Gaze cues in complex, real-world scenes direct the attention of high-functioning adults with autism

Elizabeth Redcay (redcay@umd.edu)
Daniel O'Young (droyoung@umd.edu)
L. Robert Slevc (slevc@umd.edu)
Department of Psychology, University of Maryland
College Park, MD 20742 USA

Penelope L. Mavros (lmavros@mit.edu)
John D. Gabrieli (gabrieli@mit.edu)
Pawan Sinha (sinha@mit.edu)
Department of Brain & Cognitive Sciences, Massachusetts Institute of Technology
Cambridge, MA 02139 USA

Abstract

Abstract Autism is characterized by atypical use of social communicative cues, such as another person's gaze or point. Despite these real-world difficulties, experimental manipulations often reveal minimal group differences. One factor that may contribute to this failure to find differences is the use of oversimplified and decontextualized social stimuli to examine these behaviors (e.g., a solo floating face). In the current study, we examined whether typical individuals and those with high-functioning autism spectrum disorder would use subtle gaze cues embedded in a natural, real-world scene to aid them in a change detection task using flicker presentation. Each scene contained three changes, and in some pictures, one of those changes was in the direction of gaze of the people in the scene. Even though neither group was aware that gaze cues aided in identification of the change, both groups showed a robust effect of gaze cues in change detection, such that changes in the line of gaze were detected first in a scene more often than those not in the line of gaze. These data illustrate typical use of gaze cues in high-functioning adults with ASD even in the context of a complex, naturalistic scene. Our findings suggest that attention to gaze cues may not be at the root of difficulties with joint attention in adults with autism

Keywords: change blindness; joint attention; autism spectrum disorder.

Introduction

Imagine we are taking a walk in a park and a bird flies overhead. I point to it and look at you, then you look at the bird and you tell me it's a magpie. These simple instances of joint attention, or the intentional coordination of one's own attention with another on an object or topic, occur often in everyday social interactions. Joint attention interactions begin in infancy and provide a robust social learning tool for those who engage in them (e.g., Baldwin et al., 1996; Tomasello, Carpenter, Call, Behne, et al., 2005). Atypical joint attention is a hallmark characteristic in individuals with autism spectrum disorders (ASD) (e.g., Charman, 2003; Mundy & Newell, 2007, but see Gernsbacher, Stevenson, Khandakar, & Goldsmith, 2008) and early joint attention abilities are correlated with atypical language and social development. While joint attention refers to both the initiation of a bid for joint attention and the response, the focus of the current paper is on processes that may underlie atypical responding. Atypical responding to joint attention could be due to general differences in visual attention (e.g., Brenner, Turner, & Müller, 2007), social attention specifically, for example reduced attention to people, faces, and eyes (Klin, Jones, Schultz, Volkmar, et al., 2002; Pelphrey et al., 2002), and/or a failure to direct one's own attention based on cues from others, to name a few. These various aspects of joint attention behavior have been investigated in a number of different experimental paradigms, however evidence for difficulties with these processes in individuals with autism has been mixed - at least in experimental contexts.

Social attention in autism has been investigated in several ways including the collection of eye-tracking data during viewing of videos, scenes, or pictures of faces and the examination of response patterns during a change blindness paradigm[1]. The first eye-tracking studies to examine whether social attention was atypical in ASD revealed reduced attention to people, and in particular to their eyes, during video viewing (Klin et al., 2002; Pelphrey et al., 2002). While more recent evidence also supports this atypical focus of attention on people within a scene, and on eyes within a face (e.g., Jones, Carr, & Klin, 2008; Dalton et al., 2005; Spezio, Adolphs, Hurley, & Piven, 2007), other evidence does not (e.g, Bar-Haim, Shulman, Lamy, & Reuveni, 2006). Recent studies have capitalized on change blindness methods in order to ask whether attention in a complex scene is prioritized to social aspects of the scene. These studies find that visual attention is prioritized for social agents (New, Schultz, Wolf, Niehaus et al., 2010; Fletcher-Watson, Leekam, Benson, et al., 2009) and eyes (Fletcher-Watson, Leekam, Findlay, & Stanton, 2008) in typical individuals and those with ASD. Thus, among a

[1] In a change blindness paradigm participants must identify small change(s) between two images through comparing images side-by-side or through flicker presentation.

high-functioning group of participants with ASD, there is mixed support for problems with social attention, suggesting that either this may not be a source of atypical joint attention (at least by adulthood) or the experimental paradigms used are failing to capture the difficulties.

In a joint attention context social attention is necessary but not sufficient to coordinate attention with another. If I just looked at you pointing to the magpie but didn't look at the magpie I would not have engaged in joint attention with you nor would I have learned the name for that type of bird. Indeed, individuals must use the other person's shift in attention (e.g., through gaze) to redirect their own attention to achieve joint attention. Thus, one hypothesis is that atypical use of gaze, rather than social attention alone, may underlie atypical joint attention. Researchers have examined the effect of gaze cueing on attention in experimental tasks and again find mixed to weak support for an atypical response in autism. However, these studies have been largely devoid of social context. These studies have mostly been conducted through the use of a modified Posner cueing task in which participants are told to push the left or right button when they detect a target on the left or right side of the screen, respectively. A face at the center of the screen shifts gaze just prior to appearance of the target to a location that is either congruent or incongruent with the target location. Greater reaction time for the incongruent than congruent trials suggests reflexive use of the gaze cue information to redirect attention even though participants are told the gaze cue is irrelevant to the task. In a review of 12 experiments, 8 revealed no differences between autism and control groups with this method (review, Nation & Penny, 2008), suggesting reflexive orienting of attention to gaze cues in ASD is fairly typical. As mentioned above, this failure to find a difference could be due to the lack of social context in the stimuli. A study using eye-tracking methods examined attention to objects in a person's line of gaze in a real-world scene. While individuals with autism reliably followed the person's gaze to the objects, they looked less at the objects of attention than controls (Freeth, Chapman, Ropar, & Mitchell, 2010). This study illustrates typical gaze following in ASD individuals, but suggests atypical use of gaze information (i.e., less looking at the objects). One limitation of the study, though, is that the gaze cues were so salient in the scenes that the study may not be tapping into more subtle, real-world difficulties in attention to and use of gaze information to orient attention to relevant aspects in ones environment.

In sum, studies of social attention using eye-tracking or change blindness methods do not examine the effect of gaze on attention reorienting, while gaze cueing paradigms that do examine the effect of gaze have previously used oversimplified stimuli with minimal social context or real-world validity. To overcome these limitations and examine whether the object of another person's attention is prioritized in a complex visual scene, we used a change blindness paradigm in which gaze cues were subtly embedded in a complex, natural scene.

Methods

Participants

Eleven adults with autism spectrum disorder (ASD) (29.6 ± 4.2 years, 8 male) and fifteen typically developing adults (TD) (24.4 ± 5.2 years, 9 male) participated in this study. All participants gave written informed consent and received monetary compensation for their participation. Two TD subjects were excluded from subsequent analysis, one for having been previously diagnosed with depression and another for an ophthalmologic developmental disorder. Participants entered the study with a diagnosis of autism or Asperger's from their community healthcare provider but in order to confirm a research diagnosis of autism spectrum disorder, an autism behavioral therapist (P.L.M.) who was certified on the Autism Diagnostic Observation Schedule (ADOS) – Module 4 (Lord et al., 2000) administered and scored the ADOS. A psychiatrist confirmed a diagnosis on the spectrum by viewing tapes of the ADOS interview. Of the 11 participants, 8 met criteria for autism (i.e., a combined social-communication score of 10 or higher), the other three 3 met criteria for spectrum (i.e., a combined social-communication score of 7 or greater). Social-communication scores ranged from 7-14 with a mean of 10 (stdev 2.24).

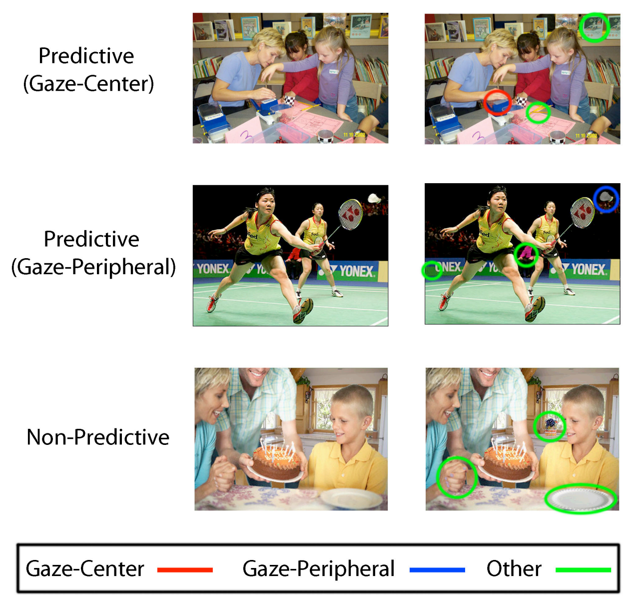

Figure 1: Examples of the picture types (Predictive or Non-Predictive) and change types (gaze-center, gaze-peripheral, non-gaze center, non-gaze peripheral).

Stimuli

Twenty-nine color photographs of natural scenes were used to create the stimuli. Each photograph included between one and three people with visible faces and several objects. The photographs were edited using Adobe Photoshop. For each photograph, three changes were made to each picture.

Attempts were made to balance the changes in the center and periphery across pictures. Center regions were defined as the area within an oval that is half of the height and width of the entire picture, while peripheral regions consisted of any areas outside of the center regions. Twenty of the photographs had a change that was within the line of direct gaze of the person(s) in the photograph. These twenty photos are labeled 'Predictive' because one of the changes can be predicted by the gaze direction. The other nine photos ('Nonpredictive') were included as fillers so that participants were unlikely to notice the predictive nature of the gaze changes.

Stimulus ratings

Eight new participants not informed of the purpose of the current study rated each change within the set of predictive pictures as 'center' or 'periphery' based on the definition given above. Additionally, these participants judged whether the change occurred in the foreground or background of the scene. Two changes could not be categorized as center or periphery (50% ratings for each). These two changes were within the same picture so that picture was removed from all further analyses. Thus, out of 19 predictive pictures, 11 changes were rated as in the center and in the line of gaze (gaze-center), 8 were in the periphery and in the line of gaze (gaze-periphery), 15 were in the center and not in the line of gaze (non-gaze center), 23 were in the periphery and not in the line of gaze (non-gaze periphery). All gaze changes were rated as in the foreground of the picture whereas non-gaze changes were a mix of foreground and background, thus the grounding (foreground vs. background) of changes was included as a covariate in the statistical models (below).

Visual controls

Photographs were analyzed for visual saliency using the saliency toolbox (Walther & Koch, 2006). This toolbox identifies the most salient 'objects' (or locations) in a scene. Saliency was determined based on a combination of intensity, orientation, and color maps. When choosing regions in which to make a change, we attempted to avoid these most salient regions. In order to compare whether saliency values from the pixels that contained a change differed between the change types, a saliency map was generated which contained a saliency value at each pixel. Regions of interest were created for each change region in each picture. Mean saliency value was extracted from within each change region using Matlab. Another potential low-level feature that could have influenced change detection was size of the change. The size of the change was determined by counting the number of pixels in the regions of interest for each change. Two one-way ANOVA's were conducted to examine the effect of saliency and size on change category (gaze center, gaze periphery, non-gaze center, non-gaze periphery). No significant difference in size of the change types was found ($F(3)=.576, p<.63$) but saliency did show an effect of change category ($F(3)=4.19, p<.01$) with changes in the center and line of gaze showing higher saliency values than changes in the periphery. Pairwise contrasts were examined using Tukey's HSD ($\alpha<.05$), and no differences in saliency were found between nongaze-center changes, gaze-center changes, and gaze-periphery changes or between gaze-periphery and non-gaze periphery changes. Saliency and change size were both included as covariates in the model (below).

Task

The experiment was conducted on an iMac computer with stimuli presented on an auxiliary 19" monitor using Matlab Version 7.7 (R2008b) with Psychophysics Toolbox Version 3. Participants received written and verbal instructions that they would be viewing a series of picture pairs and that these pairs would be presented in rapid alternation and would be identical except for three changes, such as changes in the color or the presence of an object. Participants were asked to identify these changes as quickly as possible and to respond via a button press. Participants were first given a practice task consisting of two trials that were identical to the actual task to ensure that subjects fully understood the task. Each trial began when the subject indicated that they were ready by pressing the mouse button. The subject would then be presented with the original photograph for 1000ms, a blank screen for 200ms, then the altered image for 1000ms, and another blank screen for 200ms. This sequence was looped until the subject indicated via a button press that a change was observed between the photographs. The button press brought up a blank screen. The subjects were required to give a verbal description of the change and to point on the blank screen in the area where the change was observed. The experimenter would record the change on the computer. Accuracy was determined online by the experimenter. When the subject indicated they were ready, this process would continue with the same photograph sequence. The subsequent trial would begin with a new stimulus once all three changes were observed, or until a time limit of 3 minutes was reached. Stimulus order was randomized for each subject.

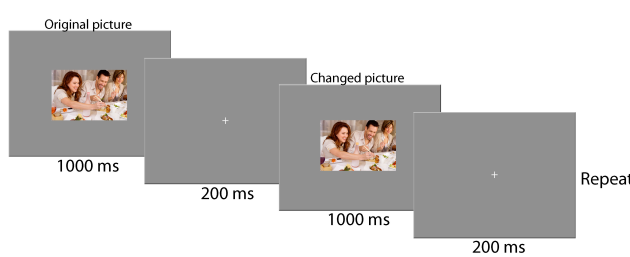

Figure 2: Timeline of one trial

Statistical analyses

Separate analyses were conducted on total number of changes detected and on the first change detected in each picture using logistic mixed-effects models as implemented in the lme4 package (Bates, Maechler, & Bolker, 2011) in the R software package (version 2.14.1; R Development Core Team, 2011). *Gaze* (change in the line of gaze or not), *location* (center or peripheral change) and *group* (ASD or control) were treated as fixed effects using orthogonal contrast coding, and participants and items were treated as crossed random effects, with the maximal random effects structure supported by the data. In addition, change *saliency*, *size*, and *grounding* (foreground or background) were included as centered fixed effect covariates.

Mixed effects models are useful for data such as these because they do not require aggregation across items nor do they require fully balanced data (Jaeger, 2008). Log-transformed response times were analyzed with similar (non-logistic) models. For readability and for purposes of graphical presentation, values are described as proportions (calculated as means of participant means) rather than as log-odds ratios and as raw response times (after excluding times exceeding two standard deviations from each participant's mean response time) rather than log transformed times.

Results

Gaze cues facilitate change detection

Participants first detected 53.5% of the changes in the line of gaze compared to only 25.3% of the changes not in the line of gaze; this 28.2% difference was reflected in a significant main effect of gaze (see Figure 3a; $b = 1.46$, $SE = 0.47$, $z = 3.09$, $p < .01$). Unsurprisingly, participants were (marginally significantly) more likely to first detect changes that were larger ($b = 0.30$, $SE = 0.02$, $z = 1.69$, $p < .10$). Although participants first detected numerically more changes in the periphery than in the center (37% vs. 32%), this difference did not reach significance ($b = 0.64$, $SE = 0.39$, $z = 1.64$, *n.s.*). There was, however, a marginally significant effect of location when the covariates of size, saliency, and grounding were not included in the model ($b = 0.90$ $SE = 0.54$, $z = 1.68$, $p < .10$); this likely reflects the fact that center changes were nearly always also foreground changes with higher saliency values than changes in the periphery. (Note that the model does not show concerning levels of collinearity; all variance inflation factors < 1.7).

There is evidence that changes in the foreground of pictures are easier to detect than changes in the background (Rensink, O'Regan, & Clark, 1997), however *grounding* did not explain significant variance in change detection or response times, suggesting that these differences were relatively minor.

Analysis of detection times to the first change (Figure 3b) revealed a similar pattern of results.[2] A main effect of gaze showed that participants detected changes in the line of gaze an average of 2.3 seconds faster than changes not in the line of gaze ($b = -0.30$, $SE = 0.13$, $t = -2.37$), a main effect of saliency showed faster detection of more visually salient changes ($b = -0.40$, $SE = 0.17$, $t = -2.30$), and a marginally significant effect of group ($b = -0.33$, $SE = 0.18$, $t = -1.82$) showed that control participants detected their first change an average of 2.4 seconds faster than ASD participants.

No effect of group on identification of gaze changes

No other effects or interactions reached significance (all *ps* > .1); in particular, the effect of gaze did not differ for ASD and control participants (29.0% vs 27.6%, respectively).

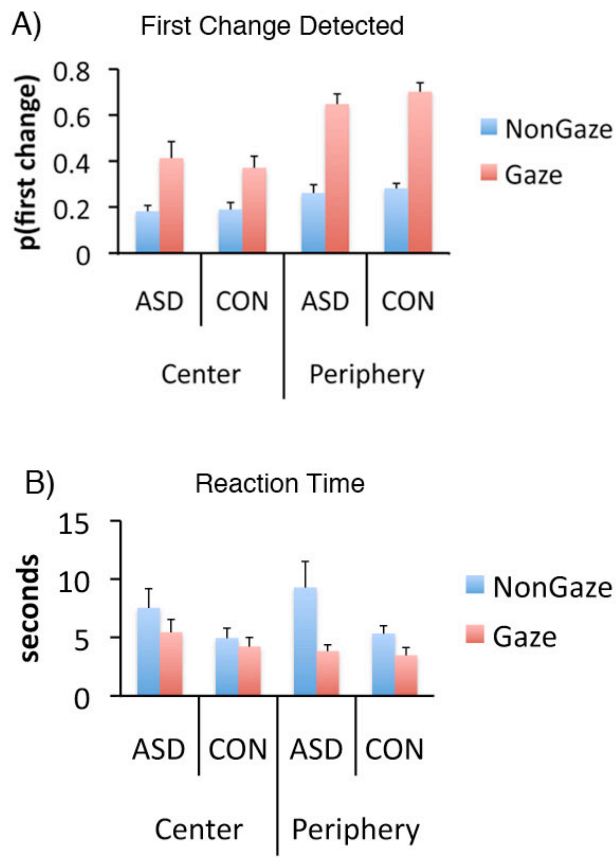

Figure 3: Effect of gaze on first change detected (A) and reaction time to detect change (B).

Total number of changes detected by group

Overall, ASD participants detected fewer changes than did controls, however this was largely due to the performance of one ASD participant who missed 35% of the changes (compared to an average miss-rate of 5.3% for the rest of the ASD group and 2.8% for the control group). With this participant excluded, ASD participants did not detect significantly fewer changes than did controls (94.7% vs. 97.2% detected; $b = -0.71$, $SE = 0.75$, $z = -0.95$, $p > .10$), although a marginally significant gaze by group interaction ($b = -2.08$, $SE = 1.22$, $z = -1.71$, $p = .09$) showed that ASD participants were more likely to miss changes that were *not* in the line of gaze (missing 6.6% non-gaze changes vs. 2.6%

[2] The lme4 package cannot currently estimate *p* values for *t*-statistics in models with random slopes, however common practice is to assume that *t* values greater than 2 are statistically significant.

of gaze changes) whereas controls showed a smaller difference, numerically in the other direction (2.4% missed non-gaze vs. 3.6% missed gaze changes).[3] ASD participants also took longer to detect all three changes (when all changes were, in fact, detected) then did control participants (an average of 51.5 vs. 40.1 seconds, respectively; $b = -0.16$, $SE = 0.05$, $t = -3.00$).

Discussion

Subtle gaze cues robustly affect visual attention

A robust effect of gaze on change detection was found in both the typical and ASD groups. This effect cannot be explained by low-level visual effects like size or saliency or grounding (foreground vs. background) of the change because the effect of gaze on first change detected and on time to detect the change were significant even with these variables as covariates.

Gaze cueing effects in a change detection paradigm have been demonstrated in typical adults previously (Langton, O'Donnell, Riby, & Ballantyne, 2006) but the gaze cues in those stimuli were highly salient (e.g., one person in the picture at a desk with body facing forward and some objects around him). Our findings provide a stronger test for the role of gaze in object detection through the presentation of multiple changes within a complex scene with multiple people and subtle gaze cues. In fact the cues were so subtle that in a post-test debriefing session, participants reported that they were unaware that direction of gaze provided any information about the location of the changes. Thus, these findings provide strong support that the object of someone's attention is prioritized during visual search – even without explicit awareness of the utility of gaze cues in this context.

No effect of group on change detection

Surprisingly, no effect of group was found. In fact, there was a trend for individuals with ASD to show a greater effect of gaze on change detection, especially for changes in the periphery. While we predicted an effect of group, this lack of a difference is consistent with several other change blindness studies suggesting normal prioritization of attention to social agents in ASD (Fletcher-Watson et al., 2008; New et al., 2010). Our findings extend previous work by showing normal prioritization of attention to the object of another person's attention in ASD even when the gaze cues were subtly embedded into the scene. These findings suggest that attention to (and use of) gaze information in high-functioning adults with autism may not be impaired and thus are not a determinant of atypical social interactions in adults.

An alternative possibility is that these (and other) findings of a failure to find group differences in offline, experimental contexts suggest that difficulties in social attention and gaze processing are due to inherent difficulties with real-time social interactions which are not captured by these offline tasks. The unpredictability and fast-pace of live interactions may add sufficient challenges to cause an otherwise capable system of social attention to break down. This conclusion remains speculative however without concurrent data from participants in the context of a real-time face-to-face interaction.

Finally, other factors may have contributed to this lack of a group difference. The participants in this study were high-functioning adults with autism and Asperger's disorder. Thus, their level of social impairment is by definition less severe than the majority of individuals with autism. Second, they have had years to develop strategies for success in social interactions, such as directing attention to the face and eyes. Indeed, atypical gaze processing may be greatest early in life (e.g., Klin, Jones, Schultz, & Volkmar, 2003; Leekam, Hunnisett, & Moore, 1998) but through treatment and compensatory strategies these differences may be minimized by adulthood.

Conclusions and Future Directions

These data show that normal use of gaze information in high-functioning adults with autism is not restricted to visually simplistic scenes; instead, in complex, real-world scenes with subtle embedding of gaze cues individuals with ASD show normal attentional prioritization to objects in the line of another's gaze. An important question for future research will be to determine when and how adults with autism do show atypical use of gaze information (e.g., see review by Klin, Jones, Schultz, & Volkmar, 2003). Atypical use of gaze information may be the most robust in real-time face-to-face contexts that are unpredictable and quickly changing. However, limited research has been done to investigate spontaneous difficulties with joint attention in adults with autism. This work will be critical to understand the specific difficulties with social interaction experienced throughout the lifespan in autism. For example, factors that underlie atypical social interactions in a toddler may be very different than those of an adult. Understanding how joint social attention is atypical will allow for more targeted inteventions and treatments for adults with autism, an area of relatively less investigation (e.g., Autism Speaks Strategic Plan, 2009).

Acknowledgments

The authors thank Kang Won Choi for discussions on the design of the study. We gratefully acknowledge Rashida Callendar, Joy Ekuta, and Eugenia Luo for assistance with stimuli creation and editing and Ariana Mann for assistance with stimuli creation and pilot testing. This work was supported by funding from the Simons Foundation Autism Research Initiative (SFARI) awarded to J.G. and P.S and a postdoctoral fellowship awarded from the National Institute of Child Health and Human Development awarded to E.R.

[3] All other analyses are reported over data from all participants, but note that the pattern of results does not change appreciably if this participant is excluded.

References

Baldwin, D. A., Markman, E. M., Bill, B., Desjardins, R. N., Irwin, J. M., & Tidball, G. (1996). Infants' Reliance on a Social Criterion for Establishing Word-Object Relations. *Child development*, *67*(6), 3135–3153. Wiley Online Library.

Bar-Haim, Y., Shulman, C., Lamy, D., & Reuveni, A. (2006). Attention to eyes and mouth in high-functioning children with autism. *Journal of autism and developmental disorders*, *36*(1), 131-7.

Bates, D. M., Maechler, M., & Bolker, B. (2011). Linear mixed-effects models using S4 classes. *R A Language and Environment for Statistical Computing*. R package version 0.9975-0.

Brenner, L. a, Turner, K. C., & Müller, R.-A. (2007). Eye movement and visual search: are there elementary abnormalities in autism? *Journal of autism and developmental disorders*, *37*(7), 1289-309.

Charman, T. (2003). Why is joint attention a pivotal skill in autism? *Philosophical transactions of the Royal Society of London. Series B, Biological sciences*, *358*(1430), 315-24.

Dalton, K. M., Nacewicz, B. M., Johnstone, T., Schaefer, H. S., Gernsbacher, M. A., Goldsmith, H H, Alexander, A. L., et al. (2005). Gaze fixation and the neural circuitry of face processing in autism. *Nature neuroscience*, *8*(4), 519-26. doi:10.1038/nn1421

Fletcher-Watson, S, Leekam, S R, Benson, V., Frank, M. C., & Findlay, J M. (2009). Eye-movements reveal attention to social information in autism spectrum disorder. *Neuropsychologia*, *47*(1), 248-57.

Fletcher-Watson, Sue, Leekam, Susan R, Findlay, John M, & Stanton, E. C. (2008). Brief report: young adults with autism spectrum disorder show normal attention to eye-gaze information-evidence from a new change blindness paradigm. *Journal of autism and developmental disorders*, *38*(9), 1785-90.

Freeth, M., Chapman, P., Ropar, D., & Mitchell, P. (2010). Do gaze cues in complex scenes capture and direct the attention of high functioning adolescents with ASD? Evidence from eye-tracking. *Journal of autism and developmental disorders*, *40*(5), 534-47.

Gernsbacher, M. A., Stevenson, J. L., Khandakar, S., & Goldsmith, H. Hill. (2008). Why Does Joint Attention Look Atypical in Autism? *Child Development Perspectives*, *2*(1), 38-45.

Jaeger, T. F. (2008). Categorical Data Analysis: Away from ANOVAs (transformation or not) and towards Logit Mixed Models. *Journal of memory and language*, *59*(4), 434-446. Elsevier Inc. Jones, W., Carr, K., & Klin, A. (2008). Absence of preferential looking to the eyes of approaching adults predicts level of social disability in 2-year-old toddlers with autism spectrum disorder. *Archives of general psychiatry*, *65*(8), 946-54.

Klin, A., Jones, W., Schultz, R., & Volkmar, F. (2003). The enactive mind, or from actions to cognition: lessons from autism. *Philosophical transactions of the Royal Society of London. Series B, Biological sciences*, *358*(1430), 345-60.

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), 809-16.

Langton, S. R. H., O'Donnell, C., Riby, D. M., & Ballantyne, C. J. (2006). Gaze cues influence the allocation of attention in natural scene viewing. *Quarterly journal of experimental psychology (2006)*, *59*(12), 2056-64.

Leekam, S R, Hunnisett, E., & Moore, C. (1998). Targets and cues: gaze-following in children with autism. *Journal of child psychology and psychiatry*, *39*(7), 951-962.

Lord, C., Risi, S., Lambrecht, L., Cook, E. H., Leventhal, B. L., DiLavore, P. C., Pickles, a, et al. (2000). The autism diagnostic observation schedule-generic: a standard measure of social and communication deficits associated with the spectrum of autism. *Journal of autism and developmental disorders*, *30*(3), 205-23.

Mundy, P., & Newell, L. (2007). Attention, Joint Attention, and Social Cognition. *Current directions in psychological science : a journal of the American Psychological Society*, *16*(5), 269-274.

Nation, K., & Penny, S. (2008). Sensitivity to eye gaze in autism: is it normal? Is it automatic? Is it social? *Development and psychopathology*, *20*(1), 79-97.

New, J. J., Schultz, R. T., Wolf, J., Niehaus, J. L., Klin, A., German, T. C., & Scholl, B. J. (2010). The scope of social attention deficits in autism: prioritized orienting to people and animals in static natural scenes. *Neuropsychologia*, *48*(1), 51-9.

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), 249-61.

Rensink, R. A., O'Regan, J. K., & Clark, J. J. (1997). To See or not to See: The Need for Attention to Perceive Changes in Scenes. *Psychological Science*, *8*(5), 368-373. SAGE Publications.

Spezio, M. L., Adolphs, R., Hurley, R. S. E., & Piven, J. (2007). Abnormal use of facial information in high-functioning autism. *Journal of Autism and Developmental Disorders*, *37*(5), 929-939. Springer.

Tomasello, M., Carpenter, M., Call, J., Behne, T., & Moll, H. (2005). Understanding and sharing intentions: the origins of cultural cognition. *The Behavioral and brain sciences*, *28*(5), 675-91; discussion 691-735.

Walther, D., & Koch, C. (2006). Modeling attention to salient proto-objects. *Neural networks : the official journal of the International Neural Network Society*, *19*(9), 1395-407.