Social and Nonsocial Visual Prediction Errors in Autism Spectrum Disorder

Rachel K. Greene, Shuting Zheng, Jessica L. Kinard, Maya G. Mosner, Christopher A. Wiesen, Daniel P. Kennedy, and Gabriel S. Dichter

Impaired predictive coding has been proposed as a framework to explain discrepancies between expectations and outcomes in autism spectrum disorder (ASD) that may contribute to core symptoms of the disorder. However, no eye tracking study has directly addressed this framework in the context of visual predictions of social and nonsocial stimuli. The current study used eye tracking to examine violations of learned visual associations of both social and nonsocial stimuli. Twenty-six adolescents with ASD and 18 typically developing control (TDC) adolescents completed an outcome expectation eye tracking task in which predictive cues correctly (80% of trials) or incorrectly (20% of trials) indicated the location (left or right) of forthcoming social or nonsocial stimuli. During violation trials, individuals with ASD focused their gaze relatively more often on stimuli presented on locations that violated the learned association and less often on locations that corresponded with the learned association. This finding was not moderated by stimulus type (i.e., social vs. nonsocial). Additionally, participants who looked at incorrectly predicted locations more often had significantly greater ASD symptom severity. These results are consistent with theories that characterize ASD as a disorder of prediction and have potential implications for understanding symptoms related to prediction errors in individuals with ASD. ***Autism Res*** *2019, 12: 878–883.* © 2019 International Society for Autism Research, Wiley Periodicals, Inc.

Lay Summary: Individuals with autism spectrum disorder (ASD) exhibit impairments making predictions that may impact learning. In this study, we used eye tracking methodology and found that individuals with ASD were less likely to look at the predicted location when a visual routine was violated. This pattern was evident for both social and nonsocial images and was associated with greater ASD symptom severity. These findings provide additional support for predictive challenges in ASD.

Keywords: autism spectrum disorder; prediction error; eye tracking

Introduction

A recent conceptualization of autism spectrum disorder (ASD) is that deficits in predictive ability contribute to core ASD traits [Sinha et al., 2014; Van de Cruys et al., 2014]. For example, the "insistence on sameness" commonly observed in individuals with ASD may reflect self-imposed order that helps individuals process what they perceive to be an unpredictable world. Impairments in the capacity to anticipate future outcomes may also impact social functioning. For instance, deficits in theory of mind, a core social cognitive impairment in ASD [Baron-Cohen, Leslie, & Frith, 1985; Perner, Frith, Leslie, & Leekam, 1989], may represent difficulties predicting implicit social meaning as well as the mental states of others.

Deficits in predictive abilities likely impact learning in individuals with ASD. A key component of learning is the expectancy violation that occurs when an outcome differs from an expectation. This expectancy violation promotes changes in behavior during future encounters with a given stimulus [Niv & Schoenbaum, 2008; Schultz, Dayan, & Montague, 1997]. If the process of learning from expectancy violations is disrupted, errors with similar events will likely persist. Such learning deficits have been observed in individuals with ASD broadly [Mussey, Travers, Klinger, & Klinger, 2015], as well in the context of reward learning tasks [Lin, Adolphs, & Rangel, 2012]. The severity of these learning impairments appears to be moderated by stimulus type, such that individuals with ASD may demonstrate greater impairments in social relative to nonsocial learning paradigms [Lin et al., 2012].

From the Department of Psychology and Neuroscience, University of North Carolina at Chapel Hill, Chapel Hill, North Carolina (R.K.G., M.G.M., G.S.D.); Department of Psychiatry, University of California, San Francisco, California (S.Z.); Carolina Institute for Developmental Disabilities, University of North Carolina at Chapel Hill School of Medicine, Chapel Hill, North Carolina (J.L.K., G.S.D.); The Odum Institute, The University of North Carolina, Chapel Hill, North Carolina (C.A.W.); Department of Psychological and Brain Sciences, Indiana University, Bloomington, Indiana (D.P.K.); Department of Psychiatry, University of North Carolina at Chapel Hill School of Medicine, Chapel Hill, North Carolina (G.S.D.)

Received May 14, 2018; accepted for publication February 8, 2019

Address for correspondence and reprints: Rachel K. Greene, Department of Psychology and Neuroscience, University of North Carolina at Chapel Hill, Chapel Hill, NC, 27514. E-mail: rachel_greene@med.unc.edu

Published online 25 February 2019 in Wiley Online Library (wileyonlinelibrary.com)
DOI: 10.1002/aur.2090

Eye tracking methods have been commonly used in studies of ASD as a measure of social visual attention [Dawson, Meltzoff, Osterling, Rinaldi, & Brown, 1998; Klin, Jones, Schultz, Volkmar, & Cohen, 2002; Pelphrey et al., 2002], and numerous studies have reported significant visual preference for nonsocial over social stimuli in ASD across development [Bird, Press, & Richardson, 2011; Chawarska, Macari, & Shic, 2013; Riby & Hancock, 2008, 2009; Shic, Bradshaw, Klin, Scassellati, & Chawarska, 2011]. Additionally, individuals with ASD typically make relatively fewer [Goldberg et al., 2002] and slower predictive saccades [D'Cruz et al., 2009] to visual cues (e.g., dots) compared to their typically-developing peers. However, to date, no study has used eye tracking to examine prediction error processing of individuals with ASD during visual violations of an association. This is a notable omission given that understanding how individuals with ASD respond to violations in learned associations may provide insight into the learning differences observed in this population [Wills, Lavric, Croft, & Hodgson, 2007].

The current study used eye tracking to examine gaze patterns in individuals with ASD in response to violations of learned associations using both social and nonsocial stimuli. It was hypothesized that individuals with ASD would show more impaired predictive coding, as measured by the time spent looking at and the number of gaze visits to the cue-predicted location during expectancy violations, and that the magnitude of this impairment would be associated with ASD symptom severity. Because predictive deficits in ASD may be exacerbated when processing social stimuli [Sinha et al., 2014], it was further hypothesized that greater impairment would be observed in the context of social stimuli.

Methods

Participants

Twenty-five adolescents with ASD (age $M = 14.78$, $SD = 1.62$) and 18 typically-developing control (TDC) adolescents (age $M = 14.81$, $SD = 2.08$) participated in the study (see Table 1). ASD diagnoses were confirmed by the Autism Diagnostic Observation Schedule, Second Edition [ADOS-2; Lord et al., 2012], and participants with ASD met a cutoff of at least 15 on the Social Communication Questionnaire [SCQ; Rutter, Bailey, & Lord, 2003] at the time of initial screening. Caregivers also completed the SCQ as an initial screening measure. The SCQ is a parental report instrument designed to identify children with signs of autism that includes 40 yes/no questions and provides a cutoff score (i.e., >15) that indicates autism risk. The SCQ has strong psychometric properties as a screening tool, with sensitivity of 0.88 and specificity of 0.76 when discriminating between autism and non-autism cases [Chandler et al., 2007].

Participants in the TDC group met the following inclusion criteria: (a) no known genetic, psychiatric, or medical conditions, including developmental or cognitive delay; (b) no current psychotropic medications; and (c) score less than 15 on the SCQ. All participants were ambulatory, had no significant physical or sensory impairments (e.g., deafness or blindness), and had a full-scale IQ >80, measured by the Kaufman Brief Intelligence Test [KBIT; Kaufman, 1990].

Table 1. Demographics for the ASD and TDC Groups

	ASD (n = 25)	TDC (n = 18)	
	Mean (*SD*)	Mean (*SD*)	*P* value
Age	14.78 (1.62)	14.81 (2.08)	0.97
Verbal IQ (VIQ)	105.24 (16.98)	110.78 (11.97)	0.24
Performance IQ (PIQ)	101.80 (18.02)	104.83 (14.98)	0.56
Full scale IQ (FSIQ)	104.40 (18.22)	109.28 (14.88)	0.36
Male: female ratio	22:3	17:11	<0.0007[a],**
SRS total raw score	92.16 (21.51)	21.61 (14.92)	<0.0001**
SCQ total score	21.04 (5.21)	1.33 (1.57)	<0.0001**
Visit count to cue-predicted location during violation	1.72 (0.70)	4.44 (2.06)	0.038*
Visit count to cue-predicted location during nonviolation	46.76 (10.90)	47.94 (10.03)	0.72

Note. *$P < 0.05$; **$P < 0.01$.
[a]Pearson's χ^2 P value.

ASD participants were recruited from the Carolina Institute for Developmental Disabilities (CIDD) Autism Subject Registry. TDC participants were recruited using a university-wide mass email system as well as referrals from local public schools. Following consent, diagnostic testing (ASD group only), and cognitive testing, participants completed an eye tracking task, clinical report measures, and stimulus ratings. All participants were compensated $15 per hour.

Materials and Measures

Eye tracking task. The eye tracking paradigm was displayed on a Tobii X120 eye tracker integrated with a 23″ display monitor. Before beginning the task, participants' were positioned so that their eyes were approximately 60 cm from the monitor, and their eye gaze was calibrated. Once all nine locations were precisely calibrated, participants were asked to remain still during the task. Participant data with less than 50% gaze acquisition accuracy were excluded from the subsequent analyses, including two TDC participants and three ASD participants.

Participants completed an outcome expectation eye tracking task. Prior to administration of the eye tracking task, participants completed a training session to learn two visual cue associations: they were instructed that whenever they saw the red circle, the image that followed this cue would usually appear on the left, and when they saw the blue square, the forthcoming image would usually appear on the right (Fig. 1). They were then shown a booklet with several examples and asked to identify, using the previously learned cues, on which side the subsequent image would

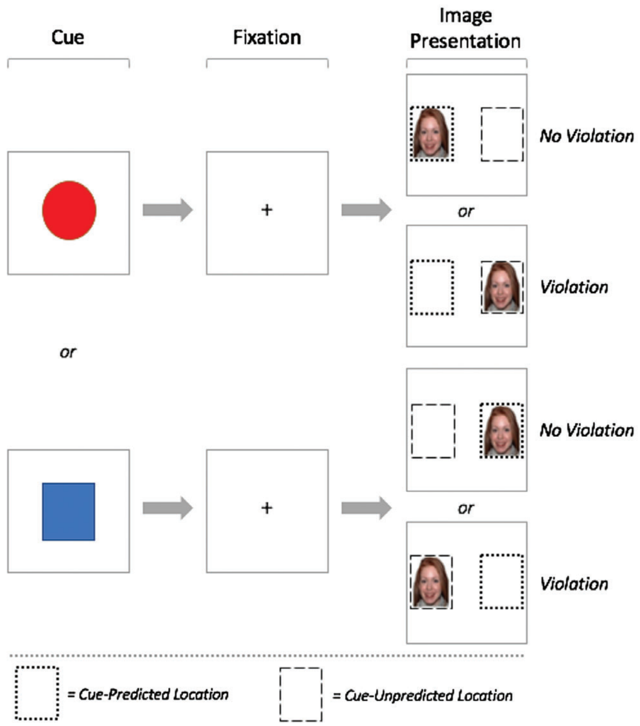

Figure 1. The eye tracking task included a cue that predicted on which side (left or right) the forthcoming image would be presented. Prior to the task, participants learned that a circle and a square predicted that the image would appear on the left and right sides of the display, respectively. On 80% of trials, the cues accurately predicted the location (left or right) of the image, and on 20% of trials, the cue incorrectly predicted the location (left or right) of the image. One task block presented social images (as shown here) and one task block presented nonsocial images. Dashed and dotted lines did not appear in the visual stimulus and are solely used within this figure to demonstrate the cue-predicted and cue-unpredicted locations.

appear. When it was clear that the participant understood these instructions, they were told that during the task they should look at the images as soon as they appeared. It was also explained that, although these cues would correctly predict the subsequent image a majority of the time, sometimes the image may not appear on the expected side. Each task trial consisted of the presentation of one of the two learned cues followed by the presentation of a social or nonsocial stimulus. On 80% of the trials, cues accurately predicted the learned image location (left or right; nonviolation condition). On 20% of the trials, cues incorrectly predicted the learned image location (left or right; violation condition). The task was presented across two runs: one run containing social stimuli (i.e., faces) and one run containing nonsocial stimuli (i.e., trains, electronics, street signs). The order of these runs was counterbalanced across participants.

Eye tracking metrics. Two eye tracking outcome measures were extracted: total fixation duration and visit count. Both metrics were collected starting from the time the image (e.g., face or object) appeared on the screen, just following the presentation of the fixation cross (see Fig. 1). Rectangular areas of interests for both cue-predicted and cue-unpredicted locations were traced for all trials. The AOIs were the same size and centered around the same locations and captured the entire stimulus.

Social and nonsocial stimuli. Social stimuli consisted of Happy-Direct Gaze Closed Mouth Female NimStim images [Tottenham et al., 2009]. Nonsocial stimuli did not contain any face or body images and were drawn from a set of nonsocial images used in previous ASD studies [see Sasson, Dichter, & Bodfish, 2012]. Following the eye tracking task, participants completed a rating task in which they were shown a subset of the pictures of smiling faces and pictures of nonsocial objects they viewed in the eye tracking paradigm and were asked to rate each image on: (a) how pleasant-to-unpleasant they found the image (i.e., valence) and (b) how boring-to-exciting they found the images (i.e., arousal), using 9-point Likert scales.

Cognitive assessments. To assess general cognitive functioning, determine study eligibility, and match diagnostic groups, participants were administered the KBIT, a brief measure of verbal and nonverbal intelligence. All participants were required to meet verbal and performance IQ cut offs of 80 or higher. This assessment was administered at the beginning of the testing session and lasted approximately 45 min.

Autism diagnostic assessment. ASD participants were administered either module 3 or module 4 of the ADOS-2 to confirm diagnoses of ASD. Module administration was determined by developmental age and verbal ability. This measure was administered by a research-reliable clinician. This portion of testing lasted approximately 45 min, throughout which participants were asked to complete activities such as telling a story and giving an account of a routine daily activity. Additionally, they were asked questions regarding their perceived role in social situations and understanding of personal responsibilities. It was determined whether participants met ASD criteria based on the ADOS-2 algorithm cut off scores.

Autism symptoms. Participants and caregivers in both diagnostic groups completed the social responsiveness scale [SRS; Constantino & Gruber, 2002] as an index of change in ASD symptoms before and after treatment. This 65-item measure served to assess the severity of social deficits associated with ASD as they occur in natural settings. Participants answered each question using a given 4-point Likert scale, which ranged in severity. Questions included content regarding intense interests or preoccupations and perceptions of social ability. The SRS can reliably distinguish individuals with ASD from individuals with other psychiatric diagnoses [Constantino et al., 2003].

Results

All statistical analyses were conducted using SAS 9.4 (SAS Institute Inc., Cary, NC).

Ratings of Faces and Objects

Results of 2 (Group: ASD, TDC) × 2 (stimulus: social, nonsocial) ANOVAs revealed main effects of stimulus type on valence and arousal ratings, such that the nonsocial stimuli were rated as more pleasing than social stimuli across participants in both groups, $F(1,43) = 5.99$, $P = 0.019$, $\eta_p^2 = 0.12$, and more arousing, $F(1,43) = 8.13$, $P = 0.007$, $\eta_p^2 = 0.16$. There were no significant interactions with group for either valence or arousal ratings, all *P's* > 0.05. Finally, *post hoc* analyses revealed ASD participants rated the nonsocial stimuli as significantly more pleasing than did TDCs, $t(43) = 2.07$, $P = 0.045$, $d = 0.64$. There were no differences between groups in valence or arousal ratings of face stimuli, all *P's* > 0.05.

Eye Tracking Analyses

Visit count. Poisson regression analyses of gaze visit count included the following factors: Group (ASD, TDC), Expectancy (violation, no violation), and Stimulus Type (nonsocial, social). The saturated model examined the number of gaze visit counts participants made to both the cue-predicted location and the cue-unpredicted location during nonsocial and social violation trials. Contrasts between effects revealed Group was a significant predictor of gaze preferences for cue-predicted visual targets during violation trials, Wald χ^2 (2, $N = 43$) = 10.06, $P = 0.0065$, $r = 0.48$ (see Fig. 2), reflecting that individuals with ASD made fewer gaze visits to the cue-predicted location during nonsocial and social violation trials relative to TDC participants. This effect was not moderated by Stimulus Type, $P > 0.05$.

Total fixation duration. Visit count results were corroborated by analyses of total fixation durations. A Group (ASD, TDC) × Expectancy (violation, no violation) × Stimulus Type (nonsocial, social) repeated measures ANOVA revealed no significant interaction between these three factors, $P > 0.05$. However, the Group (ASD, TDC) × Expectancy (violation, no violation) interaction was significant, F (1, 42) = 10.65, $P = 0.002$, $\eta_p^2 = 0.20$. Tukey–Kramer adjusted *post hoc* analyses revealed that groups differed in the amount of time spent looking toward or away from the cue-predicted location depending on Expectancy (i.e., violation or no violation). Specifically, on violation trials, individuals with ASD spent relatively more time looking at the cue-unpredicted (i.e., the presented social or nonsocial stimuli) relative to the cue-predicted location that was empty, $p = 0.02$. These results are consistent with analyses of visit count data reported above.

Correlations Between Eye Tracking and ASD Symptoms

Correlational analyses examined the associations between number of visits to the cue-predicted location during violation trials and total scores on the SCQ and SRS. These analyses revealed that the number of visits to the cue-predicted location during violations was significantly negatively correlated with SCQ total scores, $r(42) = -0.34$, $P = 0.026$, and SRS raw total scores, $r(42) = -0.40$, $P = 0.009$ across both groups (see Fig. 3). These results suggest that as ASD symptom severity increases, gaze toward the cue-predicted location during violation trials decreases. The SCQ correlational findings should be considered exploratory, as those results do not survive Bonferroni correction, where $\alpha = 0.017$. The SRS findings do, however, survive Bonferroni correction. Additionally, when examined within diagnostic groups

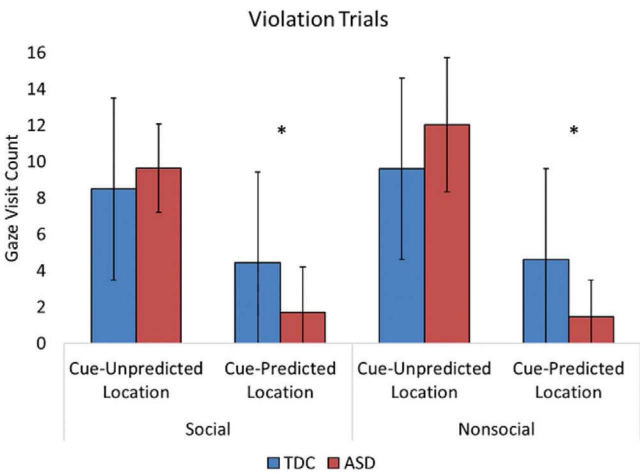

Figure 2. * = $P < 0.05$. Number of gaze visits to cue-predicted and cue-unpredicted locations during social and nonsocial violation trials.

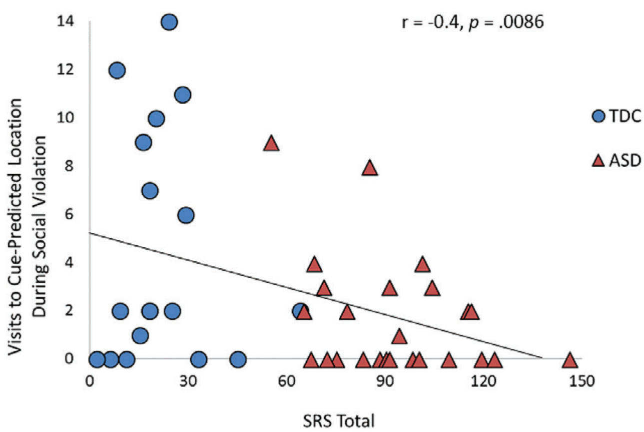

Figure 3. Scatterplot of the relations between the number of gaze visits to the cue-predicted location during social violation trials and social impairment, measured by the SRS.

separately, the relationship between SRS and gaze visits to cue-predicted locations during violations was marginally significant for the ASD group, $r(24) = -0.37$, $P = 0.069$, and nonsignificant for the TDC group, $r(17) = -0.05$, $P = 0.84$. Correlations between eye tracking metrics and SCQ scores were not significant when analyzed within diagnostic groups separately.

Correlations Between Eye Tracking and Verbal IQ

Because of the variability in the Verbal IQ (VIQ) of the participants with ASD, correlational analyses were conducted to examine the relationship between VIQ and eye tracking metrics within the ASD group alone. These analyses revealed no significant relationship between the number of gaze visits to cue-predicted locations during violation trials and the VIQs of participants with ASD, $r(24) = 0.18$, $P = 0.39$. Additionally, there were no associations between these eye tracking metrics and Nonverbal IQ (NVIQ), $r(24) = 0.28$, $P = 0.18$, or full-scale IQ (FSIQ), $r(24) = 0.25$, $P = 0.22$, in the ASD group.

Discussion

The current study examined social and nonsocial visual prediction errors in ASD. Results revealed that individuals with ASD demonstrated relatively impaired predictive abilities, as evidenced by fewer gaze visits and less time spent looking at the cue-predicted location during violation trials. Because these eye tracking metrics were not significantly associated with the cognitive profiles of participants with ASD, these results are attributable to predictive abilities. These findings support a framework that characterizes ASD as a disorder of prediction [Sinha et al., 2014]. These results are also consistent with Pellicano and Burr's [2012] Bayesian perceptual theory of ASD that hypothesizes that individuals with ASD may weigh in vivo sensory stimuli more heavily than prior experiences, leading to deficits in inferential abilities and learning. Therefore, it is possible that the simple presence of a visual stimulus, as opposed to a blank location that represented the cue-predicted location, overrode the rule of the learned routine. Lawson, Rees, and Friston [2014] argued that the Bayesian perceptual theory of ASD may, in fact, be attributed to deficits in predictive coding, and the current findings are consistent with that hypothesis.

Visual prediction errors were not impacted by whether the experimental stimuli were social or nonsocial. This finding may reflect broadly impaired predictive ability in ASD, irrespective of stimulus type. It is also possible that the lack of significant stimulus type effects indicates that static images, like those used in the current study, are not as effective as dynamic stimuli within the context of eye tracking studies, as has been demonstrated previously [Chevallier et al., 2015]. Social predictive impairments in ASD, in particular, have been attributed to difficulties interacting with dynamic objects [Sinha et al., 2014], and this perceived unpredictability of social situations may not be captured by still images of faces. Because dynamic stimuli could evoke a more polarizing visual response to social relative to nonsocial stimuli than we have observed in the current study, future studies should employ paradigms utilizing videos or other dynamic presentations to examine responses to visual prediction errors in ASD.

Results may also be understood within the context of increased ASD rule-following behaviors, because participants were not explicitly directed to look in the predicted location during violations. Instead, they were instructed to look at the presented stimuli as quickly as possible. For example, when the task violated instructed rules, individuals with ASD may have been more likely to abide with the task instructions rather than update their cue-outcome associations [Pellicano & Burr, 2012]. This tendency may result in challenges when learning novel tasks or generalizing learned rules in distinct settings (e.g., learning in therapy how to use appropriate social greetings during social interactions with a peer). One limitation of the current study is that eye gaze latencies to areas of interest could not be extracted. Latency outcomes were calculated for areas of interest during the image presentation (e.g., faces or objects) portion of the paradigm (i.e., immediately following the fixation cross) and revealed that many participants made saccades in the direction of the stimulus prior to presentation. Future eye tracking studies examining predictive ability in ASD should prioritize examining latency of predictive saccades as an outcome measure of interest.

Learning is largely dependent on prediction error experiences [Kamin, 1968]; therefore, responses to violations in routines may provide important insight into learning impairments in ASD [Wills et al., 2007]. This study is the first to our knowledge to examine gaze responses to visual routine violations in individuals with ASD, and results revealed significant impairments in social and nonsocial visual predictive ability during rule violations, measured by eye tracking gaze metrics. Furthermore, the severity of predictive impairments was associated with ASD symptom severity. Overall, these results corroborate theories that characterize ASD as a disorder of prediction and may have relevance for mitigating ASD symptoms related to prediction errors in individuals with ASD [Sinha et al., 2014].

Acknowledgments

The authors would like to thank the families who participated in this research. Support for this project was provided by the Clinical Translational Core of U54 HD079124. GSD was supported by U54 HD079124 and MH110933. JLK was supported by T32-HD40127. Data analytic support was provided by the University of North Carolina at Chapel Hill Odum Institute.

Conflict of Interest

The authors declare that they have no conflicts of interest.

References

Baron-Cohen, S., Leslie, A. M., & Frith, U. (1985). Does the autistic child have a "theory of mind"? Cognition, 21(1), 37–46.

Bird, G., Press, C., & Richardson, D. C. (2011). The role of alexithymia in reduced eye-fixation in autism spectrum conditions. Journal of Autism and Developmental Disorders, 41 (11), 1556–1564. https://doi.org/10.1007/s10803-011-1183-3.

Chandler, S., Charman, T., Baird, G., Simonoff, E., Loucas, T. O. M., Meldrum, D., … Pickles, A. (2007). Validation of the social communication questionnaire in a population cohort of children with autism spectrum disorders. Journal of the American Academy of Child & Adolescent Psychiatry, 46(10), 1324–1332.

Chawarska, K., Macari, S., & Shic, F. (2013). Decreased spontaneous attention to social scenes in 6-month-old infants later diagnosed with autism spectrum disorders. Biological Psychiatry, 74 (3), 195–203. https://doi.org/10.1016/j.biopsych.2012.11.022.

Chevallier, C., Parish-Morris, J., McVey, A., Rump, K., Sasson, N. J., Herrington, J., & Schultz, R. T. (2015). Measuring social attention and motivation in autism spectrum disorder using eye-tracking: Stimulus type matters. Autism Research, 8(5), 620–628. https://doi.org/10.1002/aur.1479.

Constantino, J. N., Davis, S. A., Todd, R. D., Schindler, M. K., Gross, M. M., Brophy, S. L., … Reich, W. (2003). Validation of a brief quantitative measure of autistic traits: comparison of the social responsiveness scale with the autism diagnostic interview-revised. Journal of Autism and Developmental Disorders, 33(4), 427–433.

Constantino, J. N., & Gruber, C. P. (2002). The social responsiveness scale. Los Angeles: Western Psychological Services.

Dawson, G., Meltzoff, A. N., Osterling, J., Rinaldi, J., & Brown, E. (1998). Children with autism fail to orient to naturally occurring social stimuli. Journal of Autism and Developmental Disorders, 28(6), 479–485. https://doi.org/10.1023/A:1026043926488.

D'Cruz, A.-M., Mosconi, M. W., Steele, S., Rubin, L. H., Luna, B., Minshew, N., & Sweeney, J. A. (2009). Lateralized response timing deficits in autism. Biological Psychiatry, 66(4), 393–397.

Goldberg, M. C., Lasker, A. G., Zee, D. S., Garth, E., Tien, A., & Landa, R. J. (2002). Deficits in the initiation of eye movements in the absence of a visual target in adolescents with high functioning autism. Neuropsychologia, 40(12), 2039–2049. https://doi.org/10.1016/S0028-3932(02)00059-3.

Kamin, L. J. (1968). "Attention-like" processes in classical conditioning.

Kaufman, A. S. (1990). Kaufman brief intelligence test: KBIT. MN: American Guidance Service Circle Pines.

Klin, A., Jones, W., Schultz, R., Volkmar, F., & Cohen, D. (2002). Visual fixation patterns during viewing of naturalistic social situations as predictors of social competence in individuals with autism. Archives of General Psychiatry, 59(9), 809–816.

Lawson, R. P., Rees, G., & Friston, K. J. (2014). An aberrant precision account of autism. Frontiers in Human Neuroscience, 8, 302. https://doi.org/10.3389/fnhum.2014.00302.

Lin, A., Adolphs, R., & Rangel, A. (2012). Impaired learning of social compared to monetary rewards in autism. Frontiers in Neuroscience, 6, 143.

Lord, C., Rutter, M., DiLavore, P. C., Risi, S., Gotham, K., & Bishop, S. (2012). Autism diagnostic observation schedule–Second edition (ADOS-2). Los Angeles: Western Psychological Services.

Mussey, J. L., Travers, B. G., Klinger, L. G., & Klinger, M. R. (2015). Decision-Making Skills in ASD: Performance on the Iowa Gambling Task. Autism Research, 8(1), 105–114.

Niv, Y., & Schoenbaum, G. (2008). Dialogues on prediction errors. Trends in Cognitive Sciences, 12(7), 265–272.

Pellicano, E., & Burr, D. (2012). When the world becomes 'too real': a Bayesian explanation of autistic perception. Trends in Cognitive Sciences, 16(10), 504–510. https://doi.org/10.1016/j.tics.2012.08.009.

Pelphrey, K. A., Sasson, N. J., Reznick, J. S., Paul, G., Goldman, B. D., & Piven, J. (2002). Visual scanning of faces in autism. Journal of Autism and Developmental Disorders, 32(4), 249–261.

Perner, J., Frith, U., Leslie, A. M., & Leekam, S. R. (1989). Exploration of the autistic child's theory of mind: Knowledge, belief, and communication. Child Development, 60, 689–700.

Riby, D. M., & Hancock, P. J. B. (2008). Viewing it differently: Social scene perception in Williams syndrome and autism. Neuropsychologia, 46(11), 2855–2860. https://doi.org/10.1016/j.neuropsychologia.2008.05.003.

Riby, D. M., & Hancock, P. J. B. (2009). Do faces capture the attention of individuals with Williams syndrome or autism? Evidence from tracking eye movements. Journal of Autism and Developmental Disorders, 39(3), 421–431. https://doi.org/10.1007/s10803-008-0641-z.

Rutter, M., Bailey, A., & Lord, C. (2003). The social communication questionnaire: Manual. Los Angeles: Western Psychological Services.

Sasson, N. J., Dichter, G. S., & Bodfish, J. W. (2012). Affective responses by adults with autism are reduced to social images but elevated to images related to circumscribed interests. PLoS One, 7(8), e42457. https://doi.org/10.1371/journal.pone.0042457.

Schultz, W., Dayan, P., & Montague, P. R. (1997). A Neural Substrate of Prediction and Reward. Science, 275(5306), 1593–1599.

Shic, F., Bradshaw, J., Klin, A., Scassellati, B., & Chawarska, K. (2011). Limited activity monitoring in toddlers with autism spectrum disorder. Brain Research, 1380, 246–254. https://doi.org/10.1016/j.brainres.2010.11.074.

Sinha, P., Kjelgaard, M. M., Gandhi, T. K., Tsourides, K., Cardinaux, A. L., Pantazis, D., … Held, R. M. (2014). Autism as a disorder of prediction. Proceedings of the National Academy of Sciences, 111(42), 15220–15225.

Tottenham, N., Tanaka, J. W., Leon, A. C., McCarry, T., Nurse, M., Hare, T. A., … Nelson, C. (2009). The NimStim set of facial expressions: Judgments from untrained research participants. Psychiatry Research, 168(3), 242–249. https://doi.org/10.1016/j.psychres.2008.05.006.

Van de Cruys, S., Evers, K., Van der Hallen, R., Van Eylen, L., Boets, B., de-Wit, L., & Wagemans, J. (2014). Precise minds in uncertain worlds: predictive coding in autism. Psychological Review, 121(4), 649–675. https://doi.org/10.1037/a0037665.

Wills, A. J., Lavric, A., Croft, G. S., & Hodgson, T. L. (2007). Predictive learning, prediction errors, and attention: evidence from event-related potentials and eye tracking. Journal of Cognitive Neuroscience, 19(5), 843–854. https://doi.org/10.1162/jocn.2007.19.5.843.