducted at University of Iowa
    - Funding Support: DoD ASD grant
- Name: **Gary Gaffney**
    - Project Role: Co-Investigator, Physician
    - Person month: 1.66 months

    - Contribution: Oversaw diagnoses, subject recruitment, assessments, data compilation/reports
    - Funding Support: DoD ASD grant
- Name: **Rose Schmitt**
    - Project Role: Research Coordinator, Research Assistant
    - Person month: 7.14 months
    - Contribution: assessments, subject recruitment, subject scheduling, data compilation, work on abstracts/reports/posters, IRB and HRPO maintenance
    - Funding Support: DoD ASD grant
- Name: **Rachel Dyke**
    - Project Role: Research Assistant
    - Person month: 0.38 months
    - Contribution: subject recruitment
    - Funding Support: DoD ASD grant
- Name: **Erin Thiemann**
    - Project Role: Research Assistant
    - Person month: 0.57 months
    - Contribution: subject recruitment, eye-tracker testing
    - Funding Support: DoD ASD grant
- Name: **Paul Barnard**
    - Project Role: Research Assistant
    - Person month: 2.14 months
    - Contribution: trainer, subject recruitment
    - Funding Support: DoD ASD grant
- Name: **Trevor Johnson**
    - Project Role: Research Assistant
    - Person month: 1.77 months
    - Contribution: trainer, subject recruitment
    - Funding Support: DoD ASD grant
- Name: **Kristin Lucas**
    - Project Role: Volunteer Research Assistant
    - Person month: 1.96 months (as a volunteer – was not paid)
    - Contribution: trainer, subject recruitment
    - Funding Support: Not applicable
- Name: **Roger Thompson**
    - Project Role: Research Assistant
    - Person month: 1.1 months
    - Contribution: trainer, subject recruitment
    - Funding Support: DoD ASD grant
- **Has there been a change in the active other support of the PD/PI(s) or senior/key personnel since the last reporting period?**
        - No
    - **What other organizations were involved as partners?**
        - This was a joint project between UVA and UI
        - MBFARR LLC, San Jose, CA was the simulator company that worked with this project, delivered and set up the simulator at

UI, and did programming for Automated VRDS training. Software modifications and purchase of U.I.'s simulator was funded through this DoD grant, but MBFARR generously contributed many volunteer hours to this project, e.g. participating in weekly conference calls.

- **SPECIAL REPORTING REQUIREMENTS**
  - **COLLABORATIVE AWARDS:** *For collaborative awards, independent reports are required from BOTH the Initiating PI and the Collaborating/Partnering PI. A duplicative report is acceptable; however, tasks shall be clearly marked with the responsible PI and research site. A report shall be submitted to https://ers.amedd.army.mil for each unique award.*
  - **QUAD CHARTS:** NA

- **APPENDICES**
  - **Appendix 1**: Scale of Apprehensive Driving
  - **Appendix 2**: 2015 AAAM presentation: Autism, Training and Driving: Predicting Future Licensure Success
  - **Appendix 3**: Manuscript for journal submission: Can Virtual Reality Driving Simulation Training Improve Driving Performance of Autism Spectrum Disorder Youths with a Learner's Permit?
  - **Appendix 4**: Revised manuscript for publication in the Journal of Autism and Developmental Disorders: Driving Simulator Performance in Novice Drivers with Autism Spectrum Disorder: The Role of Executive Functions and Basic Motor Skills
  - **Appendix 5**: 2014 application for DoD RCT funding: Evaluating and Enhancing Driving Skills of Individuals with Autism Spectrum Disorder: Aiding Autonomy and Self-Esteem

Novice Driving Questionnaire: SAD (Scale of Apprehensive Driving)

How many times did your teen take the DMV driving knowledge test before he/she passed it? __

Teens can sometimes be excited or nervous about learning how to drive. This can occur when they *talk about* driving, *prepare* to drive, and/or while *driving.* Their eagerness or discomfort may be expressed through their *thoughts, actions,* or *physical responses*.				
To what extent does your teen do the following:	**Not at all**	**A little**	**Some-what**	**A Lot**
When talking about driving…				
Is enthusiastic about driving and/or learning how to drive?	0	1	2	3
Is worried or concerned about driving e.g., making mistakes, being criticized, getting in an accident?	0	1	2	3
Asks about whether s/he can drive?	0	1	2	3
Avoids talking about driving?	0	1	2	3
Smiles and is physically excited about possibly driving?	0	1	2	3
Becomes agitated or tense when talking about driving?	0	1	2	3
When Getting Ready to Drive…				
Thinks about where and how to drive?	0	1	2	3
Worries about whether s/he is going to make a mistake or get in an accident?	0	1	2	3
Eagerly goes to the car and gets behind –the-wheel?	0	1	2	3
Comes up with excuses or resists getting behind –the-wheel?	**0**	**1**	**2**	**3**
Gets physically excited when getting behind –the-wheel?	0	1	2	3
Gets agitated or physically upset when getting behind –the-wheel?	0	1	2	3
When Driving..				
Pays attention to the road, driving rules and other driving demands?	0	1	2	3
Gets distracted with worries about not being able to drive safely?	0	1	2	3
Drives spontaneously while being aware of things all around?	0	1	2	3
Drives hesitantly, slowly, focusing narrowly on just one or two things?	0	1	2	3
Becomes relaxed, calm, and enjoys the experience of driving?	0	1	2	3
Gets agitated, tense, and/or physically upset?	0	1	2	3
General issues				
How likely is it that your teen will be able to drive a car safely after the next two months?	0	1	2	3
How motivated is your teen to secure an independent driver's license?	0	1	2	3
How much do **you** worry *before* your teen begins to drive?	0	1	2	3
How much do **you** worry *while* your teen is driving?	0	1	2	3

Presented at the October 2015 national meeting of the American Association Automotive Medicine in Philadelphia

Autism, Training and Driving: Predicting Future Licensure Success

Timothy Brown, Ph.D.[1], Dan Cox, Ph. D.[2], Gary Gaffney, M.D.[3,], Rose Schmitt, B.S.[1] Ron Reeve[2], Matthew Moncrief, B.S.[2]

[1]National Advanced Driving Simulator, Center for Computer Aided Design, The University of Iowa, Iowa City, Iowa
[2]University of Virginia School of Medicine,
[3]College of Medicine, The University of Iowa, Iowa City, Iowa

INTRODUCTION

The ability to drive is a critical skill for young people to acquire in the developmental process of achieving independence and becoming productive citizens, particularly in many areas of the country that do not have easy access to effective mass transit. Surveys of parents for individuals with Autism Spectrum Disorder (ASD) indicate that learning to drive safely is a very difficult task[1,2]. However, these challenges are not insurmountable as novice adolescent drivers can improve their driving skills with training in a simulator[3-5], and adolescents with ASD can quickly and successfully learn to use virtual reality technology and computer-assisted instruction to learn about emotions and social problem solving[6]. Driving simulators have many advantages for both evaluating and training driving skills including exposure to and rehearsing responding to high risk situations, ability to make objective comparisons, and the ability to both playback and rehearse maneuvers. The objective of this research was to identify the most promising predictors of future licensure and the essential elements of a virtual reality driving simulator-training program for individuals with ASD.

METHODOLOGY

Individuals meeting criteria for an autism spectrum disorder were enrolled into this study. Upon consent, subjects and guardians were asked questions to confirm diagnosis and given the Social Responsiveness Scale, 2nd Edition (SRS-2)[7], the Behavior Rating Inventory of Executive Function (BRIEF)[8], the Behavior Assessment System for Children, 2nd Edition (BASC-2)[9], and the Scale of Apprehensive Driving (SAD)[10]. While guardians completed the psychometrics, subjects underwent a simulator exam evaluating cognitive, visual, and motor skills followed by an initial driving assessment. Subjects and guardians were then given the take-home documentation and training sessions were scheduled. At each training session, on-road homework was assigned to supplement the simulator training. Subjects and a trainer were expected to complete self- and trainer-assessments of driving performance at least once between training sessions. After 10-12 training sessions, a post-assessment evaluated cognitive, visual, and motor skills followed by a final simulator driving assessment. An on-road assessment with a driving instructor was offered as part of the study after the post-assessment. Upon completion of study procedures, follow-up occurred approximately once a month for six months. Data used in this analysis was collected using the following instruments: SRS-2, SAD, and BRIEF. Additionally, the outcome licensure data was collected from

follow-up self-reports. A total of 26 subjects (ages 15-22, four females, twenty-two males) enrolled in this phase of the study. One person was lost to follow-up.

RESULTS

Of the twenty-five subjects in this analysis seven obtained their license within six month of completing the training and eighteen did not, A stepwise logistic regression identified (χ^2 = 18.88, 5 df, p =0.0020) a significant model that is able to predict whether an individual on the autism spectrum would be successful at obtaining a license within six months of the completion of the driver training. The model includes five factors from three of the included scales in predicting licensure. Increases in emotional control and self-monitoring, as measured on the BRIEF, are associated with increased likelihood of licensure. More enthusiasm on the SAD was also related to increased likelihood of licensure. Increased agitation when talking about driving and increased social awareness on the SAD were associated with a decreased likelihood of licensure. These results are detailed in Table 1.

Table 1. Logistic Regression Maximum Likelihood Estimates

Parameter	DF	Estimate	Standard Error	Prob	Odds Ratio
Increased Social Awareness	1	-0.56	0.31	0.0677	0.57
Increased Emotional Control	1	0.36	0.31	0.2352	1.44
Increased Self-Monitoring	1	0.52	0.92	0.1053	1.68
Is enthusiastic about driving	1	2.09	1.73	0.2279	8.06
Gets agitated talking about driving	1	-3.83	3.67	0.2977	0.22
Intercept	1	-21.51	22.09	0.3303	

CONCLUSIONS

These results suggest that it is possible to determine which individuals on the autism spectrum are most likely to be successful at obtaining a license following this training approach. Due to the sample size, the interpretation of these results is limited, but does point to some factors that seem to influence successful licensure that warrant further investigation. This knowledge can help to inform physicians and care givers about the likelihood of success by identifying those individuals most likely to benefit from this training approach. Future analyses will focus on further refining this model through inclusion of additional subjects and predicting driving safety using reported driving outcome data during the follow-up period.

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Can Virtual Reality Driving Simulation Training Improve Driving Performance of Autism Spectrum Disorder Youths with a Learner's Permit?

Daniel J. Cox[1], Timothy Brown[2], Veerle Ross[3], Matthew Moncrief [1], Rose Schmitt[2], Gary Gaffney[2], Ron Reeve[1]

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[2]University of Iowa

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Word count: ___

Abstract

Objective: This study evaluated whether Virtual Reality Driving Simulation Training (VRDST) could improve VRDS performance, psychological comfort with driving, and on-road driving performance of young drivers with Autism Spectrum Disorder (ASD) holding a learner's permit.

Procedure: This multi-center study (U.Va. and U.I.) consented 73 young drivers (age range= 15-24, μ age= 17.96, 78% male). Participants completed an assessment at time 0 and 3 months, which included parents completing questionnaires (Social Responsiveness Scale-Second Edition [SRS-2] and the Scale of Apprehensive Driving [SAD]) and drivers completing driving simulator-based assessments of executive functioning and tactical driving skills. Following baseline assessment, drivers were randomized to one of four groups: (1) Routine Training (RT) following the Department of Motor Vehicles (DMV) guidelines, (2) Standard VRDS training (Standard) where performance feedback was provided by a human trainer, (3) Automated VRDS training (Automated), where the simulator provided real-time audio feedback (e.g. "too fast, too slow, swerving, across midline" etc.), or (4) Standard+Eye-Tracking (Eye-Tracking), where drivers additionally viewed video feedback from eye-tracking technology informing where the driver was looking when executing different driving maneuvers, such as turning, going through intersections, etc. For the next two months, all drivers and parents were instructed to follow the DMV guidelines for behind-the-wheel training necessary for a full driver's license. Subjects assigned to groups 2-4 additionally received 10-12 one hour-long VRDST training sessions. Post assessment also included an on-road assessment administered by a certified driving instructor who was unaware of subjects' previous group assignment and training experience.

Results: (1) Compared to a normative group, driving performance of novice drivers with ASD were significant worse on tactical but not executive function driving parameters at baseline. (2) After the training phase, while controlling for baseline, it was found that both Standard and Automated training significantly improved VRDS driving performance when compared to RT. (3) Although executive functioning improved pre-post, no difference was found between groups. (4) SAD scores showed that attitudes concerning contemplation about and preparation to drive did not differ between the groups at post-assessment. However, attitudes concerning actual driving did significantly improve for the VRDS groups at post-assessment compared to RT. (5) Analyses showed that the groups did not differ in terms of passing an on-road assessment or (6) securing an independent driver's license over the subsequent six months, though for both on-road assessment and licensure, Eye-Tracking had the highest success rate.

Conclusion: VRDST holds significant promise to aid individuals with ASD in improving driving performance and comfort, but further research needs to focus on how best to generalize VRDST skills to real world driving.

Key words: Autism, Asperger, driving, virtual reality, driving simulation, driving safety

INTRODUCTION

Driving with autism spectrum disorder

The recent upsurge in research on motor vehicle driving for individuals with an autism spectrum disorder (ASD) reflects an improved understanding of this disorder's lifetime course and changing functional impairments across development (Classen & Monahan, 2013; Classen, Monahan, & Hernandez, 2013; Cox, Reeve, Cox, & Cox, 2012; Huang, Kao, Curry, & Durbin, 2012; Reimer et al., 2013; Sheppard, Ropar, Underwood, & van Loon, 2010). While many individuals with ASD have secured a driver's license and are able to safely operate a motor vehicle, emerging research indicates that the acquisition of safe driving skills is difficult for this population (Classen et al., 2013; Cox et al., 2012; Huang et al., 2012; Ross et al., 2015a). Therefore, individuals with ASD are less likely than their peers to acquire a driver's license, or obtain it significantly later (Cox et al., 2012; Daly, Nicholls, Patrick, Brinckman, & Schultheis, 2014). Once they obtain their license, they can perceive themselves as confident and skilled drivers. However, they often prefer other ways of transporting, for instance walking, which might be related to experienced anxiety during driving (Chee et al., 2015; Reimer et al., 2013).

Difficulties in learning to drive might be caused by the negative interference of characteristics that are often associated with ASD. For instance, executive functioning difficulties, reflected in limited self-monitoring, creativity, mental flexibility, and planning abilities, can cause driving to be stressful and dangerous (Ross et al., 2015a). Specific for driving, adolescents with ASD are less likely to identify socially relevant road hazards such as pedestrians (Sheppard et al., 2010), and are less likely to monitor all relevant visual fields during driving (Reimer et al., 2013). To further complicate the matter, great variability is present among the ASD population. The relationship between ASD and driving might not always be negative and could even be positive, such as when a tendency for perfectionism is considered beneficial when learning how to drive (Ross et al., 2015a).

Only a limited number of studies used driving simulators to assess driving skills in ASD, and on-road studies have never been reported. This gap in the research is surprising given the critical role that motor vehicle driving plays in adolescent development and functional independence. For individuals with and without ASD, acquiring a driver's license is associated with increased participation in full-time academic programs, plans to attend college, and a history of paid employment relative to age-eligible but non-driving adolescents with ASD (Huang et al., 2012).

The few studies that were executed provide initial indications concerning difficulties that adolescents and young adults face when learning how to drive. First, it was found that adolescents with ASD showed difficulties with shifting attention, sequential task-

performance, and the integration/coordination of visuomotor responses. When they drove a simulated drive, they performed worse on lane maintenance, visual scanning, speed regulation, signaling, and adjusting to stimuli when compared to healthy controls (Classen et al., 2013; Monahan, Classen, & Helsel, 2013). Another experimental study found that when young male adults were distracted by a mobile phone, both the ASD and the control groups increased their gaze focus to the road ahead, therefore paying less attention to the overall driving environment. However, the ASD group especially paid less attention to traffic. Moreover, young adults with ASD in this study had an increased heart rate which possibly indicated stress and anxiety (Reimer et al., 2013). The results from the latter were confirmed in a study from Wade et al. (2014) which found that the gaze from a group of adolescent ASD drivers was higher in the vertical direction and towards the right in the horizontal direction during simulated driving. The ASD group demonstrated higher skin conductance levels (SCL) and skin conductance response rates (SCR), again indicating increased anxiety when driving.

Collectively, experimental and survey studies are consistent in stressing the necessity of not only increasing the documentation of driving skills in adolescents and young adults with ASD, but also the use of an individualized approach to train driving skills to obtain a driver license while reducing anxiety to drive. Developing driver-training programs is critical to improve functional outcomes and promote independence of adolescents and young adults with ASD.

Virtual reality driving simulation training (VRDST)

VRDST offers a safe environment to assess and provide targeted interventions for individuals who are in the process of obtaining a driver's license (Adler, Resnick, Kunz, & Devinsky, 1995; Brooks, Mossey, Collins, & Tyler, 2013; Hoffman, Lee, Brown, & McGehee, 2002). Applied to the needs of adolescents and young adults with ASD, the use of VRDST allows a controlled and safe environment, naturalistic settings, repetition, modified scenarios to foster generalization of learned skills, a primarily visual world, preferred computer interactions, reduced boredom and fatigue, individualized approach, and the inclusion of eye-tracking (Bölte, 2004; Parsons, Mitchell, & Leonard, 2004; Strickland, 1997). The latter allows feedback on gaze guidance, which provides important training benefits as eye gaze patterns indicate and gaze training increases drivers' competence (Malik, Rakotonirainy, & Maire, 2009; Pradhan, Pollatsek, & Fisher, 2007).

VRDST has already shown successful improvement in driving performance. For example, VRDST improved driving performance in elderly drivers (e.g., Casutt, Theill, Martin, Keller, & Jäncke, 2014), novice drivers learning to drive (Allen, et al, 2007; Cox, Moncrief, Wharam, Mourant & Cox, 2009), and improved visual search for hazards in young novice drivers (Vlakveld et al., 2011). Furthermore, VRDST proved useful for

patient populations. For instance, VRDST improved driving performance, accompanied by a reduction in road rage and risky driving, in military personnel recovering from traumatic brain injury (Cox et al., 2010) and patients recovering from stroke (Akinwuntan et al., 2005).

Research on driver training in adolescents and young adults with ASD is almost non-existent. Furthermore, to the best of our knowledge, not a single VRDST exists that involves the assessment and training of executive functioning. Previous research indicates that including executive functioning is warranted. First, executive functioning has been related to driving performance in adolescents and young adults with ASD (Cox et al., In submission) as well as in other populations, such as adolescents and young adults (Lambert, Simons-Morton, Cain, Weisz, & Cox, 2014; Mäntylä, Karlsson, & Marklund, 2009; Ross et al., 2015b), elderly (Aksan, et al., 2012; Cuenen et al., In Press; Freund, Colgrove, Petrakos, & McLeod, 2008), and ADHD (Cox, Madaan, & Cox, 2011; Reimer, Aleardi, Martin, Coughlin, & Biederman, 2006). Second, executive functioning training has been proven to transfer to driving performance. For example, computer-based cognitive training was found to be predictive of improvements in driving simulator performance in elderly drivers (Ball, Edwards, Ross, & McGwin, 2010; Cassavaugh & Kramer, 2009).

Research questions

The hypotheses examined in the current study were

1. Novice drivers with ASD drive worse on VRDS than experienced drivers.
2. VRDST leads to improved driving performance on a virtual reality driving simulator.
3. VRDST focusing on driving-relevant executive functioning improves that ability.
4. VRDST improves novice drivers' attitude toward driving.
5. VRDST increases the likelihood of passing an on-road driving assessment.
6. VRDST improves the likelihood of securing an independent driver's license.

METHODS

Overview

A total sample of 73 individuals (UVa: n= 37; Iowa: n= 36, age range= 15-24, μ age= 17.96, 78% male) who earned their learner's permit were randomized to one of four conditions for three months. Assessments occurred at baseline and at month 3, with follow-up for six more months to see if they earned an independent driver's license. Baseline assessments included driving performance on a VRDS and questionnaires completed by parents. Post-assessment repeated these measures and also included a

standardized on-road driving assessment administered by a trained driving examiner who was unfamiliar with the drivers' group assignment.

Facilities

The Driver Guidance System (DGS) VRDS is a realistic driver's cockpit and controls with side- and rear-view mirrors and air conditioning. The driver's view is projected onto an 8ft diameter, 210^{o} curved screen (Figure 1). The reliability and validity of the simulator tasks were previously established (see Cox 2014 for a detailed description of the psychometric evidence and Figure 1).

The VRDS has two assessment capabilities: operational and tactical (Cox et al., in submission). Following the framework from Michon (1985), the operational level captures capabilities necessary to safely control a vehicle. The tactical level refers to maneuvering a vehicle in different traffic environments and situations (Dickerson & Bédard, 2014).

Figure 1. Simulator displaying a road hazard (motorcyclist emerging from behind traffic) requiring a defensive maneuver.

For the current study, operational testing consisted of executive functioning tests that were modeled after traditional neuropsychological tests, i.e. dual tasking, response inhibition, and working memory. Tests included driving-relevant stimuli, responses, and context. This allowed an enhancement of ecological validity. All of the current tests used the same environment, thus reducing re-adaptation from one test to another. The examinee drove down the middle lane of a three-lane highway at 35mph, maintaining a constant distance from a lead car. To equate task instructions, all subjects heard the same instructions, delivered at the same point, by the simulator's synthetic voice. Three executive functioning tasks were administered: dual tasking, response inhibition, and working memory (see Table 1 for a description). All three executive functioning abilities have previously been linked to driving (Cascio et al., 2014; Cassavaugh & Kramer, 2009; Cox et al., in submission, Ross et al., 2014 & 2015b). Dual tasking refers to the simultaneous execution of tasks. Response inhibition assesses the ability to suppress the processing, activation, or expression of information (or action) that would otherwise interfere with the attainment of a desired cognitive or behavioral goal (Dempster, 1992; Hofmann, Schmeichel, & Baddeley, 2012). Working memory is a limited capacity system responsible for the temporary storage, rehearsal, updating, and mental manipulation of information for use in guiding behavior (Baddeley,

2007). The working memory test was a complex span task modeled after the automated operation span task (Conway et al., 2005; Unsworth, Heitz, Schrock, & Engle, 2005) and provided an index of overall working memory functioning. All the executive functioning tests placed demands on the same stimulus modality (i.e., visual). Executive functioning composite scores were created for primary and secondary variables of all three tests (see Table 1). Scores were first converted to z-scores, allowing a common metric, and then summed. Thus, the composite score was an overall reflection of executive-functioning driving abilities. A composite score of "0" was average, while a negative composite score was below average.

Task	Description	Primary	Secondary
Dual Tasking	Lead car's brake lights come on 8 times and passes over 8 potholes. Driver is to brake to all brake lights and steer around all potholes as quickly as possible.	Correct Responses Hybrid*	Reaction times braking and steering filtered** for inattention errors
Response Inhibition	Same as Dual Tasking, but inhibit previous prepotent response, i.e. do not respond to brief brake lights or grey potholes while continuing to brake to long brake lights and steer around black potholes.	Correct Responses Hybrid*	Reaction times braking and steering filtered** for inattention
Working Memory	Same as Response Inhibition but the driver also has to remember 1 to 3 road signs recently passed in the order they appeared.	Signs Recalled In Correct Order	Correct Responses Hybrid*

Table 1. Simulator executive functioning tests, task description, and selection of primary and secondary variables. *Hybrid: including effectual turns for grey and black potholes and correct brakes to short or long brake lights. **Filtered: mean reaction time scores were only included if a minimum number of trials were responded to, otherwise -3 was applied for that z-score.

Tactical testing is analogous to an on-road test of driving skills, but performed in a safe, reliable, yet challenging virtual world. The tactical test involved driving on a standardized route, which included five miles of rural, six miles of highway, and four miles of urban roads. Drivers negotiated realistic anticipated and unanticipated roads, signal, traffic, and hazard demands. Thirty-one performance variables were monitored throughout the entire route, such as swerving, rolling stops, speeding, and collisions. Fifteen of these variables were selected for inclusion in a tactical driving composite score (see Table 2). This selection was based on a previous assessment of the relation between variables and crash history as well as prior experience with patient groups, hereby selecting variables to readily distinguish between groups while being related to traffic safety. The tactical composite score was calculated like the executive functioning

composite score, except it incorporated tactical variables. Our past research has demonstrated the usefulness of a tactical composite score as a valid overall measure of driving performance. For instance, it predicted future driving collisions of seniors (Cox, Taylor, & Kovatchev, 1999), differentiated drivers with and without attention deficit hyperactivity disorder (Cox, Merkel, Hill, Kovatchev, Seward, 2000), and predicted driving mishaps of novice drivers during their first six months of independent driving (Cox et al, 2015). ***The tactical composite score was the primary outcome variable.***

Category	Variables
Braking	Crash (Collections), Bump (Collections), Rolling Stops (Ratio Rolling/Total)
Speed	Tailgating (Collections), Deceleration (Total Mag Active), Speed Plus 5 (Total Time Active), Speed Plus 20 (Total Time Active), Speed Limit 35-45 (SD Mag Active)
Steering	Off Road (SD Time Active), Off Path (Reset Collections), Off Road (Reset Collections), Midline (Avg Mag Active), Lane Position (SD Active)
Judgement	Number of Lane Changes Without Signal, Speed Minus 20 (Avg time active)

Table 2. Tactical variables.

Driver training

Routine training. RT involved giving the family the DMV training manual and instructing them to follow the training program detailed in this manual. This included a tracking sheet to encourage and record on-road driving experience.

Standard. VRDST involved a minimum of eight and a maximum of twelve 60-minute sessions, depending on how quickly the trainee progressed through the VRDST modules. Within a training session, the focus alternated between operational driving ability deficits identified during baseline assessment and tactical driving skills. Training was a mastery-based program, not progressing to a subsequent stage of training before mastering the earlier training module. During the sessions, the trainer would first demonstrate the task to the trainee and then monitor their performance while providing continual positive verbal feedback. The training stages were as follows:

1. Review Pre-Assessment and Identify Executive Functioning Deficits
2. Maintaining Lane Position on Straight Roads, Curvy Roads, and in Turns
3. Braking, Stopping, and Speed Maintenance
4. Refining Lane and Speed Maintenance with Executive Functioning Tests
5. First Generalization of Skills on a Rural and Urban Route with No Traffic
6. Use of Mirrors and Turn Signals
7. Hazard Detection
8. Multi-Tasking
9. Navigating Traffic
10. Second Generalization of Skills on a Rural and Urban route with Traffic

Automatic: This condition was identical to Standard except the simulator provided auditory feedback in real-time when the driver transgressed thresholds for the following:

- Driving too fast (for specific road segment and against normative population)
- Driving too slow (for specific road segment and against normative population)
- Swerving
- Rolling stops
- Missed stops
- Not using turn signals (lane change and turning)
- Position in lane (for specific road segment and against normative population)
- Turning too wide (for specific road segment and against normative population)
- Turning too tight (for specific road segment and against normative population)
- Tailgating
- Bumps/crashes

Eye-Tracking. Eye-Tracking (Mobile Eye XG, Applied Science Laboratories; Bedford, MA) was incorporated into Standard VRDST in various ways. First, videos were produced, typically three per module, of the trainer's eye view while they performed the driving tasks. This largely replaced the demonstration in Standard training when the trainer would exchange seats with the trainee. These videos were produced using the eye-tracker, so a crosshair was present showing exactly where the trainer looked while they drove. Second, the trainee wore the eye-tracker during their drives. Once a segment was completed, the trainer and trainee would review performance. This was particularly helpful around intersections. For example, the trainer could clearly see if a failure to stop was because the trainee never scanned for a stop sign or checked the state of the stoplight, or if they had checked and either ignored or misinterpreted the sign.

Procedure

Assessment Phase. Interested adolescents and their parents came to the driving laboratory, were thoroughly informed about the study, screened for inclusion/exclusion criteria, and consented/assented. To confirm the diagnosis of ASD, parents completed the SRS-2 during the pre-assessment. To quantify the adolescent's attitude towards driving, parents completed the SAD at both pre- and post-assessments. The SAD is an 18 item questionnaire that assesses adolescent's behavioral, cognitive, and physical responses, both

Figure 2. Driver wearing eye tracking glasses while driving the simulator.

negative and positive, toward thinking about driving, preparing to drive, and while driving. It has internal consistency with an alpha of __ that differentiates neuro-typical from ASD drivers (p<.0_) (ref). At the same time, drivers were assessed on the VRDS with both operational/executive functioning and tactical tests.

At post-assessment, certified and independent driving examiners put the drivers through a four-stage assessment. Examination took place in a driver education car with dual brakes. The examiner or driver could stop the drive at any point if either thought safety was being compromised. The examination was also stopped if any stage was failed. The four stages were (1) DMV vehicle inspection, (2) closed-course drive, e.g. driving range, (3) navigating a quiet residential loop, (4) 10-minute DMV-relevant course that included:

- Four right turns
- Two left turns
- One yield on green
- One 3-way or 4-way stop with a turn merging into heavier 4-lane traffic
- A lane change
- Pulling into a turn lane
- One speed limit change, going from higher to lower speeds

Training Phase. During the first year, subjects were randomized to either Standard or Automated VRDST. This allowed us to determine the optimal training condition on which to add eye-tracking the following year. Automated was not found to be superior to Standard, so eye-tracking was added to Standard VRDST. During the second spring-summer, 23 subjects were recruited, assigned to the RT group, and 19 of these were subsequently crossed over to Eye-Tracking training. This design allowed us to identify whether automated feedback was beneficial before moving on to eye tracking and minimized the amount of time RT subjects had to wait before receiving training, while controlling for season of training and on-road driving (summer). Subject recruitment took place during the spring and summer of 2013 and 2014 and training took place during the summer and fall of each year because the availability of adolescents was highest and weather and road conditions were similar across sites in the summer months.

Participants

This multi-center study recruited subjects from the catchment areas surrounding the University of Virginia and the University of Iowa, through newspaper ads, internet ads, flyers, and public announcements. Participants had to meet the following inclusion criteria:

- Diagnosed with ASD (including Asperger's, Autistic Disorder, PDD, or PDD-NOS)

- Social Responsiveness Scale 2.0 (SRS) scores fall within the cut-off criteria for ASD or Autism
- Have a valid learner's permit
- Age 15-25 years
- Able to operate the driving simulator without simulation sickness
- Able to attend up to 15 study visits (2 assessment visits, an on-road visit, and up to 12 training sessions) in a three month period
- Parent or legal guardian able and willing to provide in-car driving training at home

Exclusion criteria were:

- Not able to understand written or spoken English,
- Diagnosis of Intellectual Disability (ID) or Mental Retardation (MR),
- Brain injury,
- Diagnosed genetic disorder or chromosomal abnormality (e.g., Down Syndrome, Prader-Willi Syndrome, Fragile X, Angelman Syndrome),
- Severe physical, medical, or psychiatric condition that impairs driving ability (e.g., muscular dystrophy, psychosis),
- Person requires adaptive equipment to drive, such as hand accelerators or pedal extenders.

Requiring a learner's permit assured basic levels of driving knowledge and intellectual capabilities. Requiring on-road training opportunities served multiple purposes, including allowing transfer of training from the virtual to the physical world, promoting desensitization of driving avoidance and anxiety, and partially satisfying the DMV requirements toward securing an independent driver's license. No subjects were disallowed to participate because of the above exclusion criteria.

Individuals were compensated $70 for the on-road driving assessment. Sixty nine subjects completed the pre-assessment and 63 subjects completed the post-assessment. Six subjects dropped out of the study due to scheduling difficulties or family events. Ten subjects failed to attempt the on-road assessment due to a parent's or child's anxiety surrounding readiness to drive. Table 3 displays the demographic data for the four groups. Following post-assessment, RT subjects crossed over to VRDST+Eye-Tracking feedback to allow them to experience VRDST.

	N assigned/ completed	Age	Male %
RT	23/19	17.96	73.9
Standard	14/14	17.93	85.7
Automated	14/13	17.86	85.7
Eye-Tracking	18/17	18.05	72.7

Table 3. Demographic data.

RESULTS

Hypothesis 1, novice drivers with ASD drive worse on VRDS than experienced drivers. ASD baseline operational and tactical composite scores were compared to a previously collected normative sample (n= 333, age= 25-75). For this, the selected operational and tactical pre-assessment variables were transformed to z-scores based on the mean and SD of the normative group, after which they were summed into one operational or tactical composite score. Descriptives and frequencies reflect the deviation of baseline performance from the normative mean.

Based on the normative mean (μ) and standard deviations (SD), z scores were computed for the variables contributing to the Tactical, Executive Functioning Primary and Executive Functioning Secondary tests and then summed into a composite score. Table 4 reveals that our novice ASD drivers did not differ from the normative sample in terms of executive Function, but that their Tactical scores were significantly worse, more than 4 standard deviations below the Normative sample.

Groups	**Tactical**		**Executive Function, Primary**		**Executive Function, Secondary**	
	μ/SD	Median	μ/SD	Median	μ/SD	Median
ASD	-23.34/ 39.44	-11.74	-.82/ 2.75	-0.42	-3.22/ 6.44	-2.13
Normative	-.09/ 5.88	1.19	-.3/ 2.42	0.14	-1.83/ 5.42,	-0.82
T test	4.879, p<.001		1.568, p=.12		1.648, p=.10	

Table 4. Mean, SD and median comparing ASD to Normative sample in terms of Tactical, Executive Function Primary and Executive Function Secondary composite scores

Hypothesis 2: VRDST leads to better driving performance on a virtual reality driving simulator. To evaluate the effects of VDST on tactical driving performance, the pre- and post-assessment scores were transformed to z-scores based on the mean and SD from the ASD group on both assessments and summed, leading to tactical composite scores. Transformation to z-scores based on the normative group was not possible as the post-assessment drive differed from the pre-assessment drive. For these composite scores, a 1X4 ANCOVA (between-subjects factor: Group) determined the difference between

different VRDST groups (RT, Standard, Automated, Eye-Tracking) on the post-assessment while controlling for baseline. The results were Bonferroni-corrected.

A significant effect of Group was found for the tactical post-assessment while controlling for baseline (F= 4.23, p< .01, η2p= .18, μ RT= -3.16, μ Standard= 1.63, μ Automated= 1.96, μ Eye-Tracking= -.19). Pairwise comparisons showed that the only significant difference existed between the RT versus Standard and Automated groups (see Table 5 for the mean differences). Baseline was positively related to post-assessment, indicating that a better tactical pre-assessment performance was associated with a higher tactical post-assessment performance (F= 57.62, p< .001, η2p= .50, B= .51)

Group (a)	Group (b)	Mean difference (a-b)	Significance
RT	Standard	-4.79*	**.03**
	Automated	-5.13*	**.02**
	Eye-Tracking	-2.98	.33

Table 5. Mean differences and significance levels for the groups at tactical post-assessment, controlled for baseline.

Hypothesis 3: VRDST focusing on driving-relevant executive functioning improves that ability. As the same executive functioning tests were used at both pre- and post-assessment, z-scores transformations were again based on the normative sample to investigate the group effect relative to the normative sample. Scores from participants who used double feet to respond or who performed poorly (i.e., >3 SD below mean), were replaced with -3. For both primary and secondary variables, baseline and post-assessment scores were entered into a 2X4 ANOVA (within-subject factor: Assessment, between-subjects factor: Group) to determine whether executive functioning performance improved differently between groups.

For the primary executive functioning composite score, a significant main effect of assessment indicated that the primary performance measures improved at post-assessment (F= 24.86, p= .00, η2p= .30, μ pre= -.78, μ post= .87). The effect of training did not vary across groups as indicated by a non-significant effect of Assessment X Group (F= .69, p= .56, η2p= .03, see Table 4 for descriptives of Group per Assessment).

Again, for the secondary executive functioning composite score, a significant main effect of assessment indicated that the secondary performance measures improved at post-assessment (F= 6.76, p= .01, η2p= .10, μ pre= -2.59, μ post= -.89). The effect of training did not vary across groups as indicated by a non-significant effect of Assessment*Group (F= 1.61, p= .20, η2p= .08, see Table 6 for descriptives of Group per table 5).

Composite	RT	Standard	Automated	Eye-

				Tracking
Executive functioning^{1_P}	μ= -1.40 SD= 3.36	μ= -1.00 SD= 2.88	μ= -.64 SD= 2.88	μ= -.07 SD= 2.04
Executive functioning^{2_P}	μ= .13 SD= 2.03	μ= 1.37 SD= 1.69	μ= 1.01 SD= 2.22	μ= .96 SD= 2.21
Executive functioning^{1_S}	μ= -2.53 SD= 6.51	μ= -4.58 SD= 4.35	μ= -1.46 SD= 6.55	μ= -1.80 SD= 6.08
Executive functioning^{2_S}	μ= -1.36 SD= 6.19	μ= -.64 SD= 4.89	μ= -1.74 SD= 6.06	μ= .18 SD= 6.78

Table 6. Descriptives of the executive functioning composites per Group; 1_P: baseline-primary composite, 2_P: post-primary composite, 1_S: baseline-secondary composite, 2_2S: post-secondary composite.

Hypothesis 4: VRDST improves novice drivers' attitude toward driving.SAD scores were transformed to two scales: a 12-item scale including positive and negative (reverse coded) items for contemplating driving and anticipating driving, and a 6-item scale including positive and negative (reverse coded) items concerning actual driving. It was necessary to make this division because many of the subjects at baseline had not started behind-the-wheel training. Post-assessment scores on these scales were entered into two 1x4 ANCOVAs (between-subjects factor: Group) to determine the difference between different groups controlling for the respective baseline. A higher score indicated improved attitudes towards driving. The results were Bonferroni-corrected.

For the 12-item SAD, there was no significant effect of Group indicating that the post-assessment scores, controlled for baseline, did not differ significantly between groups (F= 1.61, p= .20, η2p= .08, μ RT= .37, μ Standard= .70, μ Automated= -.16, μ Eye-Tracking= -.02). Baseline was positively related to post-assessment, indicating that a higher pre-assessment score was associated with a higher post-assessment score (F= 30.81, p= .00, η2p= .36, B= .56).

Analyses for the 6-item SAD contained a significant effect of Group, indicating that the post-assessment scores differed between groups while controlling for baseline (F= 2.95, p= .04, η2p= .15, μ RT= .34, μ Standard= 1.47, μ Automated= .67, μ Eye-Tracking= .77). Pairwise comparisons (see Table 7 for the mean differences) indicated that although each VRDST group scored higher when compared to the RT group, the difference was only significant for the comparison between Standard and RT. Baseline again was positively related to post-assessment, indicating that a higher pre-assessment score was associated with a higher post-assessment score (F= 10.22, p= .00, η2p= .17, B= .36).

Group (a)	Group (b)	Mean difference (a-b)	Significance

RT	Standard	-1.13*	**.03**
	Automated	-.33	1.00
	Eye-Tracking	-.44	1.00

Table 7. Mean differences and significance levels for the groups for the post-assessment 6-item SAD, controlled for baseline.

Hypothesis 5: VRDST increases the likelihood of passing an on-road driving assessment, A chi-squared test of Independence compared the on-road driving performance per group. The outcome measure was coded as 1= did not come in for assessment because of anxiety/fear of failing, 2= was examined but failed, 3= passed.

The on-road driving performance did not differ significantly between groups (χ^2= 6.21, p= .40) indicating that on-road performance was independent from the type of training (see Table 8 for the counts and percentages).

	RT	Standard	Automated	Eye-Tracking
Anxiety	2	2	4	2
	20% (OR)	20% (OR)	40% (OR)	20% (OR)
	16.7% (Group)	14.3% (Group)	33.3% (Group)	14.3% (Group)
Failed	6	8	7	5
	23.1% (OR)	30.8% (OR)	26.9% (OR)	19.2% (OR)
	50% (Group)	57.1% (Group)	58.3% (Group)	35.7% (Group)
Passed	4	4	1	7
	25% (OR)	25% (OR)	6.3% (OR)	43.8% (OR)
	33.3% (Group)	28.6% (Group)	8.3% (Group)	50% (Group)

Table 8. Group counts and percentages (within OR and within Group) of anxiety/fear, failed, and passed.

Hypothesis 6: VRDST improves the likelihood of securing an independent driver's license. A chi-squared test of Independence compared groups (Standard, Automated, Eye-Tracking) after six-months of follow-up to determine if there was a difference in the number that obtained a driver's license. The outcome measure License was coded as 1= yes, 2= no, 3= no follow-up, 4= dropped-out.

License did not differ significantly between groups (χ^2= 8.24, p= .22), indicating that obtaining a license at follow-up was independent from the type of training (see Table 9 for the counts and percentages).

	Standard	Automated	Eye-Tracking
Yes	2	4	6
	16.7% (License)	33.3% (License)	50% (License)
	20% (Group)	30.8% (Group)	31.6% (Group)
No	8	7	6
	38.1% (License)	33.3% (License)	28.6% (License)

	80	16.3	31.6% (Group)
No follow-up	0 0%(License) 0% (Group)	1 33.3% (License) 7.7% (Group)	2 66.7% (License) 10.5% (Group)
Dropped-out	0 0% (License) 0% (Group)	1 16.7% (License) 7.7% (Group)	5 83.3%(License) 26.3% (Group)

Table 9: Group counts and percentages (within License and within Group) of yes, no, no follow-up, and dropped-out.

DISCUSSION

1. At baseline, ASD novice drivers differ from older experienced drivers not in terms of our measures of executive function, rather they differ in terms of the gestalt of driving skills reflected in tactical composite testscore
    a. Tactical composite predicts future driving mishaps of neurotyypical novice drivers and senior drivers
2. VRDST improves this tactical composite score, specifically Standard and Automatic
    a. Technical limitations of Eye-Tracking
    b. No modeling during Eye-tracking training
3. Since our ASD drivers did not differ from the normative sample in terms of executive function, it is not surprising that VRDST did not differentiate ASD vrosignificantly improve EF.
4. It is interesting to note that attidues towds driving ijmpoved over time and experience with driving, and that VRDST only differed from RT in terms of attitudes related to the process of driving, which is the primary focus of VRDST
5. While VRDST+Eye Tracking had the highest on-road success in terms of ***both*** our test and securing an independent driver's license, 50%, this was not significantly different from other groups, possibly because of a small sample size and reduced power. However, if does point to the need to emphasize greater efforts at generalization from VR to on-road driving.

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Driving Simulator Performance in Novice Drivers with Autism Spectrum Disorder: The Role of Executive Functions and Basic Motor Skills

--Manuscript Draft--

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Abstract:	Previous studies have shown that individuals with Autism Spectrum Disorder (ASD) demonstrate poorer driving performance than their peers and are less likely to obtain a driver's license. This study aims to examine the relationship between driving performance and executive functioning for novice drivers, with and without ASD, using a driving simulator. Forty-four males (ages 15-23), 17 with ASD and 27 healthy controls, completed paradigms assessing driving skills and executive functioning. ASD drivers demonstrated poorer driving performance overall and the addition of a working memory task resulted in a significant decrement in their performance relative to control drivers. Results suggest that working memory may be a key mechanism underlying difficulties demonstrated by ASD drivers and provides insight for future intervention programs.
Response to Reviewers:	Fred Robert Volkmar, MD Editor in Chief Journal of Autism and Developmental Disorders RE: JADD-D-14-00631, "Driving Simulator Performance in Novice Drivers with Autism Spectrum Disorder: The Role of Executive Functions and Basic Motor Skills" Dear Dr. Volkmar & Reviewers, We greatly appreciate the opportunity to revise and resubmit our manuscript. The critiques were both fair and constructive. The revised manuscript has responded to

	these critiques and benefited from such revisions. We have rephrased sections outlining characteristics of our simulator as well as our interpretations to provide additional information for readers and reflect a more conservative, and accurate, stance in regards to interpreting our findings. Consistent with Reviewer 2's suggestion and consistent with current literature utilizing driving simulators, we now use the term "mid-level driving simulator" throughout the manuscript. Furthermore, we have provided additional relevant citations to driving simulation investigations throughout the manuscript and have also included further validation data of this simulator, which is commercially available, in the manuscript as well as providing an electronic supplement. This supplement, Virtual Reality Driving Simulation in Virginia Department of Motor Vehicles - Executive Summary, although currently in draft form and therfore not for publication, contains more details on the reliability and validity of this simulator package which will believe will be informative to reviewers. We have also provided more details regarding the driving scenarios, including the working memory span task, to better illustrate the tasks completed by study participants. In regard to Reviewer 2's comment that "real world driving evals have long been considered the gold standard of driving assessment…", we concur that simulation is only one way of assessing driving competency, which we now acknowledge in the limitations section, however, it is also important to recognize the inherent unreliability of on-road assessments where there is no control of variables such as traffic, weather, lighting, and objectivity of examiners' ratings. Both reviewers provided feedback regarding the chronological ages and driving status of the ASD and healthy control groups. Although this information was in first submission, we have more explicitly stated inclusion criteria and driving experience information in the Methods section as well as acknowledging the limitations of age and permit/license status as a measure of driving experienced in the Limitations section. Additionally, we have revised the language we used to describe the ASD group, both in the title and within the manuscriptto, better capture the age range of participants. We now use the term "adolescents and young adults" within the manuscript and have revised the title to "novice drivers". The term adolescents remains for the healthy control group as all included participants in the control group were under age 18. We offer the following information to provide clarification regarding the changes in screening and intake assessments: we streamlined the assessment because some previously collected variables demonstrated no indication of relevance to driving performance. Therefore, to reduce subject burden, these apparent no-productive measures were dropped. We hope this information is helpful in reviewing this revised manuscript. We look forward to hearing from you. Thank you for your time and consideration.

Driving Simulator Performance in Novice Drivers with Autism Spectrum Disorder: The Role of Executive Functions and Basic Motor Skills

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Abstract

Previous studies have shown that individuals with Autism Spectrum Disorder (ASD) demonstrate poorer driving performance than their peers and are less likely to obtain a driver's license. This study aims to examine the relationship between driving performance and executive functioning for novice drivers, with and without ASD, using a driving simulator. Forty-four males (ages 15-23), 17 with ASD and 27 healthy controls, completed paradigms assessing driving skills and executive functioning. ASD drivers demonstrated poorer driving performance overall and the addition of a working memory task resulted in a significant decrement in their performance relative to control drivers. Results suggest that working memory may be a key mechanism underlying difficulties demonstrated by ASD drivers and provides insight for future intervention programs.

Keywords: Autism Spectrum Disorder, Driving, Driving Simulator, Executive Functions

Abstract

Previous studies have shown that individuals with Autism Spectrum Disorder (ASD) demonstrate poorer driving performance than their peers and are less likely to obtain a driver's license. This study aims to examine the relationship between driving performance and executive functioning for novice drivers, with and without ASD, using a driving simulator. Forty-four males (ages 15-23), 17 with ASD and 27 healthy controls, completed paradigms assessing driving skills and executive functioning. ASD drivers demonstrated poorer driving performance overall and the addition of a working memory task resulted in a significant decrement in their performance relative to control drivers. Results suggest that working memory may be a key mechanism underlying difficulties demonstrated by ASD drivers and provides insight for future intervention programs.

Driving Simulator Performance in Novice Drivers with Autism Spectrum Disorder: The Role of Executive Functions and Basic Motor Skills

The recent increase in research on motor vehicle driving for individuals with autism spectrum disorder (ASD) reflects an improved understanding of the disorder's lifetime course and changing functional impairments across development (Classen & Monahan, 2013; Classen, Monahan, & Hernandez, 2013; Cox, Cox, Reeve, & Cox, 2012; Huang, Kao, Curry, & Durbin, 2012; Reimer et al., 2013; Sheppard, Ropar, Underwood, & van Loon, 2010). While many individuals with ASD have secured a driver's license and are able to safely operate a motor vehicle, emerging research indicates that the acquisition of safe driving skills is difficult for this population (Classen et al., 2013; Cox et al., 2012; Huang et al., 2012). Specifically, adolescents and young adults with ASD are less likely than their peers to acquire a driver's license (Cox et al., 2012), are more likely to become anxious during driving (Reimer et al., 2013), and are less likely to identify socially-relevant road hazards (e.g., pedestrians; Sheppard et al., 2010) and monitor all relevant visual fields during driving (Reimer et al., 2013). In addition, simulated driving studies suggest that individuals with ASD demonstrate difficulties with specific driving skills ranging from motor coordination to speed regulation, lane maintenance, signaling, and adjustment to unexpected events (Classen et al., 2013).

Collectively, experimental and survey studies are consistent in documenting motor vehicle driving as a critical area of functional impairment for adolescents and young adults with ASD. Only two studies (Classen et al., 2013; Reimer et al., 2013), however, have used driving simulators to assess driving skill in ASD, and neither of these studies have investigated the neurocognitive mechanisms and processes associated with

these difficulties. Investigation of this relationship is warranted given the critical role that motor vehicle driving plays in adolescent development and functional independence for individuals with and without ASD. For example, acquiring a driver's license is associated with increased participation in full-time academic programs, plans to attend college, and a history of paid employment for adolescents with ASD relative to age-eligible but non-driving adolescents with ASD (Huang et al., 2012). As such, identifying factors associated with the development of safe driving skills is critical for developing driver training programs with the potential to improve functional outcomes and independence for adolescents and young adults with ASD.

Executive Functioning

Executive functions refer to a cluster of prefrontally-mediated cognitive functions (e.g., working memory, response inhibition, set shifting) needed to perform goal-directed actions (Miyake, 2000; Rapport, Orban, Kofler, & Friedman, 2013). Interestingly, the maturation of executive functioning in typically developing individuals parallels the decline in vehicular collisions; both plateau around age 25 (National Highway and Transportation Safety Administration, 2008; Zelazo, Craik, & Booth, 2004). Additionally, lower levels of executive functioning have been associated with higher frequency of vehicular collisions, and groups at high risk for vehicular collisions (e.g., individuals with ADHD or Depression; Vaa, 2014; Bulmash et al., 2006) have been previously identified to have lower levels of executive functioning (Kasper et al., 2012; Snyder, 2013; Willcutt et al., 2005).

Executive functioning deficits have been well documented in the ASD literature (Hill, 2004; Liss et al. 2001; Ozonoff, Pennington, & Rogers 1991). In addition, several

researchers have hypothesized that many ASD symptoms – including decreased theory of mind, anticipation of consequences, inhibition, planning, and problem solving – may be outcomes of these executive functioning deficits (Banich, 2004; Hill, 2004; Ozonoff, Pennington, & Rogers, 1991). Given the robust association between executive dysfunction and impaired driving in other populations (Mäntylä, Karlsson, & Marklund, 2009; Lambert, Simons-Morton, Cain, Weisz, & Cox, 2014; Watson, Lambert, Cooper, Boyle, & Strayer, 2013), it appears likely that such deficits may contribute to driving problems for individuals with ASD. However, little is known about the extent to which underdeveloped executive functions impact motor vehicle driving performance for adolescents and young adults with ASD, and critically, *which* executive functions affect driving performance for drivers with ASD (Classen & Monahan, 2012). Understanding the mechanisms and processes underlying adverse driving outcomes from this population is critical to designing and assessing driving training programs and accommodations for this population.

Rationale, Significance, and Purpose

Driving is an important milestone for adolescents and young adults, and a critical step toward independence (Monahan, 2012; Womack & Silverstein, 2012). Although little is known about driving abilities of individuals with ASD, previous studies have identified this population to be less likely to obtain a driver's license and to demonstrate poorer driving performance than their same-aged peers (Classen et al. 2013; Cox et al. 2012). Virtual reality driving offers an ideal, safe environment to assess and provide targeted intervention to individuals who are in the process of obtaining their driver's license (Adler et al. 1995; Brooks et al. 2013; Hoffman et al. 2002).

The purpose of this study is to examine the association between driving performance, basic skills, and executive functioning among adolescents and young adults with and without ASD using a mid-level virtual reality driving simulator (VRDS). Novice drivers with ASD and healthy controls completed two driving simulation paradigms: 1) a *tactical* drive to assess overall driving performance within a simulated driving course; and 2) an *operational* drive that assessed basic skills (reaction times for steering, braking), and executive functioning (dual processing, response inhibition, working memory) within driving relevant scenarios. Following previous studies, we hypothesized that drivers with ASD would perform worse than novice healthy control drivers during the tactical drive as well as during driving-relevant executive function tasks. We further hypothesized that executive dysfunction would significantly predict impaired driving performance for ASD relative to healthy control drivers and greater severity of ASD symptoms would be associated with worse driving performance. No predictions were made regarding the specific executive functions that would predict ASD driving difficulties given the paucity of literature for this population.

Methods

Participants & Simulator Design

Participants

Subjects were 44 male adolescents and young adults, 17 with ASD and 27 healthy controls. Subjects in the ASD group were between the ages of 15 and 23, had obtained their learner's permit, and had previously received a DSM-IV (APA, 2000) diagnosis of an Autism Spectrum Disorder (Autistic Disorder, *n*=4; Asperger Syndrome, *n*=7; PDD-NOS, *n*=3). The drivers with ASD were recruited as part of a driving training study; the

healthy controls completed the same simulator tasks as the ASD group, and were recruited for another study of adolescents whom had recently obtained their driver's license. All ASD participants self-identified as White/Caucasian; of the comparison sample, two participants' ethnicity were Asian/Pacific Islander, one was Hispanic, one preferred not to respond, and the remaining were White/Caucasian (Table 1).

[TABLE 1]

For the ASD group, a diagnosis of ASD was verified by parent report using the Social Responsiveness Scale (SRS; Constantino & Gruber, 2002) or the Social Responsiveness Scale-Second Edition (SRS-2; Constantino & Gruber, 2012). As an updated version of this measure was released during the course of this study, the newer version of this widely used diagnostic measure was administered to parents of participants enrolled in the study after January, 2013 (n=8). The BASC-2 parent form (Reynolds & Kamphaus, 2004) was administered also to allow preliminary examination of the relation between parent-reported adaptive functioning (Adaptive Skills scale) and driving performance. As mentioned above, ASD subjects were recruited for a larger driving training study; this manuscript is based on pre-intervention data only.

The university's Institutional Review Board approved both studies and all participants signed an informed consent form; participants under age 18 signed an assent form and a parent signed the consent form.

Simulator

We employed the commercially available Driver Guidance System (DGS-78), a mid-level driving simulator (Figure 1). This simulator displays a 210° field of view on a curved screen inside an 8 foot cylinder. The simulator includes seatbelt, dashboard,

steering wheel, turn signal, gas and brake controls, right, left, side, and rearview mirrors, as well as an adjustable seat. A unique capability of this simulator is that it evaluates a battery of operational driving *abilities* and driving *skills* using two stages: operational tests and a tactical driving scenario.

[FIGURE 1]

The operational tests parallel basic neuropsychological tests, with the use of driving-relevant stimuli, requiring driving-relevant responses, in a driving context. The tactical test involves driving 5 miles of rural, 6 miles of highway, and 4 miles of urban roads, negotiating routine driving events (e.g., stop lights, stop signs, speed limit changes) and unanticipated events that require defensive braking (e.g., parked car pulling into driver's lane; cross-traffic motorcyclist pulling into driver's path) and defensive steering (e.g., oncoming car swerving into driver's lane; rear approaching bicyclist while turning right). The following four classes of driving variables are monitored and summed into a composite score: braking, speed control, steering, and judgment. All participants completed the operational tests prior to the tactical driving scenario; the duration of the tactical course varied depending on the driver's accuracy and efficiency in completing the course.

Psychometric evidence supports the reliability and validity of the simulator tasks, including 2-week test-retest reliability of .86 (tactical composite), a large normative sample ($N = 455$), discriminant validity for differentiating experienced from novice drivers, and concurrent validity of the simulator executive functioning tasks with established executive functioning tests (D-KEFS $r = .51$ to .71; see Virtual Reality Driving Simulation Executive Summary; Cox, 2014). The tactical composite score

significantly predicted future collisions (Cox, Taylor, & Kovatchev, 1999), and performance on the simulator parallels on-road driving (Cox & Cox, 1998).

Driving Simulator Procedure

Motor tasks/response contingency training. In this first scenario, each driver was required to process and employ two driving instruction goals presented in two separate training tasks to create response prepotency prior to the inhibition task. For both tasks, the driver followed a lead vehicle at a fixed speed, distance, and lane position. The first goal was braking; during this scenario, the lead vehicle's brake lights came on 10 times periodically for short (0.5 seconds) or long (3 seconds) durations. Drivers were instructed to remove their foot from the accelerator and press the brake as soon as both short and long brake lights were detected. Following the braking task, drivers engaged in a steering task. During this task, the lead vehicle's rear wheels passed over six "filled" potholes that were gray and six "unfilled" potholes that were black, three of each from beneath the left wheel and three of each from beneath the right wheel. Drivers were instructed to avoid both filled and unfilled potholes by steering around the potholes without leaving their lane. The primary purpose of these two tasks was to create prepotent responses to the dependent variables that were assessed later in the response inhibition and working memory tasks. Additionally, reaction times for all steering (hand/arm coordination) and braking (foot/leg coordination) trials were recorded. Drivers completed ten trials of braking followed by twelve trials of steering, presented at jittered intervals (i.e., varied duration between trials).

Executive Function Test 1 - Dual processing task. In this scenario, the braking and steering tasks were combined, such that drivers were required to attend and respond

concurrently to brake lights *and* potholes. Drivers completed a total of 16 braking and steering trials (8 of each), presented in a standardized order at jittered intervals during this second operational test. The dual processing task served to further establish response prepotency in preparation for the inhibition task described below. The dependent variable of interest in this task was total percentage of correct responses, which includes percentage correct brake responses (braking in response to short and long brake lights) and percentage correct steering responses (steering in response to filled and unfilled potholes).

Executive Function Test 2 - Response inhibition test. *Response inhibition* refers to the ability to suppress the processing, activation, or expression of information (or action) that would otherwise interfere with the attainment of a desired cognitive or behavioral goal (Dagenbach & Carr, 1994; Dempster, 1992). This third operational test required drivers to inhibit 2 of the 4 previously trained prepotent responses. This time, they were instructed *not* to press the brake when the brake lights came on for a short duration and only press the brake in response to long brake lights. Similarly, participants were instructed to ignore filled potholes by refraining from steering around them, but to continue to steer around unfilled potholes. In this scenario, all drivers completed 16 braking and steering trials (8 trials of each), presented in standardized order at jittered intervals.

The dependent variable of interest was the percentage of total correct responses, comprised of correct braking responses (braking in response to long brake lights, not braking to short brake lights) and correct steering responses (steering in response to unfilled potholes, not steering in response to filled potholes).

Executive Function Test 3 - Working memory test. *Working memory* is a limited capacity system responsible for the temporary storage, rehearsal, updating, and mental manipulation of information for use in guiding behavior. Working memory has been linked to a number of real world skills including driving (Cohen & Conway, 2008). The working memory operational test was modeled after the automated operation span task (Conway et al. 2005; Unsworth, Heitz, Schrock, & Engle, 2005) to provide an index of overall working memory functioning. Thus, it is a complex span task that requires participants to hold an increasing quantity of information (road signs) while simultaneously performing an attention-demanding secondary processing task (inhibit/not inhibit steering/braking) that places demands on the same stimulus modality (visual). This test was built upon the previous tests by requiring the participant to remember presented road signs while adhering to the response inhibition instructions from the previous scenario. Drivers were given the same instructions as the response inhibition scenario. In addition, they were told they would be passing common road signs and were instructed to remember these signs in the order presented for a later test. There were 18 unique nonverbal standard road signs (e.g., Airport, Hospital, Library) presented randomly. After passing a series of signs (ranging in number from 1 to 3), the driving simulator would automatically pause, and the driver would be presented with an array of the 18 signs on the simulator screen. The driver would then be asked to identify the signs, in the same serial order, they had passed since the last series. The working memory scenario consisted of 26 braking and steering trials, presented at jittered intervals. A total of 9 series of 1-3 road signs per series were presented at jittered intervals. The dependent variables of interest were percentage of total correct responses during the driving task

(same DV as described for the response inhibition test upon which the working memory test is built), and the number of road signs recalled in the correct serial order (out of 18 possible).

Tactical driving test. The tactical driving test monitored 31 performance variables, such as swerving, rolling stops, speeding, and collisions. Fourteen of these 31 variables were selected *a priori* based on evidence from the Virginia Department of Motor Vehicles (DMV) VRDS normative sample (448 adults, ages: 25-70; Cox, 2014) that they significantly predict on-road accident rates. These 14 variables are grouped conceptually into four primary skill areas: braking, speed control, steering, and judgment. Braking variables include: Rolling Stops (ratio of incomplete [>0 and <5 mph] to complete [0 mph] stops), Deceleration Smoothness (total magnitude of rapid decelerations; i.e., slamming on brakes), Collisions (number of collisions with another vehicle > 5 mph), and Bumps (number of collisions ≤ 5 mph). Speed control variables include: Acceleration Smoothness (total magnitude of rapid accelerations; i.e., slamming on gas), Speed Plus 5 MPH (total time spent driving 5-19 mph above the posted speed limit), Speed Plus 20 MPH (total time spent driving 20+ mph over the posted speed limit), and Tailgating (number of times driver is within 15 feet of lead car in open road condition). Steering variables include: Lane Position Variability (standard deviation of lane position; i.e., swerving); Midline (average magnitude active; composite score of how far across and for how long driver was in oncoming lane of traffic), Off Road (standard deviation time active; variability of time driver drove off road), and Off Road Resets (number of times driver failed to make a turn when instructed, requiring a reset to designated route). Judgment variables identified were: No Signal for Lane Change (number of lane changes

without using turn signal) and Speed Minus 20 MPH (average time spent 20 mph or more under the posted speed limit). An overall Tactical Driving Composite was computed from these variables and served as the primary indicator of driving performance. This composite was calculated as an average of the z-scores across the 14 variables. Mean z-scores reflect standard deviations from the normative sample mean; positive and negative values indicate better and worse performance relative to the normative sample of experienced drivers, respectively. Z-scores for each variable were computed twice: once based on the current sample for the study's primary analyses, and separately relative to the normative DMV sample to provide additional insights into the driving performance of both groups relative to experienced drivers (presented in Tables 2 and 3)[TABLE 2; TABLE 3].

Data Analysis

We used a multi-tier approach to examine the interrelation among driving performance and executive functioning in adolescents and young adults with and without ASD. In the first tier, demographics and basic motor skills were assessed, and significant between-group differences were tested as covariates for all additional analyses. In the second analytic tier, we assessed between-group differences in tactical driving performance using the empirically derived Tactical Driving Composite, with Bonferroni-corrected post hoc tests to examine the extent to which any observed differences were attributable to specific driving behaviors. The third tier examined performance on the executive functioning tasks (response inhibition, working memory), and the final tier used ANCOVA to examine the extent to which ASD tactical driving impairments may be attributable to motor and executive functioning differences detected in the preceding tiers.

A final set of exploratory analyses based on the ASD sample (n = 16) were used to facilitate hypothesis generation for future studies; parent symptom ratings were not available for the healthy control group. In this tier, Bonferroni-corrected correlations between parent-reported clinical variables (SRS-2 Total Score, BASC-2 Adaptive Skills scale) and the Tactical driving variables were computed to explore the relations between driving behavior and clinical symptoms.

Due to simulator recording error, one ASD participant's tactical driving data were missing (n = 43). Similarly, five individuals (4 ASD, 1 comparison) had non-usable operational task data due to using two feet (i.e., braking with left foot while simultaneously pressing gas with right foot) (final n = 39).

Results

Tier I: Demographics and Basic Motor Skills

There were no significant differences in race/ethnicity between the ASD and comparison group participants (Table 1), and all participants were male. However, the ASD group (M = 18.29, SD = 2.29) was significantly older than the comparison group (M = 16.59, SD = 0.55; $p < .01$). With regard to basic response speed (Table 2), the ASD group was significantly slower than the comparison group during the steering (hand/arm) motor task ($p < .001$) but not the braking (foot/leg) motor task ($p = .14$). Similarly, the groups did not differ significantly in performance on the combined steering/braking dual processing task ($p = .25$). Age and arm/hand reaction time were not significant covariates of any of the analyses reported below (all $p \geq .37$). We therefore report simple model results with no covariates.

Tier II: Tactical Driving Performance

As shown in Table 3, the comparison group performed significantly better on the Tactical Driving Composite than the ASD group (p = .009, *d* = 0.88). Exploratory post-hoc analyses of the 14 variables that comprise the Tactical Driving Composite, corrected for multiple comparisons (critical α = .003), revealed that these between-group differences were primarily attributable to "bumping" the lead car (*d* = 1.09), increased swerving (SD of lane position; *d* = 0.26), and increased lane changes (*d* = 1.04) (all *p* < .003).

Tier III: Executive Functioning

The 2 (group) x 2 (response inhibition, working memory) ANOVA for the percentage of correct steering and braking was non-significant for group (*p* = .861) and condition (*p* = .831), whereas the interaction effect was significant (*p* = .006) (Table 2). Post-hoc tests revealed that the significant interaction shown in Figure 2 was attributable to the differential effects of adding working memory demands for ASD relative to non-ASD adolescents and young adults. [FIGURE 2] That is, between-group differences in steering/braking did not reach significance for either the response inhibition (*p* = .146) or working memory (*p* = .174) conditions. However, the increase in working memory demands was associated with a significant one-tailed decrease in steering/braking performance for the ASD group (*p* = .10, *d* = -0.45) relative to a significant increase in steering/braking performance for the comparison group (*p* = .016, *d* = 0.54).

Examination of recall performance during the working memory complex span condition was consistent with the steering/braking performance changes reported above, and revealed that the comparison group recalled significantly more signs in the correct serial order than the ASD group (*p* = .026, *d* = 0.81) (Figure 2; Table 2). Collectively,

results of the executive functioning tests revealed that adding working memory demands to a complex driving task significantly disrupts driving performance for adolescents and young adults with ASD, as evidenced by significant increases in steering/braking errors and overall lower working memory performance.

Tier IV: The Association Between Working Memory, Motor Speed, and Tactical Driving

In the preceding analyses, we found that adolescents and young adults with ASD have significantly slower hand/arm reaction time (steering) and decreased working memory capacity relative to healthy controls. In the final set of analyses, we assessed the extent to which these difficulties were associated with their overall impaired tactical driving performance. To accomplish this goal, we repeated the Tier II analysis using ANCOVA to assess between-group differences in tactical driving performance with working memory (percent of signs recalled in the correct serial order) and hand/arm reaction time (seconds) as covariates. Results revealed that working memory (p = .009), but not hand/arm RT (p = .73) was a significant covariate of the Tactical Driving Composite; however, between-group differences in tactical driving performance remained significant (p = .048) after accounting for working memory. In other words, these results suggest that underdeveloped working memory abilities may help explain some of the tactical driving difficulties experienced by drivers with ASD, but additional variables will be needed to fully understand the mechanisms and processes underlying impaired driving performance among adolescents and young adults with ASD.

Tier V: Exploratory Association Between Clinical Rating Scales and Driving

In the final Tier, we examined the association between clinical rating scales (SRS-2 Total Score, BASC-2 Adaptive Skills Scale) and driving performance during the tactical and operational driving tasks for drivers with ASD (n = 16; clinical data was not available for the healthy control drivers). Across the tactical variables, clinical ratings correlated only with steering variables: driving across midline was correlated with BASC-2 Adaptive Skills (r = -.57, p > .05) and SRS-2 Total (r = .76, p > .01), and inconsistent lane positioning (SD of lane position, or 'swerving') was correlated with SRS-2 Total (r = .70, p > .05). Similarly, steering and braking reaction times correlated with BASC-2 Adaptive Skills (r = -.54 and -.64, respectively, both $p \leq .05$), and SRS-2 Total (r = .55 and .68, respectively, both $p \leq .05$). These findings are generally consistent with the between-group findings of difficulties in specific driving skills for adolescents and young adults with ASD, and suggest that future investigations may benefit from an individual differences approach to further identify clinical and cognitive predictors of driving difficulties for this population. These results should be considered preliminary and interpreted with caution, however, given the small sample size.

Discussion

The present study was the first to examine the impact of motor and executive functioning on tactical driving performance for adolescent drivers with autism spectrum disorder (ASD) relative to healthy controls. Drivers with (n = 17) and without (n = 27) ASD completed a series of tactical and operational tasks in a highly immersive simulator currently being tested by the Virginia DMV. Results revealed that drivers with ASD had significantly slower reaction times during steering (d = 1.45) but not braking. In addition, adolescents and young adults with ASD demonstrated impaired working memory

functioning (d = 0.81), such that adding working memory demands resulted in a significant decrement in their driving performance relative to healthy control drivers. Importantly, working memory abilities, but not motor speed, served as a significant covariate of driving ability, suggesting that working memory may reflect an important mechanism underlying some of these drivers' on-road difficulties. In contrast, adolescent drivers with ASD performed similarly on driving tests assessing their ability to flexibly shift between steering and braking, and drivers with ASD successfully inhibited responses at similarly high levels relative to healthy control adolescents.

Results from the tactical drive reveal that adolescents and young adults with ASD demonstrated poorer overall driving ability relative to novice drivers without ASD, despite being significantly older. This finding is consistent with previous investigations (Classen et al., 2013; Cox et al., 2012; Huang et al., 2012, Reimer et al., 2013), and extends this line of research by providing an initial examination of the role of executive dysfunction in these driving difficulties. Further, the current findings support the need for driving interventions and technological accommodations for this population given the association between tactical driving performance and on-road collisions (Cox, 2014). In the current study, the impaired driving performance of drivers with ASD appeared attributable primarily to steering and braking performance, rather than speed control or judgment variables. Specifically, adolescent drivers with ASD were more likely to "bump" the car in front of them, and less likely to maintain consistent lane positioning relative to novice, non-ASD drivers. Given this pattern, we might expect an association between driving performance and basic motor skills associated with steering and braking. Basic hand-eye (steering) and foot-eye (braking) reaction time, however, were not

significant covariates of tactical driving performance, suggesting that alternative mechanisms and processes are needed to explain driving difficulties for adolescents and young adults with ASD.

Deficits in executive functioning have been well-documented in the ASD literature (Hill, 2004; Liss et al., 2001; Ozonoff, Pennington, & Rogers, 1991); this study's findings highlight the influential role these higher order abilities play in driving performance for this population. Interestingly, the ASD group did not demonstrate impaired performance during response inhibition or dual processing tasks, whereas the addition of a working memory task (road sign recall) differentially impacted drivers with ASD. Not only did the ASD group recall significantly fewer signs in the correct serial order than the comparison group, but they also demonstrated a differential decline in their driving performance with these added cognitive demands. These results are consistent with previous findings that adolescents and young adults with ASD have particular difficulty with multi-tasking while driving (Cox et al., 2012; Reimer et al., 2012), and extend this literature by suggesting that working memory abilities significantly predict simulated driving performance, which has been found to parallel on-road driving performance in earlier investigations (Cox & Cox, 1998; Cox, Taylor, & Kovatchev, 1999).

Recognizing that adolescents and young adults with ASD performed similarly to their peers on most aspects of simulated driving (braking speed, flexibly shifting between steering and braking, correctly inhibiting braking and steering based on road demands), the current results suggest that driver training interventions should focus specifically on those areas where this population demonstrates deficits. In other words, driving training

for adolescents and young adults with ASD may exert maximum benefits by focusing on training scenarios that require increased working memory demands (e.g., multitasking) – particularly in the context of scenarios emphasizing consistent lane positioning and distance from a lead car – instead of more basic driving skills. Thus, we hypothesize that targeting working memory skills within a driving context (simulator) may improve driving-relevant working memory performance and expertise by increasing exposure to real-world scenarios that require this skill. Simulator-based interventions could also provide drivers with ASD a safe environment in which they would be exposed to multiple, relevant cognitive demands (e.g., sound system manipulation, GPS directions) while navigating a simulated course. Alternatively, assistive technology and adaptations could be developed to lessen the working memory demands required to operate a motor vehicle. More general working memory training programs may hold promise as well; however, we caution against using commercially available, computerized "working memory" training programs at this time given converging meta-analytic and experimental evidence that these programs fail to improve working memory (Rapport et al., 2013; Shipstead et al., 2012).

Regarding future directions, the healthy control group's improved performance on the steering/braking inhibition task in response to increasing working memory demands was contrary to performance patterns of experienced drivers in the normative sample (Cox, 2014) and aging drivers (Lambert, Cox, O'Connor, Cho, & Johnson, 2013; Watson et al., 2013), and suggests some modification to the simulator protocol. Specifically, typically developing adolescents and young adults may require more demanding tasks within this context (e.g., higher working memory set sizes). This hypothesis is consistent

with developmental research demonstrating that executive functions such as working memory peak in early adulthood before showing age-related decline (Park, 2002), and when considered in the context of the present findings allow us to speculate that better developed working memory may provide a partial buffer against these driver's on-road inexperience.

Limitations

The unique contribution of the current study was its investigation of the role of basic skills and executive functions in the driving difficulties experienced by adolescents and young adults with autism spectrum disorder (ASD). Several caveats require consideration when interpreting the present results despite these and other methodological refinements (e.g., use of mid-level driving simulator, assessment of executive functions in a driving-relevant context). Independent experimental replications with larger samples that include females, older drivers with ASD, and a more carefully matched comparison group are needed to confirm the present results. Notably, the comparison group was significantly younger but had recently obtained their license, whereas the ASD group had learner's permits. Although permit/license status and chronological age do not fully capture an individual's driving experience, the healthy control group likely had somewhat more driving experience, which may have contributed to the magnitude of observed group differences on the driving variables. In contrast, the increased age of the ASD group did not portend improved executive functioning as expected developmentally (Zelazo et al. 2004), and age was not a significant covariate in any of the analyses. Finally, working memory abilities predicted but did not fully account for between-group differences in driving performance, suggesting that future studies

would benefit from examination of additional mechanisms and processes such as driver anxiety, specific ASD symptoms, social relevance of road hazards, and visual field monitoring (Reimer et al., 2013; Sheppard et al., 2010).

Clinical and Research Implications

The current study was consistent with previous research documenting motor vehicle driving difficulties in individuals with ASD (Classen et al., 2013; Cox et al., 2012; Huang et al., 2012; Reimer et al. 2013), and extends this line of research by identifying specific areas of difficulty (maintaining consistent lane position and distance from a lead car) and implicating a specific executive function – working memory – in the driving difficulties experienced by these adolescents and young adults. In contrast, novice drivers with ASD did not demonstrate impairments in most basic driving skills, and were able to successfully flexibly shift between braking and steering, quickly brake in response to a lead car's brake lights, and quickly process on-road demands to successfully inhibit braking and steering when necessary in a simulated driving environment. Clinically, these findings suggest that driver training programs for adolescents and young adults with ASD may provide maximum benefit through repeated practice of scenarios that place relatively high demands on working memory (e.g., multitasking) while emphasizing consistent lane positioning and distance from a lead car – instead of more basic driving skills. In addition to increasing expertise, we hypothesize that simulated driver training may further improve driving performance for adolescents and young adults with ASD by decreasing anxiety (Reimer et al., 2013) through physiological habituation processes to the extent that each training session is of sufficient duration (i.e., 90 minutes or more). Thus, we propose that simulator-based driver training studies use extended training

sessions and measure driving skill and physiological arousal, both within and across sessions, to allow examination of the specific mechanisms and processes underlying training-related improvements for this population.

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Table 1. *Group Comparison of Demographic Characteristics*

	ASD (n=17)		Comparison (n=27)		Analysis		
	Mean	**SD**	**Mean**	**SD**	***t***	***p***	x^2
Age (years)	18.28	2.29	16.59	0.55	3.69	<.001***	
	n		**n**				
Gender(male)	17		27				44.00
Ethnicity (Caucasian)	17		23				2.77

*$p<.05$; **$p<.01$; ***$p<.001$

Table 2. *Group Comparison of Operational Driving Performance on Motor Response, Dual Processing, Response Inhibition, and Working Memory Tasks*

Operational Variable	ASD n=13		Comparison n=26				
	M	**SD**	***M***	**SD**	**F**	***p***	***d***
Composite							
Sample z-score	-0.24	0.51	0.09	0.32	5.40	.026*	0.41
DMV z-score	0.08	0.42	0.21	0.26	1.46	.235	0.93
Individual Variables							
Braking Reaction Time (sec.)	1.21	0.26	1.1	0.2	2.34	.142	0.51
Steering Reaction Time (sec.)	0.93	0.15	0.75	0.11	17.32	<.001***	1.29
DP: No. of Correct Responses	14.85	2.23	14.04	1.91	1.39	.246	-0.41
RI: No. of Correct Responses	15.62	0.65	15	1.41	2.21	.146	-0.52
WM: No. of Correct Responses	24.54	2.5	25.35	1.16	1.92	.174	0.71
WM: No. of Signs Recalled	14.62	4.66	17.04	1.89	5.38	.026*	0.81

Note: Operational composite calculated using the average z-score of the six included individual variables. Sample z-scores are derived using scores from the study sample; DMV z-scores are calculated using scores obtained from a DMV normative sample. Reaction times are reported in seconds. No. of correct responses = Number of correct steering and braking responses according to task instructions. For dual processing, correct responses reflect braking to long and short brake lights and steering around filled and unfilled potholes. For the inhibition and working memory tasks, correct responses reflect braking to long brake lights, not braking to short brake lights, steering around unfilled potholes, and not steering around filled potholes. Also for working memory task, no. of signs recalled = the number correct signs recalled in the correct serial order (out of 18); ASD = autism spectrum disorder; DP = Dual processing task; RI = response inhibition task; WM = working memory task.

*$p<.05$; **$p<.01$; ***$p<.001$

Table 3. *Group Comparison of Tactical Driving Performance*

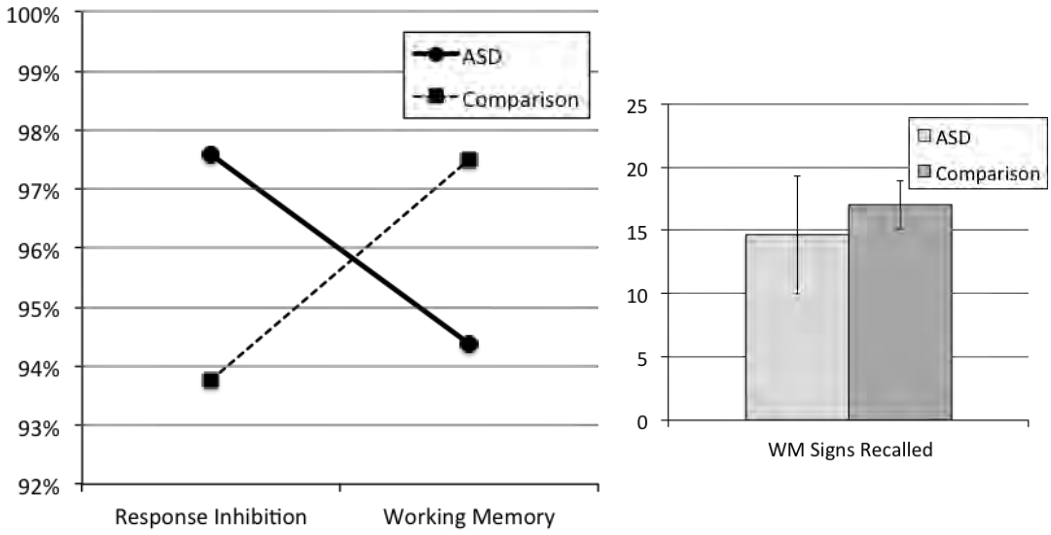
Tactical Variable	ASD n=16		Comparison n=27				
	M	**SD**	***M***	**SD**	**F(1,41)**	***p***	***d***
Composite							
Sample z-score	-0.22	0.57	0.13	0.29	7.46	.009***	0.88
DMV z-score	-1.88	2.27	-0.33	0.85	10.24	.003***	1.03
Individual Variables							
Acceleration, Tot MA	56.62	36.1	28.92	24.96	9.11	.004**	0.98
Bumps	2.06	2.49	0.37	0.63	11.43	.002***	1.09
Collisions	2.19	3.39	0.41	1.01	6.56	.014*	0.83
Deceleration, Tot MA	7.18	8.5	2.96	4.82	4.346	.043*	0.67
Lane Pos, SD Active	0.40	0.09	0.32	0.41	18.43	<.001***	0.26
Midline, Avg MA	1.85	1.58	1.24	1.61	1.47	.232	0.39
No Signal #LnChange	22.19	13.7	12.85	4.91	10.44	.002***	1.04
Off Road Resets	0.38	0.81	0.04	0.19	4.39	.042*	0.68
Off Road, SD TA	2.83	3.11	0.75	2.91	4.87	.033*	0.71
Rolling Stop Ratio	0.16	0.06	0	0	1.72	.197	4.51
Speed - 20 Avg TA	5.75	2.9	5.33	6.88	0.05	.819	0.07
Speed + 20, Tot TA	10.29	20.58	6.23	19.11	0.43	.516	0.21
Speed + 5, Tot TA	62.57	79.62	78.36	84.24	0.37	.548	-0.20
Tailgating	3.44	2.13	2.22	2.03	3.48	.069	0.60

Tactical composite scores calculated using the average z-score of the 14 included individual variables. Sample z-scores are derived using scores from the study sample; DMV z-scores are calculated using scores obtained from a DMV normative sample. Avg = average; MA= magnitude active; TA= time active; Tot = total. Acceleration Total Magnitude Active = slamming on gas; Bumps = the number of collisions with another vehicle $\leq$ 5 mph; Collisions = the number of collisions with another vehicle > 5 mph; Deceleration, Total Magnitude Active = slamming on brakes; Lane Position, Standard Deviation Active = swerving; Midline, Average Magnitude Active = how far across and how long driver is in lane of oncoming traffic; No Signal, Number Lane Changes = the number of lane changes made without using turn signal; Off Road Resets = number of times driver failed to make a turn when instructed; Off Road Standard Deviation Time Active = variability of time driver was off road; Rolling Stop Ratio = the ratio of rolling stops (>0 and <5 mph) to complete (0 mph) stops; Speed -20 Average Time Active = average time spent 20 mph or more under posted speed limit; Speed +20 Total Time Active = total time spent driving 20 mph or more over the posted speed limit; Speed +5 Total Time Active = total time spent driving 5-19 mph over the posted speed limit; Tailgating = number of times driver is within 15 feet of lead vehicle.

**p<.05; **p<.01; ***p<.05/14 (.003; alpha adjusted for multiple comparison)*

Figure 1. Driver Guidance System (DGS-78)

Figure 2. Group comparison of performance on executive functioning tasks



Note: Performance on response inhibition and working memory tasks measured by percentage of braking and steering errors; Additionally, working memory is measured by number of signs recalled.

Figure Captions

Figure 1. Driver Guidance System (DGS-78)

Figure 2. Group comparison of performance on executive functioning tasks

(Note Below Figure 2)

Note: Performance on response inhibition and working memory tasks measured by percentage of braking and steering errors; Additionally, working memory is measured by number of signs recalled.

Figures 1 and 2

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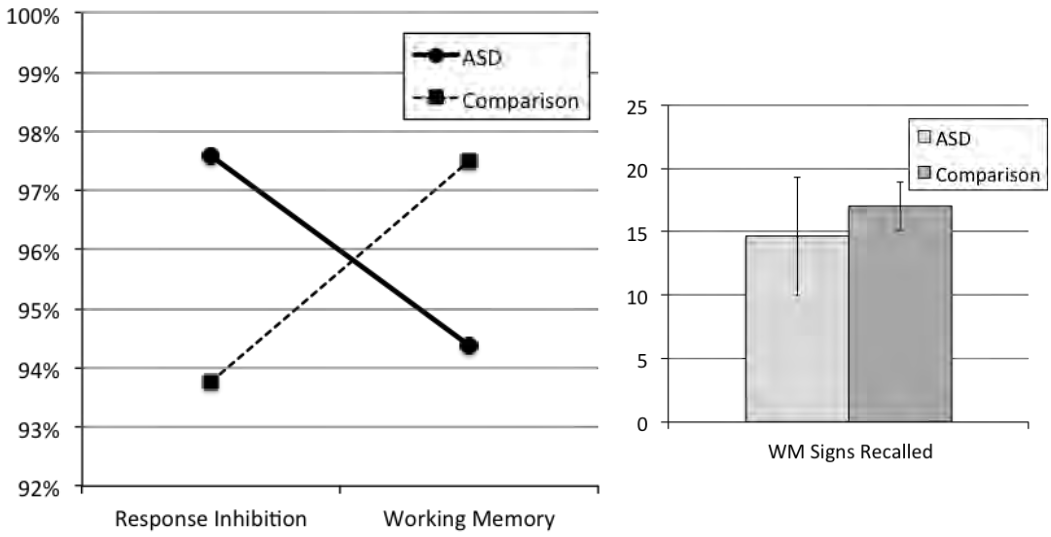
Figure 1 Top

Figure 2 Top



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TABLES

Table 1. *Group Comparison of Demographic Characteristics*

	ASD (n=17)		**Comparison (n=27)**		**Analysis**		
	Mean	**SD**	**Mean**	**SD**	***t***	***p***	x^2
Age (years)	18.28	2.29	16.59	0.55	3.69	<.001***	
	n		**n**				
Gender(male)	17		27				44.00
Ethnicity (Caucasian)	17		23				2.77

*$p<.05$; **$p<.01$; ***$p<.001$

Table 2. *Group Comparison of Operational Driving Performance on Motor Response, Dual Processing, Response Inhibition, and Working Memory Tasks*

Operational Variable	ASD n=13		Comparison n=26				
	M	**SD**	***M***	**SD**	**F**	***p***	***d***
Composite							
Sample z-score	-0.24	0.51	0.09	0.32	5.40	.026*	0.41
DMV z-score	0.08	0.42	0.21	0.26	1.46	.235	0.93
Individual Variables							
Braking Reaction Time (sec.)	1.21	0.26	1.1	0.2	2.34	.142	0.51
Steering Reaction Time (sec.)	0.93	0.15	0.75	0.11	17.32	<.001***	1.29
DP: No. of Correct Responses	14.85	2.23	14.04	1.91	1.39	.246	-0.41
RI: No. of Correct Responses	15.62	0.65	15	1.41	2.21	.146	-0.52
WM: No. of Correct Responses	24.54	2.5	25.35	1.16	1.92	.174	0.71
WM: No. of Signs Recalled	14.62	4.66	17.04	1.89	5.38	.026*	0.81

Note: Operational composite calculated using the average z-score of the six included individual variables. Sample z-scores are derived using scores from the study sample; DMV z-scores are calculated using scores obtained from a DMV normative sample. Reaction times are reported in seconds. No. of correct responses = Number of correct steering and braking responses according to task instructions. For dual processing, correct responses reflect braking to long and short brake lights and steering around filled and unfilled potholes. For the inhibition and working memory tasks, correct responses reflect braking to long brake lights, not braking to short brake lights, steering around unfilled potholes, and not steering around filled potholes. Also for working memory task, no. of signs recalled = the number correct signs recalled in the correct serial order (out of 18); ASD = autism spectrum disorder; DP = Dual processing task; RI = response inhibition task; WM = working memory task.

$^{*}p<.05$; $^{**}p<.01$; $^{***}p<.001$

Table 3. *Group Comparison of Tactical Driving Performance*

Tactical Variable	ASD n=16		Comparison n=27				
	M	**SD**	***M***	**SD**	**F(1,41)**	***p***	***d***
Composite							
Sample z-score	-0.22	0.57	0.13	0.29	7.46	.009***	0.88
DMV z-score	-1.88	2.27	-0.33	0.85	10.24	.003***	1.03
Individual Variables							
Acceleration, Tot MA	56.62	36.1	28.92	24.96	9.11	.004**	0.98
Bumps	2.06	2.49	0.37	0.63	11.43	.002***	1.09
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**p<.05; **p<.01; ***p<.05/14 (.003; alpha adjusted for multiple comparison)*

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ESM1: Virtual Reality Driving Simulation Exec Summary

Click here to download Supplementary Material: ASD&Driving_JADD_ESM1.pdf

Evaluating and Enhancing Driving Skills of Individuals with Autism Spectrum Disorder: Aiding Autonomy and Self-Esteem

Table of Contents

1 Background

1.1 ASD and the military

The rate of autism has continued to increase over the past decade. Estimates for 2010 indicate that 1 in 68 children born in 2002 had been identified with autism spectrum disorder (***ASD***). Autism also has a significant effect on military families. *Autism Speaks*, a science and advocacy organization, estimates that approximately 23,000 military dependents are affected by autism (Autism Speaks, 2012). This poses a special burden on these military families due to the unique challenges of military life, including the frequent changes in duty stations that disrupt the consistent routine needed by individuals on the autism spectrum. This is further compounded for individuals who are attempting to learn to drive, or who are driving, as these moves often involve significant changes in the driving environment. The difficulty individuals with ASD encounter while generalizing skills from one environment to another is particularly problematic in the driving domain, and can complicate this transition and negatively impact safety.

1.2 Literature Review

The recent upsurge in research on motor vehicle driving for individuals with ASD reflects an improved understanding of this disorder's lifetime course and changing functional impairments across development (Classen & Monahan, 2013; Classen, Monahan, & Hernandez, 2013; Cox, Cox, Reeve, & Cox, 2012; Huang,

Kao, Curry, & Durbin, 2012; Reimer et al., 2013; Sheppard, Ropar, Underwood, & van Loon, 2010). While many individuals with ASD have secured a driver's license and are able to safely operate a motor vehicle, emerging research indicates that the acquisition of safe driving skills is difficult for this population (Classen et al., 2013; Cox et al., 2012; Huang et al., 2012). Specifically, adolescents with ASD are more likely to become anxious during driving (Reimer et al., 2013), are less likely to identify socially-relevant road hazards such as pedestrians (Sheppard et al., 2010), are less likely to monitor all relevant visual fields during driving (Reimer et al., 2013), and are less likely than their peers to acquire a driver's license (Cox et al., 2012). In addition, simulated driving studies suggest that individuals with ASD demonstrate difficulties with specific driving skills such as motor coordination, speed regulation, lane maintenance, signaling, and adjustment to unexpected events (Classen et al., 2013).

Figure 1. Simulator displaying a road hazard (motorcyclist emerging from behind traffic) requiring a defensive maneuver.

Collectively, experimental and survey studies are consistent in documenting motor vehicle driving as a critical area of functional impairment for adolescents and young adults with ASD. However, only two studies have used sophisticated driving simulators to assess driving skills in ASD, and neither study investigated the symptoms and neurocognitive mechanisms associated with these difficulties. This gap in the research is surprising given the critical role that motor vehicle driving plays in adolescent development and functional independence for individuals with and without ASD. Acquiring a driver's license is associated with increased participation in full-time academic programs, plans to attend college, and a history of paid employment for adolescents with ASD relative to age-eligible but non-driving adolescents with ASD (Huang et al., 2012). Identifying factors associated with the development of safe driving skills is critical for developing driver-training programs with the potential to improve functional outcomes and promote independence of adolescents and young adults with ASD. Further, there is not a single study investigating the training of safe driving skills among novice drivers with ASD.

1.3 Virtual Reality

Virtual reality driving simulation (***VRDS***) offers an ideal, safe environment to assess and provide targeted intervention for individuals who are in the process of obtaining a driver's license (Adler et al. 1995; Brooks et al. 2013; Hoffman et al. 2002). Specifically, VRDS can be used to:

1) Safely, reliably, objectively, and validly assess strengths and deficits in driving-specific abilities that:
   a) Identify an individual's specific strengths and weaknesses that could individualize and focus driving training.
   b) Inform the trainee about the likelihood of being able to address weaknesses and acquire driving competency.
2) Enhance driving skill acquisition through the development of personally tailored VRDS driving training programs that:
   a) Provide a safe, low-threat virtual environment in which to learn basic driving skills.
   b) Provide exposure to a variety of roadway environments and driving conditions to support generalizability of driving skills (Figure 1).
   c) Allow immediate playback of improper driving maneuvers for subsequent rehearsal and correction.
   d) Safely expose trainees to multi-tasking (e.g. vehicle control and navigation systems), hazard detection, and defensive driving situations.
   e) Provide unique training opportunities, such as
      i) Video feedback that can be played back immediately or reviewed subsequently from a CD or the web.

ii) VRDS automated feedback to hasten the acquisition of competent driving skills, such as immediately informing the trainee when driving too fast or slow, tailgating, or swerving or steering too far to the right or left.

f) Include eye tracking to provide the trainee with feedback on where s/he was or was not looking relative to emerging driving demands (Figure 2).

3) Provide an efficient and effective means of assessing and training driving skills among those with ASD by using a standardized VRDS, assessment protocol and training modules, trainer manual, and "train the trainer" programs. This would include both VRDS training, along with parallel on-road practice procedures, forms, and exercises to facilitate generalization from virtual to real-world driving.

1.4 Preliminary Studies

We would like to point out that the current proposal evolves from a line of systematic research: Dr. Cox and MBFARR, LLC secured a DoD/DARPA SBIR grant in 2009 to develop a simulator for the assessment and rehabilitation of wounded warriors recovering from traumatic brain injury (TBI). This TBI work has continued in collaboration with Dr. Ettenhofer at the Uniformed Services University. Dr. Cox then teamed up with ASD expert Dr. Ronald Reeve at the University of Virginia (U.Va.), and together they secured a DoD Pilot Project to assess the feasibility of using VRDS in the assessment and training of novice drivers with ASD. Positive findings from this program led to recruiting Dr. Timothy Brown at the National Advanced Driving Simulator (NADS) facility at the University of Iowa to incorporate his expertise as a human factors engineer in driving simulation. This multi-disciplinary and multi-center team secured an ASD Idea Development award to investigate enhancement of VRDS in the assessment and training of novice ASD drivers. Results from this effort justify and contribute to the submission of the current Randomized Clinical Trial (RCT) proposal to document the efficacy of the culminating VRDS assessment and training program. This program is a practical and efficacious system, capable of immediate dissemination of substantive and significant benefits to those with ASD.

1.4.1 DARPA Grant

With an SBIR grant from DARPA, we developed a VRDS system to rehabilitate wounded warriors recovering from TBI. This system has two assessment capabilities, operational and tactical, which could also be used in training driving safety.

1.4.1.1 Operational Tests

To evaluate basic driving-relevant abilities that may be impaired or *developmentally deficient*, we developed driving-specific visual, motor, and cognitive tests modeled after traditional neuropsychological tests. What is unique about these tests is that they use driving-relevant stimuli, responses, and context. In order to enhance ecological validity, all of these tests employ the same environment, thus reducing adaptation from one test to another. The examinee drives down the middle lane of a three-lane highway at 35mph, maintaining a constant distance from a lead car. To equate task instructions all subjects hear the same instructions, delivered at the same time, by the simulator's synthetic voice.

Of relevance to our ASD work are two of the motor tests (braking and steering reaction time) and three executive functioning tests (dual processing, response inhibition, and working memory). Table 1 and Attachment 10, #3 provide more information about these tests, including reliability.

Figure 2. Playback view for subject's feedback, crosshairs designates where subject was looking, e.g. this trainee is looking too much down and right on sidewalk.

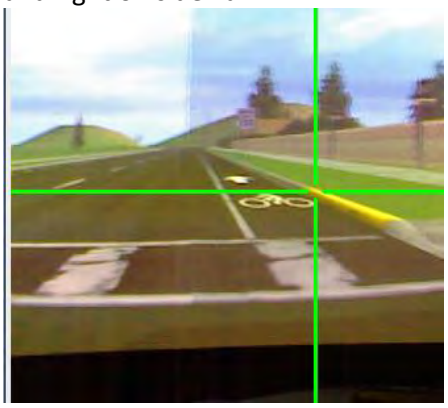


Table 1. Listing of Operational Variables *Underlined values are measures of internal consistency.*				
Operational Tests		**Task**	**Dependent Variable**	**Reliability**
Motor	*Braking* *Reaction time*	Lead car's brake lights come on 10 times: 5 for 3 sec. and 5 for 0.5 sec. Driver removes foot from accelerator and presses the brake as quickly as possible	Milliseconds between brake lights on and 5 lbs. of pressure applied to brake pedal.	r= .85**
	Steering *Reaction time*	Lead car passes over 12 potholes: 6 filled grey and 6 deep black potholes. Driver steers around potholes as quickly as possible while staying in lane	Milliseconds between when pothole appears and initiating steering maneuver.	r= .96**
Executive Function	*Dual Processing*	Lead car's brake lights come on 8 times and passes over 8 potholes. Driver is to brake to all brake lights and steer around all potholes as quickly as possible	Total correct responses: brake to brake lights and steer around potholes.	r= .82**
	Response Inhibition	Same as Dual Processing, but inhibit previous prepotent response, i.e. do not respond to brief brake lights or grey potholes, while continuing to brake to long brake lights and steer around black potholes	Total correct responses: brake to long brake lights and steer to deep potholes, and not respond to brief brake lights and grey potholes.	r= .59*
	Working Memory	Same as Response Inhibition and additionally driver has to remember 1 to 3 road signs recently passed in the order they appeared.	Signs recalled in correct order.	r= .82**
***Operational Composite Score*: Sum of z scores**				r= .52**
***. Correlation is significant at the .05 level. **. Correlation is significant at the .01 level.**				

Dual processing is a combination of braking and steering from the motor tests. *Response Inhibition* assesses the ability to suppress the processing, activation, or expression of information (or action) that would otherwise interfere with the attainment of a desired cognitive or behavioral goal (Dagenbach & Carr, 1994; Dempster, 1992). After three tests where the driver brakes in response to all brake lights and steers around all potholes (response prepotency), the driver now is instructed to brake as quickly as possible to long/three-second brake lights and not brake to short/half-second brake lights, and to steer around deep/black potholes and not avoid grey/filled potholes. *Working memory* is a limited capacity system responsible for the temporary storage, rehearsal, updating, and mental manipulation of information for use in guiding behavior. Working memory has been linked to a number of real world skills, including driving (Cohen & Conway, 2008). The *Working Memory* test is a complex span task modeled after the automated operation span task (Conway et al., 2005) and provides an index of overall working memory functioning. It requires participants to hold an increasing quantity of information in memory (road sign messages) while simultaneously performing a secondary attention-demanding processing task (to inhibit/not inhibit steering and/or braking), both of which place demands on the same stimulus modality (visual).

The *Operational Composite Score* is a sum of all operational tests. Scores on different tests are converted to z-scores, allowing a common metric, and then summed. Thus, the operational composite score is an overall reflection of basic driving abilities. A composite score of "0" is average, while a negative composite score is below average. Based on normative data we generated with the Virginia DMV (see Attachment 2, #4c), we can convert this composite score to a driving quotient (***DQ***), which is much like an intelligence quotient (IQ), with a mean of 100 and a standard deviation of 15.

1.4.1.2 Tactical Test

The tactical test is analogous to an on-road test of driving skills, but performed in a safe, reliable, and challenging virtual world. The tactical test involves driving on a standardized route, which includes five miles of rural, six miles of highway, and four miles of urban roads. Drivers negotiate realistic anticipated and unanticipated road, signal, traffic, and hazard demands. Thirty-one performance variables are monitored, such as swerving, rolling stops, speeding, and collisions. Thirteen of these variables were selected for a composite score because these variables identified drivers with a history of collisions in our DMV normative sample (Attachment 2, #4c). Table 2 details the thirteen tactical variables and the composite score's robust two-week test-retest reliability of r=.80. Of relevance to our ASD work is the ability to compare data from individuals with ASD against a normative population, which can help to identify strengths and weaknesses in skills necessary for successful independent driving.

Table 2. Listing of Tactical Variables
Variables are recorded for the entirety of the route.

Tactical Variables		**Description**	**Reliability**
Braking	*Rolling Stops*	Ratio of incomplete (>0 and <5 mph) to complete (0 mph) stops.	r= -.04
	Deceleration Smoothness	Total magnitude of rapid decelerations; i.e., slamming on brakes.	r= .67**
	Bumps	Number of collisions with another vehicle below 5 mph.	r= .49**
	Collisions	Number of collisions with another vehicle exceeding 5 mph.	r= -.42*
Speed	*Acceleration Smoothness*	Total magnitude of rapid accelerations; i.e., slamming on gas.	r= .94**
	Speeding	Total time spent driving 5-19 mph above the posted speed limit.	r= .68**
	Reckless Driving	Total time spent driving 20 mph or more over the posted speed limit.	r= .80**
	Tailgating	Number of times driver is within 15 feet of lead car during open road segments.	r= .18
Steering	*Swerving*	Lane position variability (standard deviation of lane position; i.e., swerving).	r= .83**
	Midline	Average magnitude active; integrated score of how far across and for how long driver was in oncoming lane of traffic.	r= .58**
	Off Road	Standard deviation time active; variability of length of time driver was off road.	

Judgment	*Lane Changes*	Total number of lane changes made on route.	r= .53**
	Driving Slow	Average time spent 20 mph or more under the posted speed limit.	r= .38*
***Tactical Composite Score:* Sum of z scores**			r= .80**

a. Cannot be computed because at least one of the variables is constant.

***. Correlation is significant at the .05 level. **. Correlation is significant at the .01 level.**

1.4.1.3 Tactical Composite Score

The tactical composite score is calculated like the operational composite score, except it incorporates the thirteen tactical variables. Our past research has demonstrated that the tactical composite score is a valid overall measure of driving performance that predicts future driving collisions of seniors, (Cox, Taylor, & Kovatchev, 1999), differentiates high from low risk drivers such as young seniors vs. older seniors (Cox, Broshek, Kiernan, Kovatchev, Guerrier, Giulano, George, 2004), differentiates drivers with and without attention deficit hyperactivity disorder (Cox, Merkel, Hill, Kovatchev, Seward, 2000), differentiates drivers with and without Alzheimer's disease (Cox, Quillian, Thorndike, Kovatchev, Hanna, 1998), and differentiates high vs. low risk conditions, such as intoxication vs. sobriety (Quillian, Cox, Kovatchev, Phillips, 1999), diabetic hypoglycemia vs. euglycemia (Cox, Kovatchev, Anderson, Clarke, Gonder-Frederick, 2010), adolescent ADHD drivers on methylphenidate vs. placebo (Cox, Merkel, Moore, Thorndike, Muller, Kovatchev, 2006), and as we will see, ASD from healthy controls and novice ASD drivers who did and did not receive VRDS training. ***The tactical composite score is our primary outcome variable.***

1.4.1.4 Use of the VRDS for Rehabilitation (see Cox et al, 2010, Attachment 2, #4)

We demonstrated that VRDS training for wounded warriors recovering from TBI resulted in improved driving performance and reduced road rage, did not produce simulation sickness, and was found to be engaging. Of relevance to our ASD work is that the training developed to successfully rehabilitate warriors with TBI can be adapted and serve as the basis for a training program for individuals with ASD.

1.4.2 Pilot study - VRDS and ASD driving

This U.Va. project involved two components. The first was an internet survey of parents with children who have ASD who either had or were trying to secure an independent driver's license. The survey was intended to solicit their experiences and opinions. The second component was a feasibility study to determine if VRDS could be used to assess and train driving competency of youth with ASD.

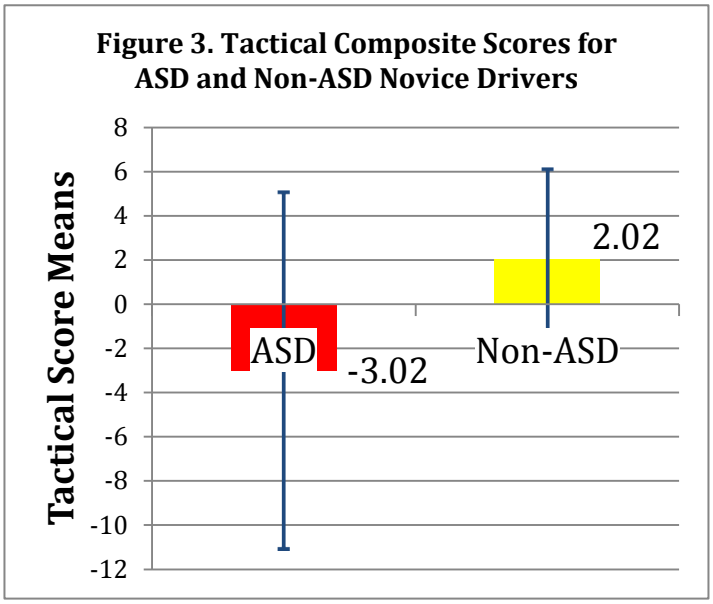
1.4.2.1 Parent Survey (see Cox et al, 2012, Attachment 2, #4)

We conducted an internet survey of the ASD adolescents' parents to discover the barriers these young adults faced when learning to drive. Participants were recruited from advertisements on ASD websites. One hundred twenty-three caregivers ultimately enrolled, of which 81% were mothers of ASD adolescents who were attempting to or had secured an independent driver's license. Caregivers rated the effect of eight ASD characteristics on their adolescent's ease of learning to drive and the difficulty with which eight driving behaviors were learned. ASD symptoms that interfered most with learning to drive were difficulties with:

- Multi-tasking
- Understanding nonverbal communications
- Tolerating unexpected changes in routine

Specific on-road driving skills especially difficult to learn were:

- Multi-tasking (e.g. merging while maintaining speed)
- Awareness of traffic
- Use of mirrors
- Speed control (e.g. driving too fast, too slow, or difficulty maintaining a steady speed)



These findings indicate training safe driving skills in individuals with ASD should focus on awareness of front, rear, and side traffic, concurrently managing multiple driving tasks (e.g., use of mirrors while maintaining speed and lane position), and anticipating the unanticipated.

1.4.2.2 VRDS Feasibility Study (see submitted manuscript, Attachment 2, #4)

We conducted a feasibility study to determine if VRDS could be used to assess and train driving competency of youth with ASD. This is the first study to examine the impact of ASD symptoms, motor control, and executive functioning on tactical driving performance in a high-fidelity VRDS. Seventeen young individuals (mean age: 18.3 years) with ASD who had earned their learner's permits were compared to twenty-seven healthy adolescent controls on operational (motor and executive function) tests and tactical (driving skill) tests in the VRDS. Additionally, parents of drivers with ASD completed the Social Responsiveness Scale and the Behavior Assessment System for Children-2 (BASC-2. Given our parent survey data, we hypothesized: 1) novice drivers with ASD would perform worse than novice drivers without ASD in terms of multi-tasking but not basic driving abilities, and that novice drivers with ASD would perform worse on overall driving skills (tactical composite score), 2) executive dysfunction in drivers with ASD would predict worse tactical composite scores, 3) more ASD symptoms, as defined by parent ratings, would correlate with worse tactical driving skills, and 4) VRDS training would improve tactical composite scores.

Hypothesis 1 Results: Compared to the controls, drivers with ASD demonstrated:

- Equivalent basic driving abilities in terms of braking reaction time, dual processing, and response inhibition.
- Worse multi-tasking/executive functioning in working memory (p=.026) and response inhibition (p=.009) during working memory testing (see Table 1).
- Worse overall tactical driving skills (p=.003, see Figure 3) due to rapid acceleration (p =.004), slamming on brakes (p =.04), swerving (p<.001), driving off road (p=.04), not using turn signals (p = .002), and low- and high-speed collisions (p = .002 and .014 respectively).

Hypothesis 2 Results: Compared to the controls, in terms of executive function ASD drivers demonstrated:

- Worse working memory (p=.009) and concurrent response inhibition (p <01).

Hypothesis 3 Results: Overall, parents' ratings of ASD symptoms correlated weakly with simulator performance.

- Symptoms correlated only with steering variables on the tactical test: driving across the midline (BASC-2 Adaptive Skills, r = -.57, p > .05, SRS-2 Total, r = .76, p > .01), and swerving (SRS-2 Total, r = .70, p > .05).

- Symptoms correlated only with steering and braking variables on operational tests. Steering and braking reaction times correlated with BASC-2 Adaptive Skills ($r = -.54$ and $-.64$, respectively, $p < .05$), and SRS-2 Total ($r = .55$ and $.68$, respectively, $p < .05$).

Hypothesis 4 Results: We were unable to investigate whether VRDS training improved tactical skills because of a technical problem in our simulator software that we identified after data had been collected. This problem was corrected for our next study. However, we learned several important things from this effort:

- We corrected the software problem, making possible a pre-post assessment in our subsequent study.
- VRDS did not trigger simulation sickness in these young ASD trainees.
- ASD novice drivers enjoyed VRDS training, and parents appreciated this safe and challenging training. (see mother's unsolicited expression of appreciation, below).
- Driving anxiety among ASD drivers was a significant barrier to on-road practice. This led us to develop a measure to quantify novice driver anxiety: the Scale of Apprehensive Driving (SAD; see Attachment 10).
- Parents relied on VRDS as the primary source of driving training, and therefore disengaged from parallel on-road training.
- It would be important to develop a standardized driving training manual with a standardized training protocol that adapted to the trainee's strengths and weaknesses.

These findings from the Pilot Study directed us to focus on multi-tasking (especially as it relates to working memory), to address issues of driving anxiety, and to work more closely with parents to encourage on-road driving training "homework" to facilitate generalization of VRDS training skills and to desensitize driving

Unsolicited Expression of Appreciation

Much of this experience utilized the magic formula that works for our kids, breaking down a seemingly insurmountable task in to small, manageable parts and giving consistent exposure. A great deal of his anxiety about driving, which is often his major roadblock to success, has resolved. Now Ian is in the best possible position to go forward with logging driving time and working towards earning his license.

My husband, Greg, and I have been knocking on doors and turning over stones, sometimes methodically, and in other instances a panic, searching for answers, solutions, and support for our child. Throughout our journey, we have found some resources to be weak and others mediocre. Then there are those connections which touch our lives so profoundly we are struck with the realization that Ian has been given the opportunity to experience something positive for not only a moment, but for a lifetime. I am happy to be able to tell you Ian's participation in the driving study has been the latter.

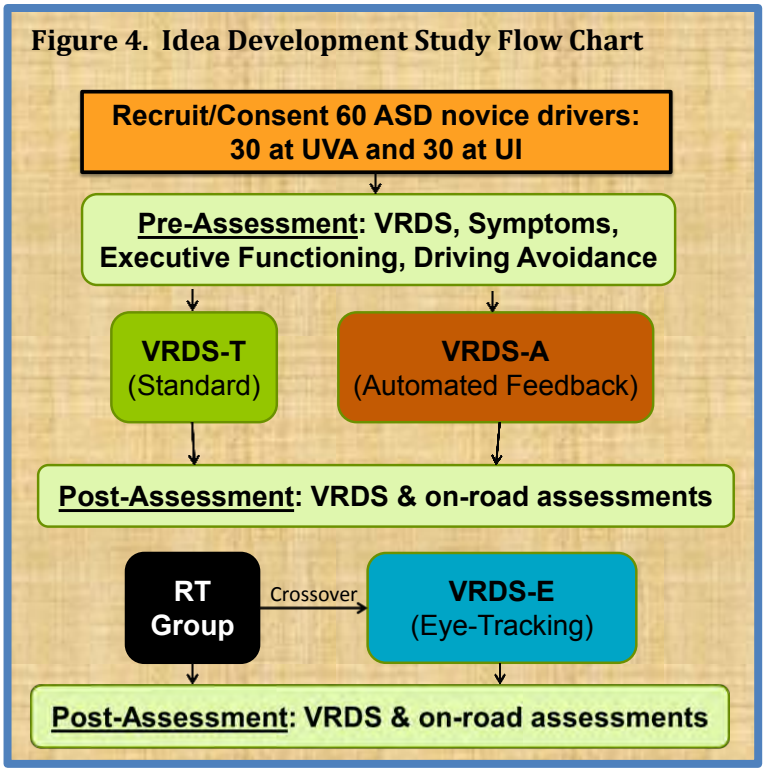
Of course, we gave pause when trading the driver's seat for the passenger's with our student. How much more when our teen is on the spectrum? A driving simulator gave our son experience and all of us comfort well before he had gone much beyond our driveway. We are particularly struck by the difference before the simulator work and afterwards. I no longer clench my teeth and have to stifle a gasp when passing neighborhood mailboxes, since Ian has become well aware of his road positioning. I'm sure our neighbors are grateful as well.

All staff involved with the study were extraordinarily kind, professional, and supportive, and put Ian at ease, which is not always an easy feat. During the study, we had promised to practice on-road work. Having weekly accountability kept our momentum going, and we were able to notice Ian's progress. Little by little he felt more comfortable in both the virtual and actual driver's seat. By the time Ian was due to take his practical assessment, he had lost his momentum with practice, and his self-confidence had waned. However, the lessons he learned remained, and he was able to complete the full assessment, step out of the car smiling, and hear a robust 'great job!' from his tester. There is nothing like hearing those words from someone. Karen R

anxiety.

1.4.3 Idea Development Award

This multi-center (U.Va., University of Iowa [***U.I.***]) study was designed to test the following hypotheses: 1) compared to routine training (***RT***) required by the DMV, VRDS training+RT (***VRDS-T***) would lead to greater improvement in driving safety and less driving anxiety, 2) VRDS-T augmented with computer-generated automated feedback (***VRDS-A***) would be superior to VRDS-T. Automated feedback involves the simulator detecting in real-time when the trainee's performance exceeds either legal (speed limit) or normative (extent of swerving) guidelines and immediately provides the trainee such feedback (e.g. "You are driving too fast"), 3) eye tracking feedback (***VRDS-E***) would significantly augment either VRDS-T or VRDS-A, whichever was found to be better. VRDS-E involves having the trainee wear Mobile Eye tracking glasses that record eye position to determine where the driver is looking. Playback of this video allows the trainee to view where s/he was looking during any part of the drive and facilitates training where to look if errors exist (see Figure 2).



As seen in Figure 4, twenty participants were recruited at each site and then randomized to either ten training sessions of VRDS-T or VRDS-A. Trainees were assessed pre- and post-training in terms of operational and tactical driving performance, driving anxiety, and on-road performance by an examiner blind to the training conditions (on-road assessment was only performed post-training). Subsequently, ten additional ASD novice drivers were recruited at each site. These participants served as RT controls, with pre- and post-assessment separated by two months. These subjects were crossed over to the VRDS-E condition and evaluated.

Currently, we have recruited all subjects, completed assessments of all VRDS-T, VRDS-A and RT, and have finalized half of our VRDS-E participants.

1.4.3.1 Preliminary Analyses:

Hypothesis 1 Results: VRDS-T led to significantly better post-assessment tactical composite scores (ANCOVA co-varying baseline performance p= .008). Figure 5 illustrates that at post-assessment, performance with RT was worse than the average of all drivers, while performance with VRDS-T was much better than the average. In terms of on-road performance, more RT participants declined taking the test compared to VRDS-A participants, and more VRDS-T participants passed the on-road test (see Figure 6).

In terms of driving anxiety, at post-assessment, SAD scores demonstrated a more positive attitude towards driving following VRDS training (Figure 7).

Hypothesis 2 Results: Those receiving VRDS-A were only marginally superior to those receiving RT (p=.059), and automated feedback did not improve VRDS-T (Figure 5).

Hypothesis 3 Results: As seen in Figure 5, after collecting half of the VRDS-E data, it appears that in its current form, required eye-tracking feedback did not significantly enhance efficacy of VRDS-T.

1.4.3.2 Discussion

As we have demonstrated with novice drivers without ASD (Cox et al, 2009) and with wounded warriors recovering from TBI, VRDS-T improved driving safety above and beyond RT. We hypothesized that computer-generated feedback would be more palatable than human-generated feedback to those with ASD, but this was not the case. This is probably due to the implementation of the automated feedback being in its infancy. While both trainers and trainees reported that the automated feedback was generally a good idea and useful, the system gave two types of frustrating and misleading feedback: 1) indicating a turn signal was not used when the turn signal had been activated, or indicating a wrong turn when the correct turn had been made, and 2) indicating that the driver was not maintaining lane position when driving on a curvy road, merging onto the highway, avoiding road hazards, or pulling off the road for an emergency. Software modification will correct these issues.

As for the benefits of trainees receiving eye-tracking feedback, preliminary analyses indicate that giving feedback to all subjects on all tactical driving elements does not significantly improve VRDS-T.

Figure 5. Outcome of VRDS training program, demonstrating that VRDS-T was superior to RT ($p<.01$), as was VRDS-A ($p<.05$), and VRDS-E ($p<.05$). Training groups were not significantly different.

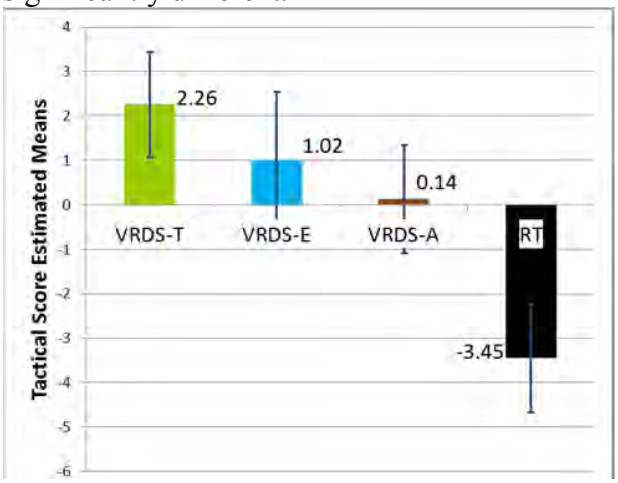
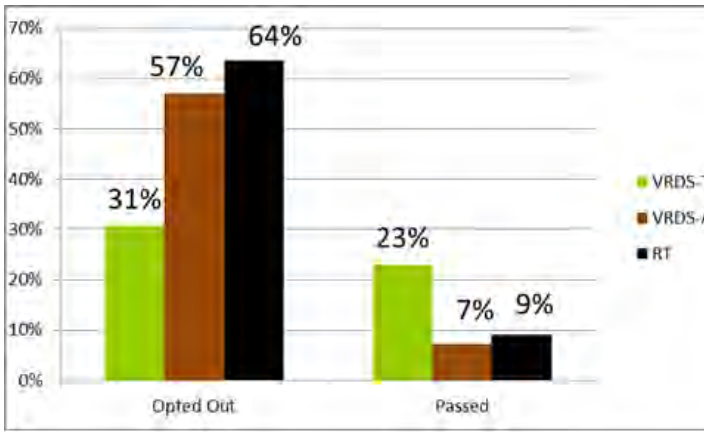
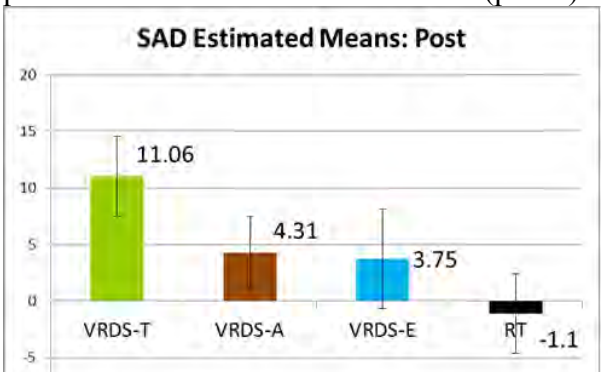


Figure 6. Percentage of participants opting out/refusing to take the on-road tests and percentage that passed the blinded on-road test.



From the Idea Development award we learned that VRDS-T can significantly improve the driving safety of novice drivers with ASD, and this is not enhanced by the current version of automated feedback or the routine use of eye-tracking. However, informal feedback from trainees indicates there are some potential benefits derived from some parts of these adjunctive elements for some trainees.

Figure 7. SAD scores were significantly more positive in VRDS-T than in Controls ($p=.02$).



2 Objectives

The purpose of this study is to evaluate the benefits of VRDS as an assessment and training tool for individuals with ASD seeking a driver's license. This would culminate in an effective, standardized training procedure that could be made available to any driving professional and his or her ASD clientele.

This NIH-registered randomized clinical trial will be the first trial to compare matched samples of novice drivers

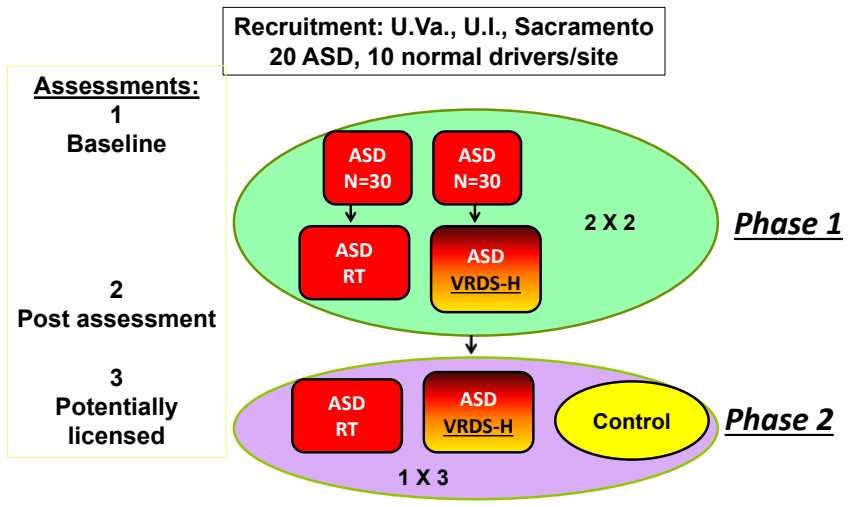
with and without ASD, and matched samples of novice drivers with ASD receiving either **VRDS-H** (Hybrid of our past VRDS-T, -A, and -E) vs. RT (see Figure 8). ASD participants receiving VRDS-H (experimental group) will be compared to those receiving RT (control group) at three assessment points, specifically: 1) at baseline after securing a learner's permit, 2) two months later following VRDS-H, and 3) when an independent driver's license could be achieved (after accumulating sufficient time and on-road driving experience to qualify). Between assessment 1 and 2, all ASD participants will be encouraged to complete DMV on-road driving training requirements for an independent driver's license. Additionally, the VRDS-H participants will receive 8-12 VRDS training sessions tailored to each individual based on their initial assessment and performance on already completed training sessions. To determine if ASD drivers' skills have been normalized at the time of potential licensure, they will be compared to non-ASD youth (normal control group) who are also ready to secure an independent driver's license.

2.1 Hypotheses

At the end of this two-year project, we will have the data to test the following hypotheses:

1) ASD participants trained with VRDS-H will demonstrate significantly better post-assessment (two-month) performance than those trained with RT in terms of (a) VRDS performance, (b) on-road driving performance, and (c) having less driving anxiety.
2) At the time of potential licensure, ASD participants trained with VRDS-H will be more likely than those trained with RT to pass the DMV licensure test and secure an independent driver's license. Moreover, the pass rate of those trained with VRDS-H will not differ significantly from the non-ASD control group.
3) ASD participants who do not secure an independent driver's license can be predicted based on an algorithm incorporating parent-reported ASD and driving anxiety symptoms, VRDS baseline assessment, and responsiveness to the initial VRDS training session.

Figure 8 Flow chart of proposed study design, with the two study phases in different colored ellipses.



2.2 Dissemination

To promote rapid dissemination of these findings, we anticipate completing Phase 1 and 2 of this project in two years, making our publications, driving manual, parent instructions, and all questionnaires immediately available to research, clinical, advocacy, and general public communities, as well as to the National Database for Autism Research (NDAR).

3 Study Design

3.1 Overview

This is a two-phase, multi-center, multi-disciplinary follow-up to our two previous DoD autism studies, in which we will document the efficacy of VRDS assessment and training of driving skills. Months 1-6 will involve preliminaries, e.g. IRB approval, simulator upgrades, and staff training. ***Phase 1*** (months 7-18) will involve enrolling twenty ASD novice drivers at each site (U.Va., U.I., and Sacramento: N=60), and completing baseline assessments of ASD symptoms, basic driving-relevant abilities (visual, motor, and cognitive), and general tactical driving skills. ASD participants will then be matched on age, sex, and baseline measures, and

block-randomized to either routine training required by the DMV (**RT**) or RT+VRDS-H training, which is a hybrid training program based on our Idea Development findings (**VRDS-H**). The post-assessment will occur two months later and will be identical to the baseline assessment, except symptom ratings will be excluded and an on-road test will be included. Phase 1 will inform us whether VRDS-H enhances RT, and whether we can predict which ASD novice drivers will not respond to either RT or VRDS-H. ***Phase 2*** (months 11-22) will involve recruiting 30 novice non-ASD drivers as a **control** group. At the time of potential acquisition of an independent license (when they are ≥16yrs and 3 months and have had a learner's permit for 9 months,), control, RT and VRDS-H drivers will be assessed and then matriculate to DMV on-road testing. Phase 2 will inform us whether VRDS-H drivers are as good as the controls, and if both of these groups perform better than the RT participants (see Figure 8). At the end of this two-year study, we will know the absolute and relative benefits of VRDS-H, and if appropriate, we will disseminate the findings, procedures, and VRDS-H materials. The project timeline is shown in Table 3. This relatively aggressive timeline is designed to expedite conclusion and dissemination of findings to the ASD community, and is determined feasible based on our Idea Development experiences.

Table 3. Project Timeline

Activities	**Months**											
	0-2	3-4	5-6	7-8	9-10	11-12	13-14	15-16	17-18	19-20	21-22	23-24
IRB approval												
Simulator upgrades												
Staff training												
Pilot testing												
Subject recruitment												
Phase 1, VRDS-H												
Phase 2												
Data analysis												
Dissemination												

3.2 Preliminaries

IRB approval: IRB approval is anticipated to go smoothly because this will be an expedited approval. The study does not represent any additional risk beyond that which participants would normally be exposed to in pursuing an independent driver's license. Additionally, a similar protocol (Idea Development Award) has already been approved by the UVa and U.I. IRBs.

Simulator Upgrades: The simulator hardware will be upgraded at each site by replacing the static, strain-gauge based turn signal with a typical mechanical turn signal that moves as you press it down or up. This will greatly improve turn signal feedback as a result of the reliability inherent in a mechanical turn signal that is behaving as drivers expect. Simulator software will also be enhanced in several ways. Automated feedback will be refined in two ways: 1) feedback regarding the use of turn signals will be made reliable, and 2) feedback concerning lane

position will be based on normative driving behavior of the DMV normative sample rather than on absolute deviation from the center of the lane. This will provide better guidance in curvy roads, highway merges, and in turns. Additionally, the nature of this computer feedback will be made user-selectable (i.e. male, female, mechanical, or no voice). Finally, additional road hazards will be created and the trainer will have the ability to turn each sequence on or off depending on the specific training demands. This is intended to enhance generalization of training and to meet the needs of individual training sessions.

Eye Tracking: The eye tracking procedures will be improved based on our experience with when its use improved training, providing teaching moments, and when the additional information did not justify the time needed for fitting, recording, and calibrating the system. The use procedures will be further standardized so that all sites are utilizing the eye tracking program in the most efficient and effective manner.

We will take four months to test the simulator upgrades, identify any issues, and rectify these before beginning baseline assessments and VRDS-H testing. This will be done at all three sites, and will conclude with a face-to-face meeting of all investigators to review these enhancements, assessment procedures, and the VRDS-H training manual and procedures. This meeting will include the on-road examiners, for training purposes and to ensure reliable scoring of trainees' performance.

3.3 Participants

Thirty participants (twenty with a diagnosis of ASD and ten without a clinical diagnosis) will be recruited at each site. To be included, participants must:

1) …(for ASD participants only) have been previously diagnosed with ASD and receiving support, satisfy the DSM-V criteria of ASD as defined by receiving a T score of 60 or above (one standard deviation above the mean) on the Social Responsiveness Scale-Second Edition (SRS-2), Goldstein & Naglieri, 2010).

2) …be between the ages of 15.5 and 22 years (high school and college age).

3) …have secured a learner's permit but not an independent driver's license yet. This sampling requirement has multiple advantages: It roughly equates subjects in terms of driving experience, it optimizes motivation because these individuals must have training to obtain a driver's license, and parents are typically very invested in supporting efforts toward securing a driver's license and independence.

4) …be able to attend 15 sessions in a three month period (three assessment visits, and up to twelve one-hour training sessions).

5) …have a parent or driving instructor who is willing to provide on-road training and complete the required DMV driving log between pre- and post-assessments.

Requiring a learner's permit (which requires passing driving knowledge and vision tests) assures basic levels of driving knowledge and intellectual capabilities. Requiring on-road training opportunities serves multiple purposes, such as allowing transfer of training from the virtual to the physical world, promoting desensitization of driving avoidance and anxiety, and partially satisfying DMV requirements to secure an independent driver's license. While we have not had any participants drop out from our current project, any who drop out of the proposed study will be replaced with the next available participant.

We will document participants' severity of ASD, use of medications, comorbidities, school achievement (e.g. number of grades completed or repeated), and other variables for post-hoc analyses. Subjects will not be excluded as a result of answers to these questions, since we have no data on which to base such exclusions at this time and we want to keep our sample as representative of the general ASD population as possible.

For the purposes of randomization, we will use the minimization method (Pocock & Simon, 1975) in which symptomology, gender, age, and data collection site will be used as stratifiers. The levels for age will be 15.5 to

17.9 and 18 to 22. The levels for symptomology will be divided into two groups, SRS-2 scores above or below 70, based on data from the prior phases of the project. We previously used the Social Responsiveness Scale-Second Edition (SRS-2), a similar parent report instrument, for our symptomology cutoffs. In accordance with the minimization method, subjects will be assigned to the condition that results in the least imbalance. In the case that there is no difference in the imbalance when assigning a subject, the subject will be randomly assigned to one of the two conditions.

3.3.1 Recruitment

Participants will be recruited through ASD specialty clinics, ASD organizations and support groups, press releases, direct referrals from educational and health care professionals, public presentations, and ASD websites. We will explicitly recruit from military installations, like the National Ground Intelligence Center in Charlottesville, VA., Fort Belvoir located outside of Woodbridge, VA., Camp Dodge and the Rock Island Arsenal, close to Iowa City, IA., and both Travis and Beale Air Force bases near Sacramento, CA. We will recruit a third of our subjects from the East coast, a third from the Midwest, and a third from the West coast for several reasons: 1) facilitation of subject recruitment, 2) quicker study resolution and dissemination of findings, 3) greater external validity by recruiting subjects from three different geographical locations, each experiencing different traffic and road system demands and receiving VRDS-H training from different professionals (occupational therapists, special educators, psychologists), and 4) to obtain a diverse sample of military families.

3.3.2 Compensation

Since post-assessments are not directly beneficial to participants but are critical for evaluating the intervention, participants will receive compensation for completing post-assessments. They will be paid $100 for turning in their on-road driving log and completing their Phase 1 post-assessment (VRDS and on-road testing). Participants will also receive $100 for completing the Phase 2 assessment.

3.3.3 Sample Size

In our Idea Development Award ($n \leq 20$/group), the composite tactical driving scores differed between Routine and VRDS training ($p=.02$). In our Pilot Study ($n = 17$/group), the composite scores differed for Routine Training in ASD and non-ASD samples ($p<.01$). Therefore, a sample size of thirty/group will give a 90% likelihood of finding significant differences ($p<.05$) in Phase 1 and 2.

3.4 Equipment

This project hinges on the use of U.Va.'s high fidelity, immersive driving simulator, which was developed for the DOD in order to assess and rehabilitate wounded warriors (see Figure 1). All three testing sites will use the same model of simulator. Advantages of the DoD-funded simulator are: 1) it is relatively inexpensive ($20,000), making it a good value for installing at multiple sites, 2) it requires minimal space, since its footprint is an 8 foot cylinder and it is controlled using a single computer, 3) it is highly immersive, containing features such as a curved 210° screen for displaying virtual environments, a fully featured cockpit including right side, left side, and rear view mirrors, an adjustable seat, dashboard, steering wheel, turn signal, gas and brake pedals, seat belt, air conditioning, and an enclosed black curtain to control distractions, 4) it has a low simulator adaptation syndrome (SAS) profile, which is important for subject retention. In our recent DMV project, no driver under the age of 25 discontinued driving due to SAS, 5) it is rapidly deployable (mass produced vs. one-of-a-kind), and 6) it has extensive testing capabilities (both operational and tactical measures).

3.5 Methods

3.5.1 Consent

Interested novice drivers with ASD, and their parents or guardians will come to one of the testing sites where they will be thoroughly informed about the study, screened for inclusion/exclusion criteria, and consented or assented. To confirm the diagnosis of ASD, parents will complete the Social Responsiveness Scale-Second Edition (SRS-2). If the driver qualifies and consents, s/he will begin assessment.

3.5.2 Assessments

There are three levels of assessment (psychometric, VRDS, and on-road), and three time points at which these assessments will be made (baseline, post-assessment, and at potential licensure - see Figure 8).

3.5.2.1 Psychological and Behavioral Measurements

Our Pilot Study project demonstrated that only the Social Responsiveness Scale-Second Edition (**SRS-2)**; Constantine & Gruber, 2012), the Behavior Assessment System for Children-2 (**BASC-2**, Reynolds & Kamphaus, 2004), and our Scale of Apprehensive Driving (**SAD**) correlated with driving parameters, so only these scales will be utilized. All three scales are parent-reports. The SRS-2 is a 65 item 4-point scale that generates t scores for children through adults. Internal consistency reliability is .95. A cutpoint t-score of 70 is associated with a sensitivity value of .88 and specificity value of .93 for ASD(Constantino, & Gruber, 2012). The BASC-2 is a 150 item 4-point scale that generates t scores with norms up to age 25. Internal consistency reliability is .94 for Externalizing, .93 for internalizing, and .95 for adaptive functioning (Reynolds, & Kamphaus, 2004). This scale is widely used as a measure of symptom severity across a range of maladaptive and adaptive symptomatology including anxiety, depression, somatization, and other "internalizing" behaviors; attention, hyperactivity, aggression, and other "externalizing" behaviors, and a variety of "adaptive" behaviors (e.g., social skills, leadership, activities of daily living). The SAD is a 20 item 5-point scale for novice drivers, with a test-retest reliability of .83, and we have demonstrated it sensitive to intervention effects. Since we developed it for this project, little psychometric data is currently available.The SRS-2 and the BASC-2 will only be administered at baseline, because the symptoms they measure are not anticipated to change over the period of the study. The intervention is anticipated to reduce driving anxiety (Figure 7), so the SAD will be administered at all three assessment times.. The SAD demonstrated discriminate validity (see Figure 5,) in the Idea Development project, demonstrating that VRDS-T participants experienced a reduction in driving anxiety while the RT participants did not.

3.5.2.2 VRDS Operational and Tactical Tests

The tactical composite score will be the primary outcome variable. It has good test-retest reliability (r=.83), is discriminant (predicts future collisions), and is valid (significantly correlates with on-road test performance). Our operational test will now include two additional components: *Divided/Selective Attention* and *Peripheral Vision*, because both our Pilot Study and Idea Development projects indicated that divided attention and multi-tasking were problematic for ASD drivers.

Our VRDS *Divided/Selective Attention* test is designed to mimic the well-documented Useful Field of View (UFOV) test (Ball, Clay, Wadley & Roth, 2005). In each trial, the examinee accelerates from a stopped position in the center lane of a three-lane road. The task is to attend directly ahead of the vehicle, where a truck and a barrel will appear in the scene. Exposure times become progressively shorter as the test progresses. When the screen refreshes back to the start line on each trial, the driver reports whether the truck was facing to the left or right, and where the additional barrel was located (3:00, 4:30, 6:00, 7:30, or 9:00 position, relative to the center of the truck). Along with the truck and barrel, speed signs appear throughout the scene to make accurate identification more difficult. The dependent variable is the shortest exposure time at which the driver correctly identifies both the truck direction and the barrel location.

In the *Peripheral Vision* test, the driver's task is to brake whenever they see the lead car's brake lights, and at the same time to state when and where they see a vehicle passing. The test utilizes the short brake light condition from the Braking

Figure 9. Driver wearing eye tracking glasses while performing the Operational Peripheral Vision Test

Reaction Time test to ensure that the driver is fixating straight ahead on the lead car. Passing cars approach from behind in the right and/or left lanes, penetrating to either 70 or 55 degrees in the periphery before dropping back out of view. The dependent variable is the angle (70 or 55 degrees) at which the driver correctly reports the presence and location (left, right, or both sides) of an encroaching vehicle on at least two of three trials when cars approached from the right, left, and both sides (Figure 9).

New to this study, drivers will wear ASL Mobile Eye tracking glasses during VRDS testing (Figure 9). These glasses monitor where a person is looking by having one camera focusing on the subject's eye and one focusing on the virtual world where the driver is looking. Gaze position will be recorded during training for three reasons: 1) to determine if the gaze patterns of novice ASD RT and control subjects differ (i.e. are ASD RT participants visually "off target" more than controls?), 2) to determine if VRDS-H improves visual focus while driving, by comparing ASD RT and VRDS-H at assessment 2, and 3) to help guide the individualization of VRDS-H training (i.e. if assessment 1 indicates an ASD novice driver does not look into turns, scan for speed limit signs, or look for potential hazards during tactical testing, then these will be targeted during VRDS-H). We are currently working with Dr. Mark Ettenhofer of the Uniformed Services University to optimally quantify drivers' eye-tracking data. The existing collaboration will benefit this project.

Examiners who administer the operational and tactical VRDS assessments will not also administer the training. This will keep the trainer blind to the training condition and will eliminate the impact of a trainer-trainee relationship on performance and motivation.

3.5.2.3 On-Road Tests

Our on-road test is modeled after the Virginia DMV on-road tests. It has five levels. The driver has to: 1) feel comfortable enough to attempt the test, 2) pass the vehicle inspection, which involves proper use of equipment such as mirrors, turn signals, and seatbelts, 3) pass the closed loop test in a parking lot to demonstrate mastery of basic driving maneuvers, 4) pass the simple, low-traffic, residential drive involving two right and two left turns, and 5) pass the DMV-modeled course, which includes negotiating four right turns and one left turn, a lane change, pulling into a turn lane, one four-way stop with a turn, merging into heavier four-lane traffic, one three-way stop, and one speed limit change from higher to lower speeds. Professional driving instructors rate examinees' performance on a DMV 0-5 rating scale, where examinees receive one point for each level of the test passed. A score of 5 is required to pass (see Attachment 10, #2) Our Idea Development Award data demonstrated that different examiners used this scale differently: One used the entire five-point scale, while another rated subjects as 0, 4, or 5 only. This demonstrated both the advantage of the objective and automated VRDS tactical composite scoring method and the need to train examiners to a higher level of agreement. We will achieve the latter by having examiners view videos of driving performance in order to reach a 95% level of consensus regarding pass/fail performance.

3.5.3 Phase 1

In Phase 1, RT and VRDS-H participants will be encouraged to accumulate and record their behind-the-wheel experience required by the DMV, both for the DMV and for this study. The VRDS-H participants will complete 8-12 VRDS-H training sessions in two months. After these two months, both RT and VRDS-H participants will undergo assessment 2. This will be the same as assessment 1 except 1) the psychological measures will only include the SAD, and 2) following the VRDS element, participants will complete an on-road assessment with a certified and insured driving instructor who will be "blind" to the ASD drivers' training background.

3.5.3.1 VRDS-H

The Trainer's Manual in Attachment 10 details the session-by-session protocol developed during our Idea Development project. Training will be personalized, based on one's performance during baseline assessment. If the trainee has specific operational skill deficits, then practice of these deficits will be repeated until resolved. For example, if the trainee has difficulty effectively steering around potholes and/or dividing attention between cross-traffic and road obstacles, then these skills will be practiced until performance is within normal limits.

The same method would apply if eye tracking data showed that a trainee had difficulty "looking into a turn" or focusing eyes 20 feet ahead of the car. These skills would then be practiced with the aid of video playback of the eye tracking results. The type of feedback trainees receive will also be customized. If the trainee finds it beneficial to receive automated feedback concerning use of turn signals but irritating when working on lane position, then the automated feedback will be engaged for the use of turn signals and turned off for lane position training. There are eight driving skills modules to be mastered during training (lane position, turning, speed control, stopping, use of mirrors and turn signals, hazard detection, and negotiating traffic and intersections). The modules are self-paced, however experience demonstrates that some individuals are unable to master certain skills. If the trainee makes no progress in any one skill after three training sessions, training will be aborted and this will be considered a VRDS-H failure. Some trainees will drop out due to failure to progress, some will master all training elements in 8 sessions, and some will require more VRDS-H training, up to 12 sessions.

It must be pointed out that VRDS-H training is not expected to be comprehensive and complete. Instead, it is anticipated to be a significant adjunct to on-road training, both hastening and making safer the acquisition of an independent driver's license and the autonomy this represents.

VRDS training is based on principles of modeling, cognitive self-instruction, positive reinforcement, scaffolding, and shaping. Initially the trainer drives the simulator, talking to himself aloud as to what to look at and do, modeling for the trainee the driving maneuvers and self-instruction. Next, the trainee does the same, gradually making his/her self-instruction quieter until it is sub-vocal. After a successful completion of the intended goal, the trainer praises the trainee and encourages the trainee to praise him/herself. Then training focuses on the next challenging objective. Following the principles of shaping, the trainee is not expected to do all of these things immediately, but rather, after mastering one element of driving, a new, additional driving skill will be layered upon the first.

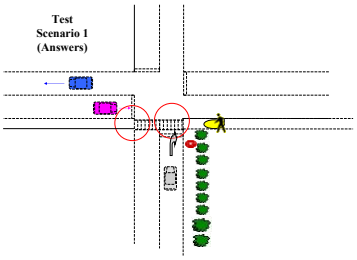
At the end of each training session, the trainer will rate the trainee's session performance using the following scale: 0= Did not grasp the concepts being trained, 1= understood what to do but could not execute the targeted skill, 2= demonstrated modest improvement in the targeted skill, 3= Demonstrated significant improvement in mastering the targeted skill and eventually mastered it, 4= Had no difficulty with the targeted skill at the outset, and quickly moved to the next skill. These performance ratings will be used as predictors of training outcome. If the trainee receives a rating of 0 or 1 on three consecutive sessions, VRDST-H will be discontinued.

VRDS-H training will follow this successful VRDS training model, but it will be enhanced in six ways:

1) The simulator hardware will be improved by making the turn signal analogous to a real car so that it will move in the direction pushed. In its current state, a strain gauge activates a turn signal when downward or upward pressure is applied to the turn signal shaft without the shaft moving.
2) The virtual environment software will be enhanced to improve generalized driving skills. This will be done by programming additional road segments, challenges, distractions, and hazards for the driver to interact with.
3) A modified version of automated feedback will be incorporated to improve training. The simulator will track driving performance in real time. When certain thresholds are exceeded, the simulator will inform the trainee (e.g. "Driving too fast" or "too slow" or "turned too wide"). This will address beta version issues with turn signal and lane position feedback. Feedback will also be personalized, activating only those feedback parameters that the trainee demonstrated difficulty with during assessment 1 and turning off any feedback parameters the trainee finds distracting. It will be further personalized by allowing the trainee to select the voice s/he find most appealing (male, female, or mechanical/non-human). This modification will address the common observation that those with ASD relate better to computer communication than human communication.

4) Eye position feedback will be utilized to customize training of difficulties identified in assessment 1. While we have not completed data collection on our eye tracking component, by the time this application would be funded, all data will be collected and analyzed, identifying the relative benefit of eye position feedback. Our current experience with novice ASD drivers indicates that our trainees face a wide range of challenges with regard to positioning their eyes. For example, some never look at the speedometer, side and rear-view mirrors, or relevant road signs. Others constantly check their speed at the expense of attending to the road, or they fixate too long on a passing sign. Still others look directly in front of the car rather than at an appropriate distance ahead of the car. Some will use the sidewalk as a reference point while making a turn, causing them to veer wide. An individual's specific gaze problems will be identified, and feedback on only those issues will be provided in VRDS-H.
5) Personalized "homework prescriptions" will be established to reinforce skills learned or to focus on difficulties identified in a particular training session. Currently we use stock homework exercises, but parents have told us that the feedback received at the end of the training session is much more informative. These will form the basis for "homework prescriptions".
6) Interactive hazard detection training will be deployed to aid individuals in better anticipating potentially hazardous situations. Our hazard detection training incorporates Risk Awareness and Perception Training (RAPT), developed by Dr. Donald Fisher at MIT. RAPT involves having the trainee look at static drawings of traffic scenarios and asking them to identify the potential hazards. Our consultant on this application, Miriam Monahan MS OTR/L CDRS CDI, is CEO of Drive Fit and she has taken advantage of new technology to develop an interactive application (app) designed for ASD novice drivers to view videos of unfolding driving events. The trainee views the dynamic image and touches the screen where a hazardous event is evolving, thus training them to better anticipate potentially hazardous situations. In addition, the app provides additional exercises that reinforce at home what is taught in our VRDS-H session, e.g. detection of road signage and traffic signals (see Figure 10).

Figure 10. **Example of RAPT static drawing**



Example of dynamic app video trainee interacts with

The user selects objects they consider critical in the sequence they think is most appropriate. Drive Fit then provides immediate feedback.

While we previously demonstrated that VRDS-T is effective in improving driving skills for both wounded warriors recovering from a TBI (Cox et al, 2010) and typical novice drivers (Cox et al, 2009), we anticipate that the proposed VRDS-H training, which is more sophisticated and personalized, will be even more efficacious and relevant to autism, including military families with ASD dependents.

3.5.4 Phase 2

The goal of Phase 2 is to compare drivers with ASD who did and didn't have VRDS-H training to non-ASD controls at a similar developmental point. We wish to see: 1) if VRDS-H "normalizes" driving skills by making them equivalent to controls, and 2) to see if RT ASD drivers "catch up" to those who received VRDS-H or if those receiving VRDS-H demonstrate a faster trajectory of developing driving skills between assessments 1 and 2. The "similar developmental period" is defined by readiness to receive an independent driver's license, as defined by minimal age, and by the amount of time possessing a learner's permit. In Virginia, Iowa, and California, the

minimal ages are 16.25 years, 16 years, and 15.5 years, respectively. The permit possession times are 9 months, 12 months and 6 months, respectively. If our participants with ASD have already achieved these milestones by the time they complete assessment 2, then assessment 3 will be scheduled two months after completing assessment 2. Assessment 3 will have the same psychometric and VRDS measures as assessment 2. However, it will not incorporate an on-road assessment, instead relying on the DMV test as an alternative. Using this DMV test for an independent license has three advantages: 1) it places legal responsibility for granting a license on the licensure agency, 2) DMV appointed examiners will not be involved or invested in this study and will be "blind" to treatment condition, i.e. they won't know whether the examinee received RT or VRDS-H training, 3) scheduling will rely on the ASD driver's personal confidence and anxiety level. Failure to schedule a DMV examination within a 1 month window of availability will be classified as a test failure.

Controls will be recruited through high schools providing driver's education and private driving instructors. ASD and control drivers will be matched in terms of gender, but not age, since our Idea Development study demonstrated ASD drivers pursuing an independent driver's license are significantly older. Like ASD drivers, control drivers will receive $100 for completion of this assessment and providing data on the status of their independent driver's license.

4 Data Analyses

This project will extensively explore multiple secondary hypotheses and findings. The data analysis plan for the primary hypotheses is as follows:

4.1 **Phase 1 Major** Hypothesis

Compared to the ASD RT (control) Group, the ASD VRDS-H group will demonstrate significantly better post assessment (2-month) performance in terms of (a) VRDS performance, (b) on-road driving performance and (c) less driving anxiety.

The major hypothesis will be tested by performing two 2(between) x 2(within) mixed repeated measures ANOVAs, for dependent variable (DV) measures (a) and (c). For (b), we will use multinomial logistic regression.

For the (a) VRDS performance measure, as focused on the tactical DQ, we expect an interaction effect of group(between) x time(within), such that the ASD VRDS-H group's performance change will be higher than the ASD RT (control) group's change.

For the (b) on-road driving performance measure, as measured by the 0-4 point scale, analyses will be performed with multinomial logistic regression, given the categorical nature of the outcome variable. The predictor variables will include a dummy-coded interaction term to determine whether the change is higher for the ASD + VRDS group.

For the (c) driving anxiety measure, as measured by the 20-item SAD scale, with each item scored 0-4 (minimum 0, maximum 80), a 2 x 2 Repeated Measures ANOVA will be used as with (a), with the expected change to be greater in the ASD VRDS-H group.

4.2 **Phase 2 Major Hypothesis**

At the time of potential licensure, compared to the ASD RT Group, the ASD VRDS-H group will be more likely to pass the DMV licensure test and secure an independent driver's license. Moreover, their pass rate will be equivalent to the Non-ASD Control Group.

For this hypothesis , a one-way ANOVA will be performed on the DV of Tactical DQ, with 3 groups (ASD RT, VRDS-H, Non-ASD Control), using contrast codes to reflect a specific comparison between the means of VRDS-H and Non-ASD Control).

For the DMV licensure test (pass/fail), a 2 x 3 chi-square test of independence will be performed, with the same 3 groups listed above, and a dichotomous outcome (pass/fail), to determine the relationship between study group membership and the proportion of persons passing or failing the DMV licensure test.

Power analyses were conducted on all procedures, and all results indicated that for all tests, power was at least 80%, and for some procedures, near 99%.

5 Dissemination

This study will produce a validated, standardized **ASD-relevant** assessment and training protocol, available to any driving professional and supported with an extensive training manual, relevant questionnaires, trainer and parent forms, and "train the trainer" workshops for interested professionals. To facilitate deployment of this technology, these workshops will be video recorded and made available on the internet. While these resources could be generalized to many different simulators, MBFARR LLC, who manufactures our VRDS and who has developed specialized software to support this study, is willing to make the VRDS and relevant software available to trainers at a cost of approximately $20,000.