RESEARCH ARTICLE

Social Attention in a Virtual Public Speaking Task in Higher Functioning Children With Autism

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Impairments in social attention play a major role in autism, but little is known about their role in development after preschool. In this study, a public speaking task was used to study social attention, its moderators, and its association with classroom learning in elementary and secondary students with higher functioning autism spectrum disorder (HFASD). Thirty-seven students with HFASD and 54 age- and intelligence quotient (IQ)-matched peers without symptoms of ASD were assessed in a virtual classroom public speaking paradigm. This paradigm assessed the ability to attend to nine avatar peers seated at a table, while simultaneously answering self-referenced questions. Students with HFASD looked less frequently to avatar peers in the classroom while talking. However, social attention was moderated in the HFASD sample such that students with lower IQ, and/or more symptoms of social anxiety, and/or more attention deficit/hyperactivity disorder inattentive symptoms, displayed more atypical social attention. Group differences were more pronounced when the classroom contained social avatars versus nonsocial targets. Moreover, measures of social attention rather than nonsocial attention were significantly associated with parent report and objective measures of learning in the classroom. The data in this study support the hypothesis of the Social Attention Model of ASD that social attention disturbance remains part of the school-aged phenotype of autism that is related to syndrome-specific problems in social learning. More research of this kind would likely contribute to advances in the understanding of the development of the spectrum of autism and educational intervention approaches for affected school-aged children. ***Autism Res*** *2013, 6: 393–410.*

Keywords: cognition and learning; school-aged development; social attention; individual differences

Introduction

The social attention theory of autism spectrum disorders [ASDs; Mundy, 1995, 2003; Mundy & Neal, 2000] suggests that the atypical developmental prioritization of attending to and processing information about other people impedes social learning and the development of language, social cognition, and social competence in affected individuals. Social attention theory began with attempts to explain the cause and impact of impairments in joint attention, or the predisposition to coordinate visual attention with others, in preschool children with ASD [Mundy, Sigman, Ungerer, & Sherman, 1986; Mundy, Sullivan, & Mastergeorge, 2009]. It became elaborated to include variants that focus on the possible role of social orienting, or an executive attention bias *away* from social stimuli, or *toward* nonsocial stimuli, in the development of ASD [e.g. Dawson, Meltzoff, Osterling, Rinalidi, & Brown, 1998; Klin, 1991; Klin, Jones, Schultz, Volkmar, & Cohen, 2002; Mundy, 1995], as well as the effects of atypical face processing [e.g. Pelphrey & Carter, 2008; Schultz, 2005].

Social attention theory, and especially research on joint attention, has led to advances in preschool diagnosis and intervention. Items that measure joint attention are included in many gold-standard screening and diagnostic instruments [e.g. Lord et al., 2000; Robins, Fein, Barton, & Green, 2001], and joint attention theory has also contributed to a more precise description of the early cognitive phenotype of autism and its relation to social learning [Charman, 2003; Mundy et al., 2009]. Perhaps most importantly, joint attention research has contributed to advances in more effective and targeted behavioral interventions for preschool children [e.g. Kasari et al., 2006, Kasari, Paparella, Freeman, & Jahromi, 2008]. In contrast, there have been relatively few programmatic attempts to translate social attention theory and research to improving the understanding of the expression of the

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cognitive phenotype of autism in school-aged children, or to advancing interventions for affected school-aged children [Mundy, Mastergeorge, & McIntyre, 2012].

Contemporary social attention studies of older children with ASD often employ rigorous paradigms that emphasize analogs of preschool social attention measures that examine attention as allocated to representations of a single person, their face, or their direction of gaze [Ames & Fletcher-Watson, 2010; Freeth, Chapman, Ropar, & Mitchell, 2010]. These paradigms may provide very important information, yet they may not emulate the types of real-life demands of social attention deployment that children must master in the course of adaptive social development [Fletcher-Watson, Leeham, Benson, Frank & Findlay, 2009]. Hence, they may not be optimally sensitive to important facets of attention development in elementary and secondary school children. The relative paucity of the application of social attention theory in school-aged research is unfortunate because frontal plasticity in the 8–18 year period suggests that the school-aged phase of development, and especially adolescence, may be an essential period of social-cognitive phenotype change in ASD and a critical window of opportunity for intervention for affected children [Blakemore & Choudhury, 2006; Luna, Doll, Hegedus, Minshew, & Sweeney, 2007].

The Parallel Processing Hypothesis of Joint Attention

An alternative research strategy to using tasks analogous to preschool measure is to use tasks that theory suggests should be sensitive to development or impairment in social attention in school-aged children with ASD. For example, one version of social attention theory suggests that the elements of social attention that are most vulnerable in ASD are those that involve the simultaneous or parallel processing of attention to self and others [Mundy & Jarrold, 2010; Mundy et al., 2009]. This assertion stems from the hypothesis that the development of joint attention in young children requires children to become facile with processing information about their own attention (self-referenced attention), while also processing information gleaned from attention to another person (other referenced attention), and information about a common referent such as an object, event, or mental representation [Mundy et al., 2009]. Joint attention theory also posits that the ability to manage the simultaneous or parallel processing and integration of information about oneself and another person makes a significant contribution to the capacity for social information sharing and social learning [Mundy, 2013; Mundy et al., 2009]. The assumption here is that social learning often requires the ability to adopt a common point of view, or point of references with others. This common point of reference can either be in the real world or a mental (cognitively represented) common point of reference. In either case, adopting a common point of reference involves the parallel monitoring one's own attention (point of view), and someone else's attention (point of view), and information about the common referent [Mundy et al., 2009, 2012].

This theory led us to consider public speaking as a means to examine social attention development as it may be related to learning in school-aged children with higher functioning ASD (HFASD). Public speaking is characterized by demands that are similar to those hypothesized for preschool joint attention. Public speaking is a complex behavior that involves the multiple parallel demands of self-monitoring one's own thoughts and speech, while attending to various members of an audience. Managing the parallel task demands of public speaking is effortful and mastered incrementally across the school-aged period [Im-Bolter, Johnson, & Pascual-Leone, 2006; Sumpter, Bokhorst, Miers, van Pelt, & Westenberg, 2010; van West, Claes, & Beboutte, 2009].

An additional advantage of public speaking tasks may be their ecological validity for the study of attention in school-aged children with HFASD. Practice with public speaking becomes increasingly common across elementary and secondary grades. However, by secondary school, 51% of students with HFASD in general education classes rarely or never present material in front of their classmates compared with 32% of other students in their classes [Newman, 2007]. The factors that give rise to this difference are not yet clear, but it may be that difficulty with public speaking tasks can provide a means to measure the difficulty that older students with ASD may have in the parallel demands of regulating social attention while engaged in speaking or interacting with others in the classroom. Joint attention theory would suggest that a measure of the ease or difficulty students with ASD have with the parallel management of attention to self and others while talking may be revealing regarding factors that may facilitate or impede social learning in school-aged children with ASD [Mundy et al., 2012]. This hypothesis is important to pursue because more than 50% of children with HFASD appear to display learning difficulties and underachieve academically relative to their intelligence quotients (IQs) [Ashburner, Ziviani, & Rodger, 2010; Estes, Rivera, Bryan, Cali, & Dawson, 2011; Mayes & Calhoun, 2008].

Social Attention Measurement in Children With HFASD and Individual Differences

To begin to address some of these issues, the first author adapted a virtual reality (VR) public speaking paradigm

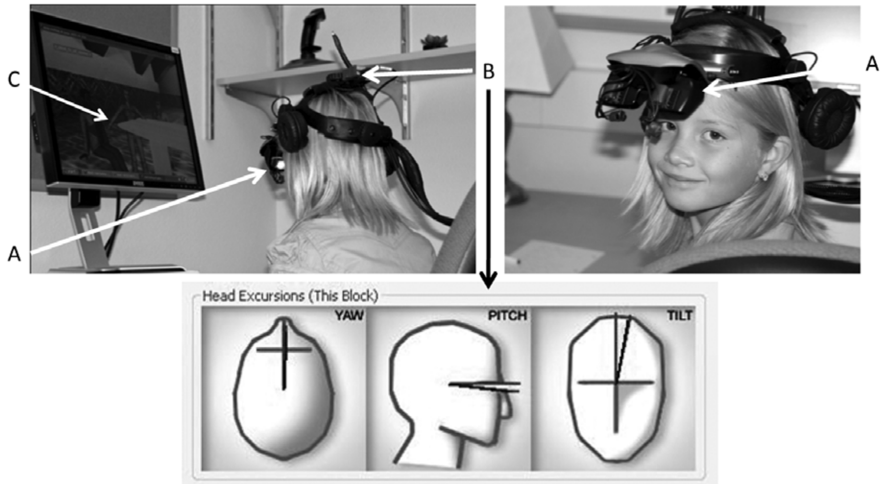

Figure 1. An 11 year old watches a virtual reality (VR) presentation (upper left) and displays head-mounted display (HMD) with video monitors in "flip up" position (upper right). (**A**) The video monitors in the HMD. (**B**) The head position monitor that provides precise information on direction of gaze in the virtual visual field based on three dimensions of head position (left/right yaw, up-down pitch, and tilt). (**C**) Video monitor displays VR imagery for tester working with participants.

developed by Bailenson et al. [2008]. VR technology was employed because the development of paradigms involving the participation of children with ASD with multiple social partners in real-life contexts, such as classrooms or peer groups, can be difficult to standardize across groups of children, problematic to implement in large samples, and challenging to translate across independent research groups for replication. Maintaining participant confidentiality can also be challenging in such contexts. Alternatively, VR paradigms provide measurement and intervention platforms in 3D that can validly emulate complex social interaction and social learning contexts while providing scientifically rigorous options in the quantitative study of children with neurodevelopmental disorders, including children with ASDs [Kandalaft, Didehbana, Krawczyk, Allen, & Chapman, 2013; Matheis et al., 2007; Mitchell, Parsons, & Leonard, 2007; Moore, Cheng, McGrath, & Powell, 2005; Parsons, Bowerly, Buckwalter, & Rizzo, 2006; Picard, 2009; Rizzo et al., 2006; Schwartz, Bente, Gawronski, Schilbach, & Vogeley, 2010]. The "Bailenson" VR task measured the degree to which participants visually attended to each of nine avatar "peers" in a 3D virtual classroom while answering concrete questions about themselves (Figs. 1 and 2).

Regardless of the task that is used, it is critical to research on attention in children with HFASD to employ designs that anticipate and attempt to explain heterogeneity in response patterns among children with HFASD [Mundy & Newell, 2007; Fletcher-Watson et al., 2009]. Our review of the literature suggested the need to consider at least four potential response moderators. Age was included because adolescents with ASD may display evidence of developmental impairments in social attention and complex social information processing that are not observed in preadolescent samples [Luna, et al., 2007; O'Hearn, Schroer, Minshew, & Luna, 2010]. IQ was an expected moderator because of its prior association with differences in information processing in children with and without developmental disorders [Kail, 2000]. Attention deficit/hyperactivity disorder (ADHD) symptom ratings were included because children with HFASD may express symptoms of ADHD, and these are associated with differences in their cognitive performance, academic achievement, and social information processing [Ashburner et al., 2010; Lee & Ousley, 2006; Sinzig, Walter, & Doepfner, 2009; Yerys et al., 2009]. Finally, social anxiety was a hypothetical moderator because of previous evidence of its effects on individual differences in public speaking [Anderson, Zimand, Hodges, & Rothbaum, 2005; Cornwell et al., 2006; Davidson, Marshall, Tomarken, & Henriques, 2000; Sumpter et al., 2010].

Research Hypotheses

The *first hypothesis* was that HFASD would look less frequently to social avatars compared with age- and IQ-matched children with typical development (TD). Because previous research has only revealed modest evidence of social attention impairments in school-aged HFASD students, an examination of the sensitivity and specificity of group differences in attention was included in the planned analyses related to this hypothesis.

The *second hypothesis* was that there would be significant heterogeneity in the social attention performance of

Figure 2. (**A**) A view of the virtual classroom and peers (avatars) from the midline avatar in the left foreground to the extreme right-hand avatar. The field of vision included at most three avatars in the foreground at any one time. Children had to turn approximately 60 degrees from midline to view the extreme right-hand avatar. (**B**) The view of the virtual reality (VR) classroom from the extreme left avatar peer back to central avatar peer. (**C**) Example of solid and faded avatar peers in the cued condition.

school-aged children with HFASD with older age, lower IQ, more ADHD inattentive symptoms, and more social anxiety symptoms associated with greater evidence of HFASD social attention impairments.

The *third hypothesis* was that impairments among ASD students may be more pronounced in a social public speaking task than in an analogous nonsocial task. This followed from social attention theory and previous evidence of more robust attention impairments on task involving attention to social compared with nonsocial stimuli [e.g. Dawson et al., 1998; Elison, Sasson, Turner-Brown, Dichter, & Bodfish, 2012; Klin, 1991].

The theoretical links as well as empirical links between social attention and learning in ASD [see Kasari et al., 2006, 2008] lead to the *fourth hypothesis* that social attention would be significantly related to measures of learning problems and academic achievement in children with HFASD that would not be mediated by variance associated with nonsocial attention, measures of inattentiveness, or IQ.

Methods

Participants

The human subjects research protocol for this research was reviewed and approved by the University Internal Review Board. Thirty-seven children with a diagnosis of HFASD and 54 typically developing controls were recruited via the Subject Tracking System of the UC Davis M.I.N.D. Institute. The groups were matched on IQ and age, with equal numbers of participants in two age groups, 8–11 years olds and 12–16 years olds (see Table 1). All children in the HFASD group met symptom criteria for ASD at the time of data collection on three convergent diagnostic criteria: the Autism Spectrum Screening Questionnaire [ASSQ; Ehlers, Gillberg, & Wing, 1999; Posserud, Lundervold, & Gillberg, 2006], the Social Communication Questionnaire—Lifetime Form [SCQ, Berument, Rutter, Lord, Pickles, & Bailey, 1999; Corsello, Hus, Pickles, Risi, & Lord, 2007], and the Social Responsiveness Scale [SRS, Constantino, 2004]. Parent report measures of ASD symptoms, rather direct observation measures, were used because the protocol of this study consisted of two 2.5-hr data collection sessions for each participant. The additional time required for a symptom observation measure was not considered to be necessary given the excellent population-based sensitivity of the ASSQ for screening for HFASD [Posserud et al., 2006], especially when used with convergent data from the SCQ and SRS, which assess behavior domains that differ from those on the ASSQ. Children in either diagnostic group were excluded if there was parent report of an identified syndrome other than autism, a significant sensory or motor impairment, a neurological disorder, psychotic symptoms, or a full-scale IQ of less than 71.

To compare whether responses to nonsocial targets would be as sensitive to diagnostic differences, a subset of 25 of 37 students with HFASD and 33 students of the 54 students with TD from the sample were also assessed

Table 1. Descriptive Mean Statistics for the Diagnostic Groups With Standard Deviations in Parentheses and Significant Diagnostic Interaction Effects Noted

	Higher functioning ASD N = 37		Control sample N = 54	
Variables	8–11 years (N = 18)	12–16 years (N = 19)	8–11 years (N = 24)	12–16 years (N = 30)
Age	9.65 (1.0)	14.16 (1.5)	9.66 (1.1)	13.84 (1.3)
VIQ	107.5 (21.3)	113.8 (17.4)	117.9 (16.1)	118.7 (18.2)
PIQ	104.5 (16.3)*	103.9 (13.7)	115.4 (13.6)	106.3 (16.2)
Full-scale IQ	106.2 (18.3)*	109.9 (14.8)	118.5 (15.1)	113.8 (17.6)
SCQ	22.7 (6.9)**	18.7 (6.0)***	4.4 (5.4)	3.8 (5.0)
ASSQ	30.3 (7.6)**	30.9 (7.4)***	2.8 (4.3)	3.0 (4.2)
SRS	94.9 (24.9)**	92.6 (14.4)***	47.7 (14.3)	46.6 (8.5)
ADHD inattention	78.6 (9.7)**	78.4 (10.1)***	52.6 (12.9)	51.7 (13.1)
Social anxiety	58.6 (12.9)	60.3 (8.5)	53.3 (9.9)	51.4 (9.4)

*$P < 0.05$; **$P < 0.01$; ***$P < .001$; significant difference (*t*-test) for diagnostic group across the younger *or* older subsamples. Attention deficit/hyperactivity disorder (ADHD) was measured with Conners ADHD Total T-Scores. Anxiety was measured with Multidimensional Anxiety Scale for Children (MASC) Social Anxiety Scale T-Scores.

ASD, autism spectrum disorder; ASSQ, Autism Spectrum Screening Questionnaire; IQ, intelligence quotient; PIQ, WASI Performance IQ; SCQ, Social Communication Questionnaire; SRS, Social Responsiveness Scale; VIQ, WASI Verbal IQ; WASI, Wechsler Abbreviated Scale of Intelligence.

on a nonsocial analog of the VR public speaking task (Fig. 1D). These subsamples were recruited on the basis of families' availability and willingness to return to the laboratory for the additional assessment. They were comparable in age, HFASD = 11.7 years (2.8), TD = 11.6 years (2.3); and full-scale IQ, HFASD = 109.5 (16.6), TD 113.6 (12.1).

Measures of Autism Symptoms

SCQ. The SCQ—Lifetime Version [e.g. Berument et al., 1999] is a 40-item parent report screener for ASD in children 4 years and older. Validity analyses indicate the SCQ scores correspond with those from the Autism Diagnostic Interview [Rutter, Bailey, Lord, & Berument, 2003] and that a criterion score of 15 has adequate sensitivity and specificity for use in a study of 8–16-year-old children with IQ > 70 [Corsello et al., 2007].

ASSQ. The high-functioning ASSQ [Ehlers et al., 1999] is a 27-item checklist screener with diagnostic validity for identifying HFASD and one of the few measures with validity for discriminating children with HFASD from those with ADHD [Ehlers et al., 1999; Kadesjo, Gillberg, & Hagberg, 1999]. A study of 9,564 children suggests a criterion score of 19 for ASD that was used in this study [Posserud et al., 2006].

SRS. The SRS [Constantino, 2004] is a 65-item, quantitative parent report index of social behaviors in children with autism or TD that is sensitive to both developmental change and genetic factors. The recommended T-score > 75 for maximum sensitivity and specificity in confirming the presence of ASD was used in this study.

Measurement of Intelligence

Wechsler Abbreviated Scale of Intelligence (WASI). Full-scale, verbal and performance IQ scores were obtained via the Wechsler Abbreviated Scale of Intelligence [WASI; Wechsler, 1999]. It consists of four subtests: vocabulary similarities, block design, and matrix reasoning. The full-scale IQ index has established internal consistency (0.98) and test–retest reliability (0.92).

Measurement of ADHD, Learning Problems, and Social Anxiety

The *Conners-3* [Conners, 2004, 2010] provided parent report of ADHD symptoms for students in this study. It was standardized on 1,373 parents of typical children, as well as 525 parents of a clinical sample of children. The Diagnostic and Statistical Manual IV (DSM-IV) Inattentive Scale T-scores were the primary measure of ADHD symptoms of relevance to this study. Inattentive scale scores were interpreted as evidence of individual differences in symptom presentation, but were not and could not be interpreted as indicative of a clinical diagnosis of ADHD inattentive subtype in participants in this study. In addition, the nine-item Conners-3 Learning Problems scale provided parent observation data on the spelling, reading, math, and concept learning difficulties of the participants.

The Multidimensional Anxiety Scale for Children [MASC; March, James, Sullivan, Stallings, & Conners, 1997] was used to gather participant self-report data on social anxiety. The MASC is a 39-item assessment of anxiety for children between the ages of 8 and 19 years. It provides standardized scale T-scores for *physical symptoms*, *harm avoidance*, and *social anxiety*. The latter was used in data analyses in this study. The MASC has been standardized on a sample of 2,698 children and adolescents without neurodevelopmental disorders, but has previously established validity as an outcome measure for anxiety treatment in with school-aged children with HFASD [Bellini, 2004, 2006; Wood et al., 2009]. MASC Anxiety Scale scores were interpreted as evidence of individual differences in symptom presentation, but were not and could not be interpreted as indicative of a clinical diagnosis of an anxiety disorder in participants in this study.

Social Attention Measurement

The virtual social attention, public speaking task was delivered via an eMagin Z800 3DVisor (eMagin Corporation, Bellevue, WA, USA) head-mounted display (HMD) with two 1.8-inch monitors that displayed stereoscopic images to the left and right eyes (Fig. 1). Head orientation and rotational motion along three rotational axes were dynamically tracked via an InterSense InertiaCube2-US/JP sensor (180 Hz update rate; InterSense, Billerica, MA, USA) positioned on top of the HMD. The sensor dynamically measured head orientation via piezoelectric, piezoresistive, and capacitive components along three axes: Y*aw*, or left-right head rotations referenced to the horizontal plane; *Pitch*, or up-down head shifts referenced to the coronal plane; and *Roll*, left-right "ear-to-shoulder" head shifts referenced to the sagittal plane (Fig. 1). WORLD VIZ *Vizard* software (WORLD VIZ, Santa Barbara, CA, USA) was used to render a virtual 360-degree virtual classroom delivered to the participant via the HMD.

The 3D virtual classroom contained one table in the foreground and one in the background. Seven virtual students (avatars) were seated at the foreground table, and two were seated at the background table (Fig. 2). To enhance participant sense of immersion into a life-like classroom, the virtual student avatars were programmed to exhibited subtle eyeblink and head motions typical of an audience of peers. The participants' stereoscopic field of view held no more than five avatars at any one time. Participants needed to turn their heads 60 degrees left or right of midline to bring the leftmost or rightmost avatars into view.

A researcher was seated behind the participants and acted as a "teacher" introducing the participant to students in the virtual classroom. A 90-sec warm-up period was provided such that the researcher instructed each participant to "Please get used to the classroom. Look around just like you would in any classroom in a new school." The researcher also instructed participants to practice looking at each avatar-student in the classroom. Participants were prompted to turn their heads 60 degrees from midline to view the leftmost and rightmost avatars.

Following the baseline warm-up, two 180-sec test conditions were presented. In the *non-cued condition* participants were asked to introduce themselves to the avatar students in the VR classroom by answering questions. The questions were concrete, factual, self-referenced questions concerning topics such as the participants' typical daily routines, favorite foods, pets in the family, etc. The researcher seated behind the participant read each question from a list of 40 questions (see Appendix S1). Before and after the first question, the researcher reminded the participants to answer the questions "*while looking at all of the people in the room*." Participants were asked to elaborate very brief answers to maintain relatively continuous and comparable verbal response rates across groups during each 3-min trial.

A *cued condition* was also presented to examine the effects of modifying task difficulty. The procedures were identical to those in the non-cued condition except that each avatar student was programmed to fade over the course of 6 sec to 70% transparency if the participant did not look at it to prompt fixation (Fig. 2B). The avatars became opaque again once fixated by the participant. We assumed that cued trials would prompt children to follow the task demands and increase their looking to avatars while speaking. Cued and non-cued trials were presented in counterbalance order across participants. A brief period of practice was presented before cued trials to familiarize participants with the effect of looking at fading avatar students.

To calibrate individual head position measurements, participants were instructed to position their head in such a way as to fixate a central point in the virtual classroom after putting on the HMD. Their corresponding line of visual regard was recorded based on software computation of an invisible line that was perpendicular to the midpoint between the eyes of the participant (i.e. head orientation vector) and projected to the central fixation point in the virtual space of the VR classroom. This computational reference enabled the software to track participants' line of regard in the virtual space more than 1,000 times per second. The software was also programmed to project an invisible sphere around each avatar's head in the VR classroom. A look event (avatar fixation) and duration was recorded any time the participant's head orientation vector and line of visual regard intersected the invisible sphere around the head of an avatar for at least 100 msec. Reports from adult pilot participants and children who participated in this study indicated that directing the computer-based head orientation vector to intersect an avatar's head corresponded to the participants' subjective perception of intentionally looking at the face of the avatars. This was also verified by evidence that all participants could intentionally fixate the face of avatars and return them to opaque status in the cued condition.

The VR software was designed to record the start and end times, as well as the reference point of each look event in the space of the virtual classroom. Two measures of attention were computed from this information. These included a measure of *orienting*, or the total number of looks to each individual avatar, and a measure of *fixation length*, or the average duration of fixations to any individual avatar. To consider possible effects of differences in verbal behavior among participants, the *total number of words* used by participants in the test trials was also recorded.

Nonsocial Attention Measure

A second version of the virtual public speaking paradigm was developed that presented participants with nine 3D nonsocial targets situated around a classroom table instead of avatar peers (Fig. 2C). The procedures were exactly the same as in the social public speaking task except the task directions instructed participants to direct their attention to "targets" at the table rather than peers at the table. Cued and non-cued conditions were presented.

Academic Achievement and Learning

Differences among the children in learning were measured with the Wechsler Individualized Achievement Test [WIAT-III; Breaux & Frey, 2010]. The WIAT-III is standardized for children from 4.5 years to 18 years and provided standardized scores of reading comprehension and math problem solving. Internal consistency for the ages/grades of students in this study exceeded 0.71 for all scales and 0.69 for test–retest reliability [Breaux & Frey, 2010]. Previous research indicates that WIAT is also valid in studies of students with HFASD [Mayes & Calhoun, 2008]. In addition, parent report on the Conners-3 was used to provide a standardized observation index of children's learning problems in school. T-scores on this nine-item scale reflect appraisals of poor spelling, poor reading comprehension, poor fact memory, forgets things learned, needs extra explanations, does not get the big picture, reads slowly, and poor math concepts.

Results

Preliminary Analyses

The data on the number of looks directed to each of the nine individual avatars were reduced to five scores, which maintained information about the participants' distribution of attention across avatar positions (see Fig. 2). These five *orienting* variables were: (a) total looks to the center avatar (center looks), (b) the average of the looks to the two avatars to the left and right behind the center avatar (behind looks), and the average of the looks to the two avatars that were, (c) immediately left and right of the center avatar (first position looks), (d) two positions to the left and right of the center avatar (second position looks), or (e) three positions to the left and right of the center avatar (third position looks, see Fig. 2). The average duration of looks to each position were also computed to yield five corresponding *fixation length* variables.

Intraclass correlations for these five *orienting* measures computed across the baseline, non-cued and cued conditions for the diagnostic groups in the social task were 0.71–0.76 HFASD and 0.81–0.88 TD groups, respectively (Ps < 0.001). Less evidence of internal consistency was observed for the five average duration *fixation length* measures in the social task; 0.45–0.46 HFASD $P < 0.01$, and especially in the TD sample, 0.28–0.56 ($P < 0.06$–0.001). Subsequent analyses also revealed very few meaningful group differences on the fixation length measures. Therefore, only the results for the frequency of fixation data (orienting) are described in this report.

There were no diagnostic group differences in average word count in the VR paradigm for either the social targets, HFASD = 222.47 (standard deviation [SD] = 51.63), TD = 236.64 (60.90) words, F (1, 75) = 0.83, $P < 0.95$, or the nonsocial targets, HFASD = 216.74 (61.2) and TD = 247.45 (75.9), F (1, 55) = 2.62, $P < 0.20$. Individual differences in word count were consistent across cued and non-cued conditions in the HFASD and TD groups, 0.92 and 0.81, respectively (Ps < 0.001). Correlation analyses also revealed no significant associations between any of the social attention measures and word count in either diagnostic group. Therefore, data on word count were not considered further in this report.

Regardless of stimulus type (social or nonsocial), both the HFASD and TD children displayed a higher average frequency of orienting to all avatars in the cued condition, mean = 18.86 (6.2), versus the non-cued condition, mean = 10.7 (8.4), $F = 7.88$, $P < 0.006$, eta^2 = 0.10. However, no significant interactions involving the cued condition with diagnostic group or diagnostic group and avatar position or moderator variables were observed. Therefore, cued condition was not considered further in this report.

Because group-based matching failed to equate the diagnostic groups on IQ, the WASI Full-Scale IQ Index was used as a covariate in all group comparisons. In addition, possible moderator effects of IQ were examined with IQ groups split on the median full-scale IQ at 107, with 15 (46%) and 17 (32%) in the lower IQ subgroup in HFASD and TD sample, respectively. Age groups were also created with a median split at 11.5 years (preadolescent vs. adolescent), which resulted in 18 (48.7%) and 28 (51.8%) students in the older HFASD and TD subgroups, respectively.

The difference between the samples on ADHD symptoms (Table 1) in this sample was such that 30 of 37

Table 2. Effects of Diagnostic Group, Social Anxiety, and Age on Social Orienting and Attention Disengagement to the Five Avatar Position in the Baseline Condition

	Avatar position				
Group	Center	Behind	First	Second	Third
Social orienting					
HFASD low SA	12.8 (9.4)	7.9 (4.3)	4.9 (2.1)	3.0 (1.6)	1.2 (0.8)
TD low SA	10.9 (5.9)	6.4 (4.2)	4.6 (3.0)	3.5 (1.9)	1.3 (1.1)
HFASD high SA	8.5 (4.1)	5.6 (3.5)	4.9 (3.4)	2.9 (2.3)	1.1 (1.3)
TD high SA	10.3 (6.8)	7.0 (5.3)	5.6 (3.0)	3.5 (2.5)	1.3 (0.9)
Attention disengagement					
Younger age group					
HFASD low SA	1.4 (0.8)	0.4 (0.5)	2.2 (0.9)	1.3 (0.4)	1.1 (1.0)
TD low SA	1.2 (0.8)	0.6 (0.4)	2.7 (1.6)	1.7 (1.4)	0.9 (1.0)
HFASD high SA	0.9 (1.1)	0.7 (0.9)	3.2 (3.1)	1.6 (1.6)	0.9 (1.1)
TD high SA	0.9 (1.0)	0.5 (0.2)	3.3 (1.6)	1.3 (1.0)	1.2 (0.8)
Older age group					
HFASD low SA	1.3 (0.7)	0.8 (0.8)	3.7 (1.5)	2.3 (1.2)	0.6 (0.5)
TD low SA	1.6 (0.9)	0.7 (0.5)	3.0 (2.5)	2.3 (1.6)	1.2 (1.0)
HFASD high SA	3.3 (3.1)	0.6 (0.3)	3.4 (1.1)	2.4 (1.5)	0.7 (0.6)
TD high SA	1.7 (1.2)	1.0 (0.8)	2.9 (2.1)	2.1 (1.4)	0.9 (0.8)

Note. Marginal means with full-scale IQ as the covariate. Social orienting = the number of avatar fixations. Attention disengagement = the average duration of stimulus fixation in seconds.

ASD, autism spectrum disorder; HFASD, higher functioning ASD; SA, social anxiety; TD, typical development.

children in the HFASD sample exceeded a T-score of 69 on the Conners Inattentive ADHD Total Score (82%), while only five participants in the TD sample (8.9%) exceeded this T-score, Fisher's exact test = 37.3, $P < 0.001$. Thus, as in other studies [Lee & Ousley, 2006], ADHD symptom presentation was nearly isomorphic with ASD symptom presentation in this sample of HFASD children. Consequently, ADHD symptoms could not be used as covariate or as a moderating variable that was comparable across diagnostic groups. Therefore, the possible moderating effect of ADHD symptoms on social attention was examined in separate analyses within the HFASD group.

Alternatively, the HFASD and TD samples could be separated into comparable subgroups on a median split of MASC Social Anxiety at T-score > 55, with 21 (58%) and 22 (41%) of HFASD and TD participants in the higher social anxiety subgroups, respectively (chi-square = 3.32 $P < 0.07$). The correlations between self-reported social anxiety on the MASC and parent reports of disturbance on the SRS Social Motivation and Conners Peer Relations Scales were comparable across the HFASD sample, r = 0.47, $P < 0.004$ and r = 0.32, $P < 0.055$, respectively, and the TD sample, r = 0.30, $P < 0.03$ and r = 0.38, $P < 0.004$, respectively. These observations supported the assumption of comparable construct validity of individual differences in self-report on the MASC Social Anxiety Scale across the diagnostic groups.

Social Attention: Baseline Condition

To determine if the diagnostic groups differed on social attention in the VR task without the task demand of speaking, a 2 (diagnostic group) × 2 (age group) × 2 (IQ group) × 2 (social anxiety group) between factors, and five repeated measures (avatar position) within mixed analysis of variance (ANOVA) on *social orienting* measures was conducted for the baseline data, with full-scale IQ as covariate. The Greenhouse–Geisser test was used because a significant sphericity effect (differences in variances) was detected for the repeated measures, Mauchly's $w = 0.056$, chi-square = 209, $P < 0.001$. The analysis revealed no main effects or interactions involving diagnostic group (see Table 2). There was a significant social anxiety group by avatar position, $F\ (1,\ 74) = 7.82$, $P < 0.007$, eta^2 = 0.10, such that, regardless of group, participants with higher self-reported social anxiety looked less frequently at the center avatar.

Hypothesis 1: Social orienting to avatars in the public speaking task. To examine the first hypothesis that the dual task public speaking paradigm would be sensitive to robust social attention impairments in HFASD students, a mixed analysis of covariance was computed. This included four between group factors, 2 (diagnostic group) × 2 (age group) × 2 (IQ groups) × 2 (social anxiety group) and one within factor, five (avatar position), with IQ as a covariate. The Greenhouse–Geisser test was again used because of the violation of sphericity for the avatar position data. To mitigate experiment-wise type 1 error, alpha was set to 0.01 for the primary analyses of main diagnostic group effects and interactions involving diagnostic group. Follow-up between groups or within-group analyses were conducted with alpha set at 0.05 to mitigate type II error.

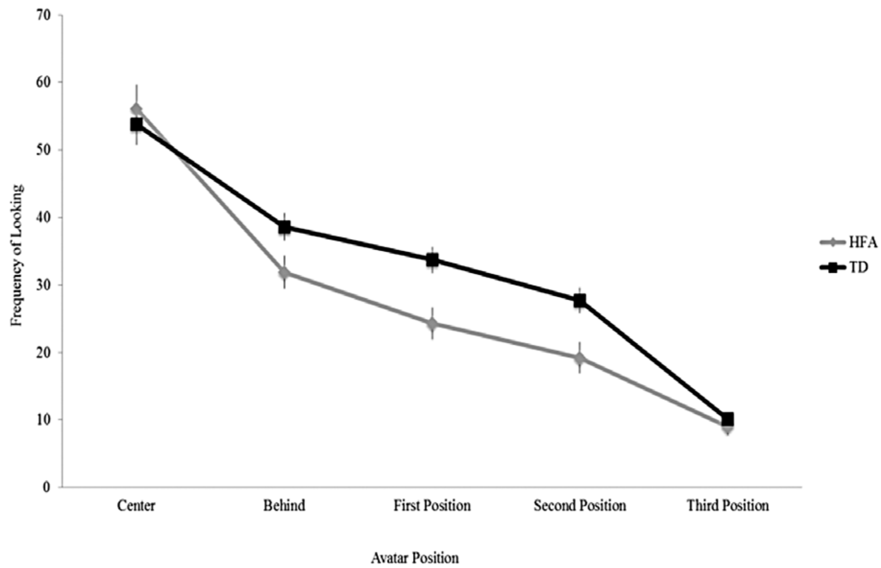

Figure 3. The comparative frequency of looks to avatar positions by the higher functioning autism spectrum disorder (HFASD) and typical development (TD) groups.

The analyses also revealed a significant effect for avatar position, $F(1, 74) = 11.35$, $P < 0.001$, eta$^2 = 0.13$, and a significant diagnostic group × avatar position quadratic interaction, $F(1, 74) = 9.96$, $P < 0.002$, eta$^2 = 0.12$ (Fig. 3). Both groups displayed a monotonic decrease in looks to avatars with distance from the center avatar, and the HFASD students displayed significantly less frequent looks to the first avatar position and second avatar position, $F(1, 74) = 6.71$, $P < 0.012$, eta$^2 = 0.08$, and $F(1, 74) = 5.80$, $P < 0.018$, eta$^2 = 0.07$, than did the TD group, respectively.

A follow-up discriminant analysis characterized the extent to which the diagnostic groups differed on orienting to the social targets in this task. The data on the frequency of looks to the five avatars position correctly identified 28 of 37 HFASD students (76% sensitivity) and 40 out of 54 TD students (74% specificity), chi-square = 26.0, $P < 0.004$. Thus, the VR public speaking task was sensitive to differences in attention that were characteristic of most but not all of the HFASD children.

Hypothesis 2: Heterogeneity in ASD and the moderators of social attention. The results from the foregoing analyses also addressed the hypothesis that there would be significant heterogeneity in the social attention of HFASD children that could be partially explained in terms of the moderating effects of IQ, social anxiety, and ADHD symptoms. The results revealed a significant diagnostic group × social anxiety group × IQ group × avatar position interaction, $F(1, 74) = 15.71$, $P < 0.001$, eta$^2 = 0.18$ (see Table 3). A quadratic diagnostic group × IQ group interaction was observed in follow-up analyses of the *lower social anxiety subgroups*, $F(1, 43) = 5.86$, $P < 0.02$, eta$^2 = 0.12$. There was no evidence of a diagnostic group effects at any avatar position in the follow-up comparison of children *with lower social anxiety and lower IQ* (Table 3). Alternatively, there was modest evidence of diagnostic group differences in higher IQ, but lower social anxiety subgroup, where the ASD sample displayed less frequent looks to the second position avatar ($P < 0.04$) than the comparable TD children (Table 2).

The analyses of participants in the higher social anxiety subgroups revealed a cubic diagnostic group × social anxiety interaction, $F(1, 30) = 9.17$, $P < 0.005$, eta$^2 = 0.23$. A robust diagnostic group difference appeared in the comparisons of the *lower IQ but higher social anxiety* children where the HFASD group looked less to all avatars except for the third position avatar than did the TD group (all Ps < 0.025, Table 3). Alternatively, the effect for diagnostic group in the higher IQ and higher social anxiety subgroup was limited to the first avatar position ($P < 0.05$, Table 3).

The effects associated with ADHD inattentive symptoms were examined in analyses of *only the HFASD sample*, which was split into a higher (T-score > 69, $N = 26$) and lower ($N = 11$) symptom subgroups based on the clinical relevance of T-scores that two or more SDs above average. Inattentive scores were used because of the face validity for studies of attention in ASD and because the total Conners ADHD scores led to a small cell ($N = 7$) with a T-score below 70. The results of a 2 (ADHD inattentive group) × 2 (social anxiety group) × 2 (IQ group) × 2 (age group) × 5 (avatar position) ANOVA revealed an interaction of social anxiety group, Conners inattentive group and avatar position, $F(1, 22) = 6.84$, $P < 0.01$, eta$^2 = 0.11$. In the *higher social anxiety subgroup*, HFASD students who

Table 3. Data Illustrating the Interaction of Diagnostic Group, IQ Group and Social Anxiety Group on Social Orienting Collapsed Across Cue Conditions in the Social Virtual Public Speaking Task

	Avatar position				
Subgroup	Center	Behind	First	Second	Third
Lower social anxiety					
Lower IQ HFASD	72.7 (31.6)	35.8 (14.2)	25.4 (10.8)	21.4 (12.8)	10.9 (7.4)
Lower IQ TD	49.7 (19.4)	33.3 (11.7)	27.1 (13.5)	21. 8(12.8)	6.4 (4.7)
Higher IQ HFASD	50.7 (18.8)	39.4 (11.3)	32.5 (12.3)	23.0 (16.0)**	11.9 (8.6)
Higher IQ TD	55.8 (12.9)	40.0 (14.1)	35.5 (12.3)	30.0 (12.4)	11.6 (7.0)
Higher social anxiety					
Lower IQ HFASD	36.4 (14.5)**	24.2 (10.3)**	16.2 (11.9)**	10.3 (9.1)**	3.3 (4.0)
Lower IQ TD	53.2 (17.2)	39.2 (21.5)	37.9 (21.4)	31.3 (18.0)	9.1 (5.8)
Higher IQ HFASD	60.4 (27.0)	29.9 (14.7)*	24.7 (15.1)**	22.1 (18.9)	10.2 (9.9)
Higher IQ TD	52.7 (24.9)	39.2 (18.6)	33.8 (16.3)	26.0 (12.7)	10.1 (6.4)

Note. Marginal means with full-scale IQ as the covariate.
*Significant diagnostic group differences in orienting to specific avatar positions within IQ and social anxiety subgroups $P < 0.05$, or $^{**}P < 0.01$.
HFASD, higher functioning autism spectrum disorder; IQ, intelligence quotient; TD, typical development.

also had higher ADHD inattentive symptoms tended to orient less frequently to social avatars than those with lower ADHD inattentive scores. Alternatively, in the *lower anxiety subgroup* parent report of higher versus lower ADHD symptoms was not associated with differences in orienting among the HFASD students (Fig. 4).

Hypothesis 3: Social and nonsocial attention. Recall that the third hypothesis concerning whether attention to tasks using social versus nonsocial targets would be more sensitive to diagnostic difference was examined with 25 students with HFASD and 33 children with TD in the sample who were also assessed on a nonsocial analog of the VR public speaking task (Fig. 1D). A 2 (diagnostic group) × 2 (age group) × 2 (IQ group) × 2 (social anxiety group) × 2 within (social vs. nonsocial targets) × 5 within (avatar/target [position) ANOVA was conducted with IQ as a covariate ANOVA and using Greenhouse–Geisser criteria. The results revealed a diagnostic group × social vs. nonsocial stimuli × avatar/target position interaction, F 1(1, 41) = 8.50, $P < 0.006$, eta^2 = 0.17 (Fig. 5). HFASD children displayed less frequent orienting looks to social avatars at positions 1 and 2, F (1, 41) = 5.40, $P < 0.025$, eta^2 = 0.12 and F (1, 41) = 5.95, $P < 0.025$, eta^2 = 0.12, respectively. In contrast, no significant diagnostic group differences were observed in contrasts of any of the nonsocial target data. This difference in sensitivity to diagnostic group differences notwithstanding, there was evidence of significant consistency in individual differences in orienting across the social and nonsocial tasks at all avatar positions in the HFASD sample, intraclass coefficient range 0.58–0.78 (Ps < 0.002), average = 0.70, but far less evidence in response consistency in the TD sample, –0.01 to 0.43 ($P < 0.95$ to $P < 0.015$), average = 0.25. In addition, it was noteworthy that *both groups displayed higher frequencies of orienting to social avatars than nonsocial targets*. The number of looks to social avatars was greater than those to nonsocial targets at every stimulus position for children with HFASD, t-tests (24) = 4.75–6.95, Ps < 0.001, and the children with TD, t-tests (32) = 5.31–10.02, Ps < 0.001.

Hypothesis 4: Social attention and learning. To examine the hypothesis that individual differences in social attention in the HFASD sample would be related to learning, the subsample of 25 children with HFASD and 33 children with TD were also assessed on the WIAT. Analyses indicated that the WIAT reading and math scores were correlated, r = 0.57, $P < 0.002$; as were the Reading and Conners Learning Problems Scale scores r = –0.70, $P < 0.001$, and the Math and Learning Problems Scale scores, r = –0.59 $P < 0.001$ in the HFASD sample. The comparable correlations were lower in the TD sample but not significantly different, r = 0.29, $P < 0.10$, r = –0.39 $P < 0.025$, and r = –0.26, $P < 0.15$. Therefore, these three variable were combined with principle components analyses to yield a factor-based latent variable reflecting learning and achievement for each diagnostic group: the one-factor solution in the HFASD sample had an eigenvalue = 2.09, reflecting 70% common variance across these measures, and the one-factor solution in the TD sample had an eigenvalue = 1.52, reflecting 50.6% common variance across measures.

The frequency of looking to distal social avatars at positions 1, 2, and 3 was significantly associated with learning and achievement in the HFASD sample, r (36) = 0.45, 0.47, 0.43, all Ps < 009, respectively. The frequency of looking to the comparable distal nonsocial targets was also associated with learning and achievement in the HFASD sample: r (24) = 0.37, 0.42, 0.42, all Ps < 0.075. To reduce these attention data, the three social and three nonsocial attention scores were combined into

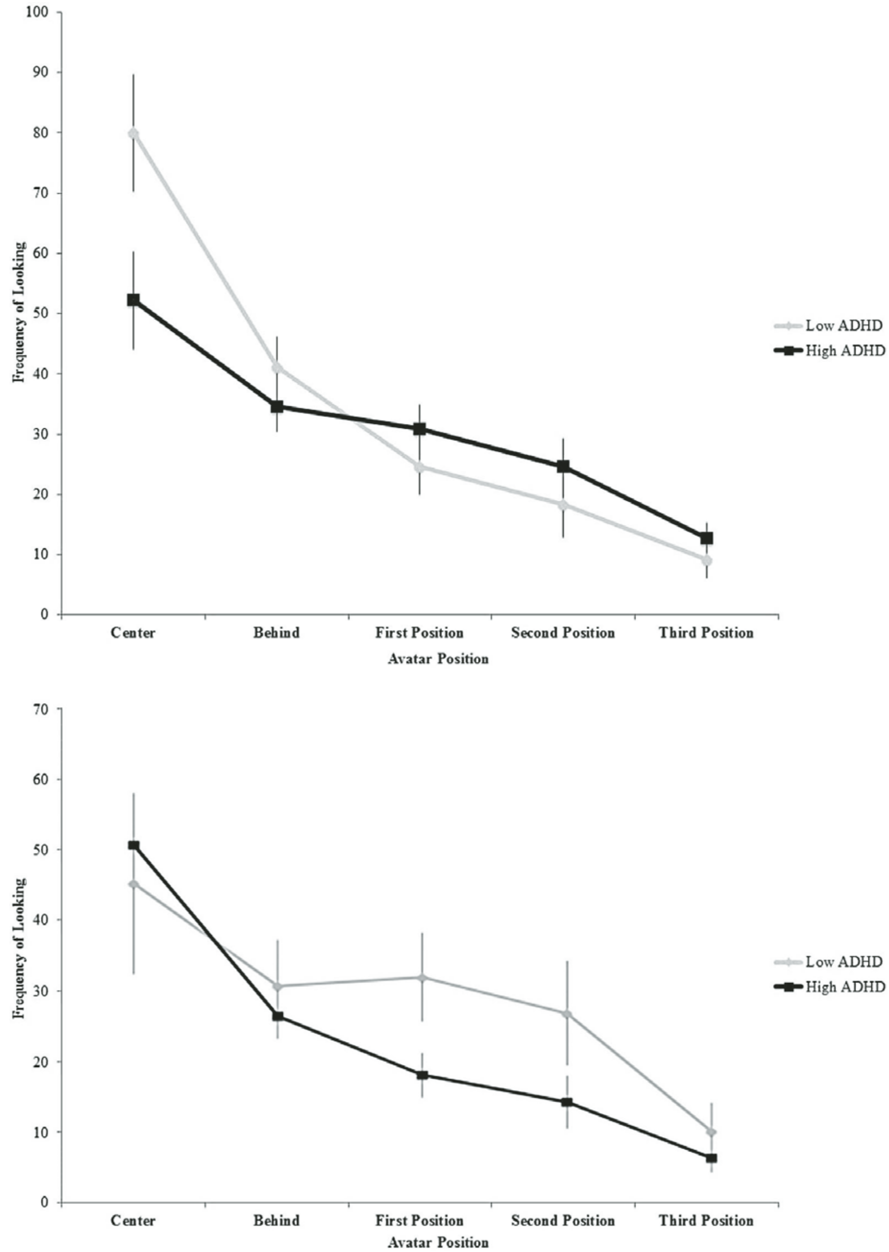

Figure 4. Comparison of attention deficit/hyperactivity disorder (ADHD) effects on orienting to avatar positions in the low social anxiety (upper panel) and high social anxiety higher functioning autism spectrum disorder (HFASD) subgroups.

factor-based latent *distal social avatar (DSA) attention* score and distal nonsocial target (DNT) scores. In the HFASD, the DSA had a one-factor solution, eigenvalue = 2.80, reflecting 93.2% of the common variance, and as did the DNT, eigenvalue = 2.79, 92% common variance. Comparable DSA attention scores and DNT attention scores were computed for the TD with one-factor solutions, eigenvalue = 2.52, 84% common variance, and eigenvalue = 2.84, 94.6% common variance, respectively.

Several regression models were computed to examine the degree to which attention scores were characterized by significant associations with learning and achievement apart from variance associated with IQ and ADHD inattentive or social anxiety symptom scores. In the first analysis, the latent learning and achievement variable was regressed onto diagnostic group (step 1), full-scale IQ (step 2), the latent DSA attention variable (step 3), diagnostic group × DSA attention interaction term (step 4), and social anxiety (step 5), as well as ADHD inattentive scores (step 6). The second analysis was identical except the DNT attention variable and diagnostic group × DNT attention interaction term replaced the DSA variable.

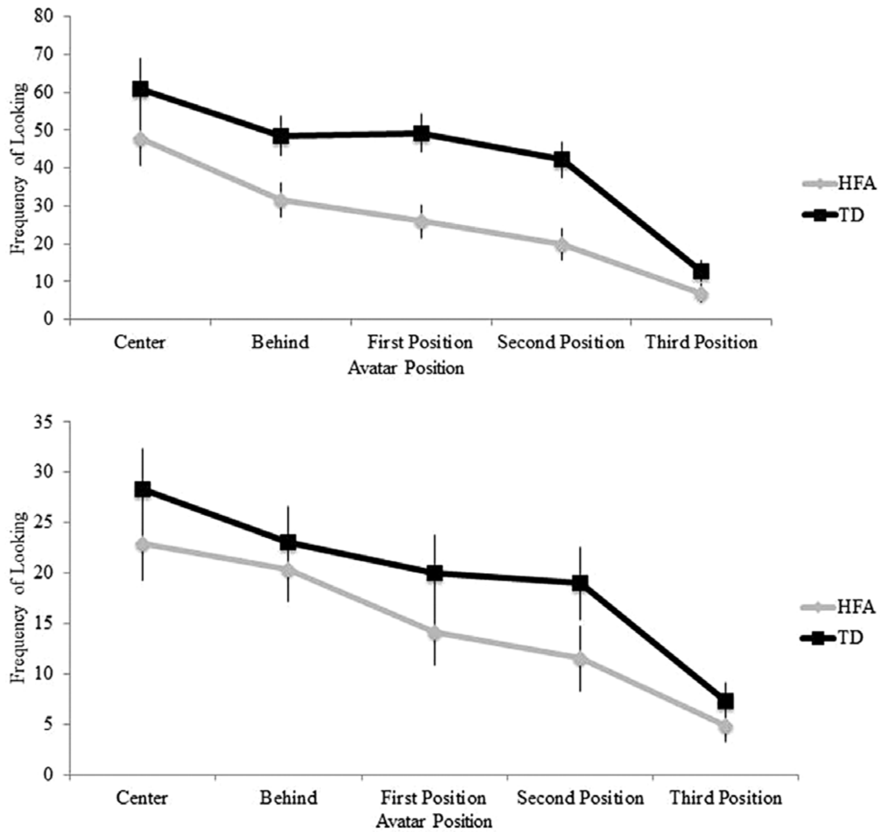

Figure 5. The comparative effects of diagnostic group on orienting to social avatars (top panel) and nonsocial targets (bottom panel) in the virtual reality classroom.

The results of the DSA attention regression model yielded a significant effect for the model at step 6, R = 0.64, adjusted $R^2 = 0.37$, F (8, 82) = 7.27, $P < 0.001$. Significant unique effects were observed for IQ, beta = 0.49, $P < 0.001$, the latent DSA attention variable, beta = 0.65, $P < 0.04$, diagnostic group, beta = –0.43, $P < 0.001$, and the diagnostic Group × DSA attention interaction term, beta = –0.58, $P < 0.05$, and the Conners inattentive scores was also observed, beta = –0.43, $P < 0.001$. The diagnostic group × DSA interaction reflected the presence of a significant positive association between distal social attention and learning and achievement in the HFASD sample, $r = 0.46$, $P < 0.005$, but not in the TD sample, $r = -0.02$. No significant effects were noted for the social anxiety score or the interactions of diagnostic group with social anxiety or inattention scores, Ps > 0.60.

The results of the DNT attention model at the sixth step were, $R^2 = 0.68$, adjusted $R^2 = 0.40$, F (8, 51) = 7.13, $P < 0.001$. Evidence of significant unique associations were limited to three variables: IQ, beta = 0.56, $P < 0.001$, diagnostic group, beta = –0.43, $P < 0.008$, and inattentive scores, beta = –0.38, $P < 0.03$. Neither the DNT attention variable, nor its interaction term was associated with significant effects in this model, Ps > 0.60.

A third model included both the DSA and DNT variables and their diagnostic group interaction terms. The results were R = 0.70, adjusted $R^2 = 0.40$, F (8, 51) = 5.72, $P < 0.001$. Significant betas were associated with IQ, 0.55, $P < 0.001$, diagnostic group, –0.34, $P < 0.05$, and inattentive scores, –0.39, $P < 0.03$. A marginal effect was associated with the DSA variable, beta = 0.73, $P < 0.15$, and the DSA × diagnostic group interaction term, beta = –0.75, $P < 0.09$. Comparable data for the DTA score was beta = –0.33, $P < 0.75$, and the DTA × diagnostic group interaction term, beta = 0.39, $P < 0.70$. Effects for social anxiety did not approach significance.

Discussion

Many children with HFASD in this study displayed evidence of atypical social orienting in experimental conditions that required them to simultaneously engage in speaking while attending to avatar peers in a virtual classroom. However, they did not display evidence of atypical social attention in a baseline condition that did not require the dual tasks of regulating attention while speaking. This pattern of findings was consistent with theory that holds that ASD cognitive and attention vulnerability is most clearly expressed on tasks that require dual task or complex top down processing [e.g. Belmonte & Yurgelum-Todd, 2003; Koolen et al., 2012; Mundy et al., 2009]. Previous research on social attention in school-aged children has revealed diagnostic group differences, but these differences have often not been large or consistent across the HFASD children [Fletcher-Watson, et al., 2009]. In this study, however, relatively robust differences that characterized 75% of the two diagnostic groups were observed. Indeed, a failure to observe evidence of diagnostic group differences only occurred in the comparisons of some of HFASD and TD children with lower IQs. Other studies have rarely reported signal detection rates for measures of social attention in research with children with HFASD, so comparison with the current literature is hampered. Nevertheless, the evidence suggests that the dual task and complex processing demands of the paradigm used in this study may have been relatively sensitive to diagnostic group effects in this postpreschool study of social attention development in children with HFASD.

Moderators of Social Attention in Children With HFASD

Another possible reason that this study revealed robust groups differences was that the design anticipated moderator effects. Accounting for potential moderators in research can lead to the meaningful partitioning of variance and improved power. Attention performance in the HFASD group, as well as the TD group to some extent, was moderated by variance in IQ, self-reported symptoms of social anxiety, and parent-reported symptom of ADHD inattentive symptoms. The results in this regard revealed a pattern of relative risk for atypical social attention among children with HFASD. Higher IQ but low social anxiety children with HFASD displayed modest evidence of risk for atypical attention allocation to distal peers relative to the TD sample. Higher IQ but high social anxiety children with HFASD displayed more evidence of risk for atypical attention to distal peers. Lower IQ but higher social anxiety children with HFASD displayed the most evidence of atypical social attention. As previously noted, no diagnostic group effects were observed in lower IQ lower social anxiety subgroups, and this appeared to be largely due to an equivalent attenuation of task performance associated with lower IQ in both the TD and HFASD children (Table 3). Finally, the data suggested that children with HFASD who display higher social anxiety and higher ADHD inattentive symptoms in this study were at especially heightened risk for atypical social attention in the virtual public speaking task.

This pattern of observations is consistent with previous studies that have shown that IQ variance *within* samples of children with HFASD is meaningfully associated with variance in their adaptive outcomes [White, Scahill, Klin, Koenig, & Volkmar, 2007]. These results are also consistent with previous reports that ADHD symptom presentation can impact social information (face) processing in HFASD children [Sinzig, Morsch, & Lehmkuhl, 2008]. Of course, the meaning of ADHD symptoms in children with ASD cannot be addressed by data in this study. ADHD assessment may provide a measure that is sensitive to variance in attention *regulation that is part of* the spectrum of phenotypic expression *of ASD* symptoms in older higher functioning children. Alternatively, ADHD measures may provide an index of the presence of a codified *comorbid disorder* that complicates ASD symptom presentation. The examination of these alternatives is an important issue for future research.

The pattern of data on the effects of social anxiety in this study were also consistent with previous observation that anxiety may be related to better verbal communication but worse reciprocal social interaction in HFASD children [Shukholdosky et al., 2008]. The sensitivity of a public speaking task performance to social anxiety effects has also previously been observed in children [Sumpter et al., 2010] and virtual emulations of public speaking in adults [Anderson et al., 2005; Davidson et al., 2000]. Here, the sensitivity of the VR task to social anxiety effects supported the construct validity of the social, public speaking emulation in a study of children with HFASD. Moreover, the link observed here between a core feature of ASD, such as social attention impairment, and individual differences in social anxiety provides data that support the validity of recent attempts to develop interventions for anxiety as part of comprehensive programs of intervention for school-aged children with ASD [Drahota et al., 2011; Wood et al., 2009].

Perhaps most importantly, though, the pattern of moderator effects observed in this study emphasizes the need to anticipate heterogeneity and examine its correlates in studies of children with ASD, especially children with HFASD. The data in this study stress the need to resist the temptation to design and interpret research as though children with HFASD children can be described as one homogeneous group with respect to some putative strength or impairment. Instead, the results encourage the development of models of variable cognitive-behavioral risk in the development of children with higher functioning ASD, if not all children with ASD [Mundy & Newell, 2007]. The use of risk and/or moderator models in our research may ultimately assist in clarifying and honing the contemporary use of the term *autism spectrum disorder*.

Social versus Nonsocial Attention

Findings from this study also indicated that the diagnostic group differences in attention were more pronounced in group comparisons of performance with social stimuli versus nonsocial stimuli. This observation was consistent with previous research and theory on the greater sensitivity of ASD attention vulnerability to tasks that involve attending to or processing social versus nonsocial information [e.g. Bhat, Galloway, & Landa, 2010; Dawson et al., 1998; Elison et al., 2012; Fletcher-Watson et al., 2009; Klin et al., 2002; Noland, Reznick, Stone, Walden, & Sheridan, 2010]. In general, there are three logically possible reasons for the greater sensitivity of social than nonsocial stimuli for atypical attention development in children with HFASD. One is that children with ASD often exhibit an atypical negative bias (aversion) to looking at social stimuli. However, this possibility was not consistent with the observation that the HFASD sample, like the TD group, displayed higher frequencies of looks to social rather than nonsocial stimuli (Fig. 5). Another possibility is that ASD children look less at social stimuli because they have an atypical positive bias (attraction) to looking at objects. However, the HFASD sample did not allocate more attention to the nonsocial targets than did the TD sample (see Fig. 5). A third hypothesis is that children with ASD display an attenuated bias (lower motivation) to social stimuli and that this leads to their atypical social attention. By default, the pattern of relevant data in this study was more consistent with this possibility.

Social Attention and Learning

One of the more important facets of the data in this study was the observation that individual differences in attention regulation during public speaking was significantly associated with a latent measure of learning in the HFASD sample. Notably, after considering covariance with IQ and other potentially mediating factors, this association with learning was only evident in multiple regression analyses of data on social attention (attention to peer avatars). It was not evident in analyses of data on attention to nonsocial targets. In addition to the social versus nonsocial target contrast discussed earlier, this pattern emphasized the importance of the role of social attention in understanding learning and development in older children affected by ASD. The specificity of the social attention to learning association in HFASD children was supported by the observation that this association was significant even after considering covariance with IQ, ADHD inattention symptoms or symptoms of social anxiety, and was observed in the HFASD sample but not the TD sample. All of these findings were consistent with but not necessarily proof of the social attention model of ASD, which it posits that atypical development in social attention contributes to social learning problems during development in children with ASD [Mundy et al., 2009, 2012]. Previous experimental [e.g. Kasari et al., 2006, 2008] and quasi-experimental studies [Bhat et al., 2010; Bono et al., 2002; Noland et al., 2010] have reported data consistent with this hypothesis in preschool studies. This may be among the first studies to provide evidence of this linkage in school-aged children.

Limitations

In this study, we assessed differences in the fluency of speech production (volubility) during the task but found no group differences on this measure, or relations of this measure to task performance within groups. However, it is possible that measures of speech dysfluency, complexity, referential clarity, or the simultaneity or sequencing of speech and orienting would be more informative regarding the specific difficulties in parallel task performance that HFASD children exhibit in a virtual public speaking task.

Even with a moderate sample size of 37 children with HFASD and 54 children with TD, the power of this study to avoid type II error (failure to recognize true effects) was limited. Moreover, the number of moderator effects noted in this study points to the complexity of the interactions that need to be considered to develop a deep, veridical picture of the processes that contribute to strengths and weaknesses in attention development and learning in older children with HFASD. Thus, there is a clear need to move consistently, if only incrementally, toward larger scale research that anticipates the nature of spectrum heterogeneity in order to arrive at a more precise understanding of the nature of ASD in school-aged children. Future research of this kind may benefit from studies of the comparative validity and meaning of measures of ADHD and anxiety symptoms in individuals with HFASD and TD. VR paradigms may be useful in this regard. Although we did not include measure of autonomic functioning during VR task performance in this study, inclusion of such measures could be revealing with regard to the meaning and effect of social anxiety and inattention in students with ASD.

In studying the effects of parallel task processing on attention regulation in children with HFASD, it may be important to consider the role of individual differences in working memory. We did not do so in this initial study, but we are examining the role of this factor in ongoing studies.

Another limit of this study was inherent to the novelty of VR paradigms. We do not know exactly how well performance in the VR emulation of a classroom in this study relates to an individual's behavior in a real classroom. Moreover, there were technical limits in our paradigm, such that the peer avatars did not ask questions of the participants and nor were they contingently responsive to the content of the participant's speech. This and other augmentations of the current paradigm may be possible and would likely increase the paradigm validity in the study of public speaking and classroom behavior in students with ASD. Nevertheless, even with the early limits of this prototype paradigm, informative relations were observed between virtual classroom behavior and a latent measure of learning and achievement in the classroom in the ASD sample. This observation, along with data from several other studies, attests to the potential of VR paradigms for providing information relevant to real-life behavior in the study of school-aged children and adults with ASD [Kandalaft et al., 2013; Mitchell et al., 2007; Picard, 2009].

Finally, many studies of attention in children with HFASD are conducted with eye-tracking methods. The VR method here employed inertial guidance of head movement along three axes to estimate line of regard. Inertial guidance estimation of visual regard estimation is less precise than eye-tracking measurement. Moreover, eye tracking can be integrated into the type of head mounted VR apparatus we used [Kim & Mundy, 2012]. Future studies may benefit from the combined applications of eye-tracking and VR technologies. However, virtual attention paradigms that use inertial guidance alone may provide an ecologically valid and complimentary alternative to eye tracking for some types of attention research. In this study, for example, the measure sensitive to atypical attention was one that reflected the tendency of children to turn their head to fixate avatars that were beyond their immediate field vision. This type of measurement is not common to static eye-tracking paradigms that limit head movement.

Conclusion

The data on group and individual differences in this study demonstrably suggest that more research on the relations between social attention disturbance and social learning in the classroom, or other contexts, may be informative in future research with HFASD. Recall that the data in this study also indicated that atypical attention to social partners among HFASD children in a public speaking task may be malleable. Significant changes in social orienting were observed in the HFASD sample in response to the cued attention condition. If the hypothetical link between social attention and social learning is supported in future research, and attention malleability is such that it provides an avenue of intervention, this may be extremely informative. Currently, the empirical literature on the factors that facilitate or impede learning in the classroom among children with ASD is extremely limited. Therefore, the foundation for the development of intervention methods for school-aged children is inadequate, and few instructional methods to improve academic outcomes for children with autism are available [Machalicek et al., 2008; Parsons et al., 2011]. Because elementary and secondary school offers the longest term and most intensive opportunity for targeted interventions in the lives of children with ASD, these children and the science of autism may be expected to benefit significantly from enhanced efforts to identify the processes that impact learning and cognitive development in school-aged children with ASD.

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Supporting Information

Additional Supporting Information may be found in the online version of this article at the publisher's web-site:

Appendix S1. Questions and prompts used in the virtual classroom public speaking paradigm.