# Abnormality in face scanning by children with autism spectrum disorder is limited to the eye region: Evidence from multi-method analyses of eye tracking data

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There has been considerable controversy regarding whether children with autism spectrum disorder (ASD) and typically developing children (TD) show different eye movement patterns when processing faces. We investigated ASD and age- and IQ-matched TD children's scanning of faces using a novel multi-method approach. We found that ASD children spent less time looking at the whole face generally. After controlling for this difference, ASD children's fixations of the other face parts, except for the eye region, and their scanning paths between face parts were comparable either to the age-matched or IQ-matched TD groups. In contrast, in the eye region, ASD children's scanning differed significantly from that of both TD groups: (a) ASD children fixated significantly less on the right eye (from the observer's view); (b) ASD children's fixations were more biased towards the left eye region; and (c) ASD children fixated below the left eye, whereas TD children fixated on the pupil region of the eye. Thus, ASD children do not have a general abnormality in face scanning. Rather, their abnormality is limited to the eye region, likely due to their strong tendency to avoid eye contact.

## Introduction

Atypical face processing is a social cognitive deficit among individuals with autism spectrum disorder

(ASD). Behavioral studies have found that ASD individuals have impairments in face recognition and discrimination (e.g., Chawarska, Volkmar, & Klin, 2010; Klin et al., 1999; Langdell, 1978; McPartland, Dawson, Webb, Panagiotides, & Carver, 2004; Pellicano, Jeffery, Burr, & Rhodes, 2007; see Weigelt, Koldewyn, & Kanwisher, 2011, for a review). Using EEG and fMRI methodologies, researchers have also found atypical neural correlates of face processing in ASD individuals (e.g., Dalton et al., 2005; Dawson et al., 2002; Monk et al., 2010; Morita et al., 2012; Pierce, Müller, Ambrose, Allen, & Courchesne, 2001; Vlamings, Jonkman, & Kemner, 2010; see Dawson, Webb, & McPartland, 2005, for a review).

Eye tracking techniques have also been used to examine how ASD individuals scan faces. Overall, existing studies have consistently found that ASD children and adults show reduced visual attention to faces compared to their typically developing (TD) counterparts (see Falck-Ytter & von Hofsten, 2011, for a review). Regarding ASD individuals' visual attention to specific face parts, there has been considerable controversy (see Falck-Ytter & von Hofsten, 2011, for a review). Some studies have found no differences in fixation to a specific face part between ASD and TD individuals (Bar-Haim, Shulman, Lamy, & Reuveni, 2006; Falck-Ytter, Fernell, Gillberg, & von Hofsten, 2010; Fletcher-Watson, Leekam, Benson, Frank, & Findlay, 2009; Rutherford & Towns, 2008). However, other studies have reported reduced attention to core features of faces (i.e., eyes, nose, mouth) in ASD individuals (e.g., Corden, Chilvers, & Skuse, 2008; Falck-Ytter, 2008; Hernandez et al., 2009; Jones, Carr, & Klin, 2008; Pelphrey et al., 2002; Speer, Cook, McMahon, & Clark, 2007).

Another important issue is the control group to which ASD children are compared. Some eye tracking studies have examined individuals with high-functioning autism (HFA) and IQs that did not differ from the TD group (e.g., Klin, Jones, Schultz, Volkmar, & Cohen, 2002; Pelphrey et al., 2002; Rutherford & Towns, 2008; Speer et al., 2007). However, most studies have matched ASD and TD groups by only chronological age, not general mental ability (e.g., Chawarska & Shic, 2009; Corden et al., 2008; Dalton et al., 2005; Hernandez et al., 2009; Van Der Geest, Kemner, Camfferman, Verbaten, & Van Engeland, 2002). It is thus unclear whether some of the inconsistent findings might be due to mental ability differences rather than ASD per se. The present study recruited a TD control group to match the ASD group's chronological age, and another younger TD group to match the ASD group's IQ.

In addition, all findings mentioned above have been based on the traditional area of interest (AOI) approach, which measures fixations that fall within a predefined area of interest (AOI), typically including the AOIs of eyes, nose, and mouth, respectively. By combining fixations on a particular AOI, one can have a relatively large sample of fixation data to obtain reliable estimates of participants' looking patterns at specific AOIs. However, the approach tends to lump fixations to a large area of the face together as qualitatively the same. Consequently, it could fail to reveal potential differences between ASD and typical individuals in fixation patterns within the area (e.g., ASD individuals may look more at peripheral areas of the eyes, whereas typical individuals may look more at the center of the eyes).

Thus, the AOI approach needs to be supplemented with alternative methods such as the iMAP approach. Unlike the AOI approach that only uses fixations longer than a predetermined length, the iMAP method developed by Caldara and Miellet (2011) uses all fixation points whose length is over 100 ms. Also unlike the AOI approach, the iMAP approach amalgamates fixations on the exact spatial location where they land and then statistically compares between conditions or groups at the pixel level. Whereas this data-driven approach has the shortcoming of failing to reveal significant differences in some spatial areas where fixations are minimal, it compensates for the shortcoming of the AOI approach by revealing spatial differences in fixations between groups or conditions at a much finer spatial resolution.

Another limitation of the AOI approach is that although the eye tracking technique provides rich information about both fixations and saccades (i.e., the rapid eye movements between fixations: Bahill, Brockenbrough, & Troost, 1981; Salvucci & Goldberg, 2000), the AOI approach focuses exclusively on fixations, not saccades. Thus, its overuse in the field has led to limited understanding of how children with or without ASD actually scan faces (see Klin et al., 2002, and Rutherford & Towns, 2008, for exceptions with ASD adults). Face processing in individuals with ASD has been found to be based on featural processing instead of holistic processing (e.g., Joseph & Tanaka, 2003). It is also predicted by the Weak Central Coherence (WCC) theory that in contrast to typical individuals' engaging in global processing and extracting coherent representations, individuals with ASD tend to engage in local and detail-focused processing (e.g., Happe & Frith, 2006). We therefore undertook a saccade path analysis to provide information about how frequently children shift attention between the facial features, such as visual fixations between the eyes, between the eyes and the mouth, and between the eyes and the nose. Analyzing saccades between fixations allows us to address this neglect in the literature and to better understand the face-processing patterns in individuals with ASD. Based on the featural processing of faces in individuals with ASD, we expected that children with

| | Male (female) | Age range | Mean age | Original raven score | Standardized raven score | AQ |
|---|---|---|---|---|---|---|
| ASD | 17 (3) | 5.17–10.92 | 7.85 (1.59) | 21.53 (8.78) | 77.16 (19.55) | 90.95 (9.87) |
| Age-matched TD | 18 (3) | 4.92–10.08 | 7.73 (1.51) | 29.33 (10.13) | 89.42 (11.23) | 57.89 (9.91) |
| IQ-matched TD | 18 (2) | 4.33–6.92 | 5.69 (0.83) | 21.60 (6.62) | 98.11 (7.01) | 62.20 (12.98) |
| Difference (t test) | | | | | | |
|   ASD vs. Age-matched TD | N/A | N/A | 0.26 | −2.59 | −2.46 | 10.43*** |
|   ASD vs. IQ-matched TD | N/A | N/A | 5.42*** | −0.03 | −4.29*** | 7.88*** |
|   Age- vs. IQ-matched TD | N/A | N/A | 5.42*** | 2.88** | −2.50* | −1.16 |

Table 1. Participant characteristics of the ASD and TD groups. *Note.* Standard deviations are shown in parentheses. *$p < 0.05$. **$p < 0.01$. ***$p < 0.001$.

ASD in the present study would scan less often between face features compared to TD children.

This study was thus conducted to address the major limitations in current eye tracking research with ASD children. We used three different, but complementary data analysis approaches concurrently. First, with the traditional AOI approach, we examined whether ASD and TD children fixate on different parts of a face differently. Second, we employed the data-driven approach to examine whether we could replicate the findings of the AOI approach and reveal more subtle differences between the groups. Third, we utilized a novel saccade path approach to analyze specific eye movement shifts between key areas of the face. By using three levels of analysis in tandem, we aimed to elucidate potential similarities and differences among TD and ASD children in face scanning that the AOI approach alone might have failed to observe.

We tested face recognition and scanning by children with ASD and age-matched and IQ-matched TD children. The two comparison groups were used to ascertain whether ASD children, after controlling for age and IQ, still show atypical face scanning patterns. We used an old-new face recognition paradigm whereby we asked children to remember a number of faces and then tested them with either "old" familiarized faces or "new" un-familiarized faces.

## Method

### Participants

Three groups of Chinese children participated: 20 with ASD (age range: 5.17–10.92 years, $M_{age} = 7.85$, $SD = 1.59$, three female), 21 age-matched TD children (age range: 4.92–10.08 years, $M_{age} = 7.73$, $SD = 1.51$, three female), and 20 IQ-matched TD children (age range: 4.33–6.92 years, $M_{age} = 5.69$, $SD = 0.83$, two female), see Table 1 for details. Children with ASD were previously diagnosed by pediatric psychiatrists according to the diagnostic criteria for autism as specified in the DSM-IV (American Psychiatric Association, 1994). Any children who were suspected of having schizophrenia, mental retardation, congenital deafness, and other developmental disorders were excluded.

Standardized diagnostic scales such as the Autism Diagnostic Interview–Revised (ADI-R, Le Couteur et al., 1989; Lord, Rutter, & Le Couteur, 1994) or the Autism Diagnostic Observation Schedule (ADOS, Lord et al., 2000) have not been officially translated into Chinese. Therefore, to confirm the diagnosis of ASD children, we used the Chinese version of the Autism Spectrum Quotient: Children's Version (AQ-Child), developed and translated by Auyeung, Baron-Cohen, Wheelwright, and Allison (2008). As reported by Auyeung et al. (2008), the AQ cut-off score is 76 with high sensitivity and specificity. Those with AQ scores below the cut-off score (76) in the ASD group, and those with AQ scores above the cut-off score in the TD groups, were excluded from the sample. Mean AQ scores of children with ASD were significantly above the cut-off score (76), $t(19) = 6.77$, $p < 0.001$, while age- and IQ-matched TD children's mean AQ scores were significantly below the cut-off score (76), $t(18) = -7.96$, $p < 0.001$, and $t(19) = -4.75$, $p < 0.001$, respectively. No age difference was found between ASD and age-matched TD children, $t(39) = 0.26$, $p = 0.80$. Children's IQ was measured using the Combined Raven Test (CRT-C2). There was no difference of original Raven scores between the ASD and IQ-matched groups, $t(37) = -0.03$, $p = 0.98$.

### Material

Twelve photos of Chinese adult female faces were used (width: 500 pixels, height: 700 pixels, resolution: 72 pixels per inch). Because of ASD children's known difficulties in face recognition, only three faces served as targets. The other nine faces were foils. All faces were frontal view and rendered grey. Also, they were matched in overall brightness and luminance using Photoshop, and overlaid with the same elliptical shape (Figure 1A). The faces were additionally normalized to
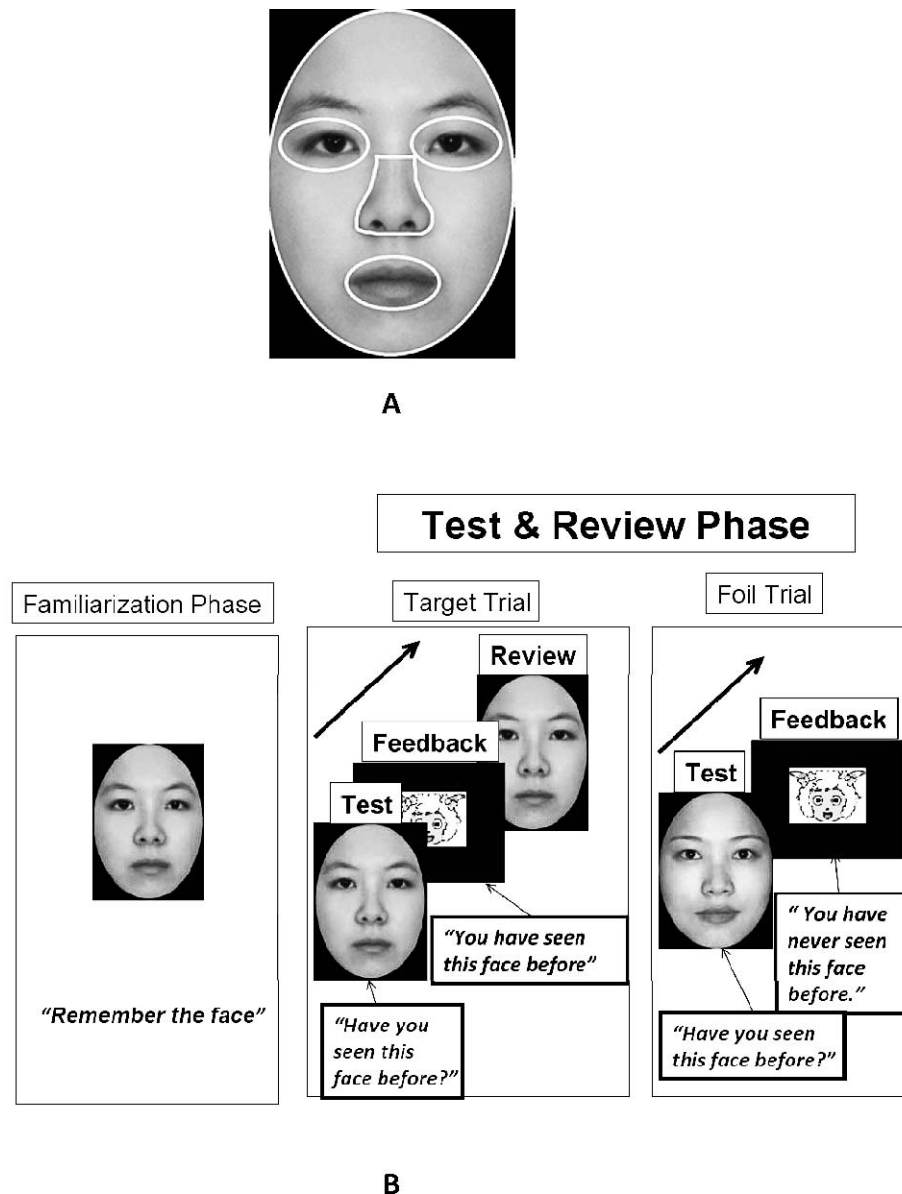
Figure 1. Sample Area of Interest (AOI) plots (A) and schematic representation of the experimental design (B).

the same face template, such that locations of major facial features were positioned approximately in the same face regions. We used a Tobii T60 eye tracker with a sample rate of 60 Hz and a screen resolution of 1024 × 768 pixels to record participants' eye movements, and Tobii Studio to present the face stimuli.

## Procedure

Children received a practice session before the experiment so as to gain familiarity with the task. Then, a calibration was conducted with the Tobii calibration program. Calibrations were considered successful when all five points showed a good fit in the computed mapping for both eyes.

The experimental session consisted of one familiarization phase and three test-review phases (Figure 1B). During familiarization, children viewed and attempted to remember three target faces. Each target face was presented for 3 s. During test-review, children saw 12 test faces that were either a target or a foil, and judged whether the face was "seen before" or "never seen before." There were an equal number of target and foil trials. In the target trials, familiarized faces were presented for children to recognize. Presentation was terminated as soon as the child responded. After the recognition phase, the target was presented once more for children to review for another 3 s (Review Phase). In the foil trials, a novel face was presented until children responded. Each foil trial used a novel face that the child had

never seen before. Order of target and foil trials was randomized. Feedback was given after each trial: either, "You have seen this face before" for target trials, or "You have never seen this face before" for foil trials. Children's responses were recorded manually, and eye movements throughout the experiment were recorded by a Tobii T60.

## Data analysis

### AOI approach

We first defined five AOIs, including whole face (i.e., area within the face contour without the hair), left eye (from the observer's view), right eye, nose, and mouth (Figure 1A). Each AOI was defined such that the entire face feature of interest plus an additional 50 pixels of edges were included. The AOIs were defined individually for each face to accommodate the slight size variability of face features even after normalization. A fixation was defined as a sustained look at the AOI for more than 100 ms, within a fixation radius of 50 pixels. During familiarization and review, each face was presented for a fixed length of 3 s, and all fixations during the time interval were counted. However, during recognition, faces were presented until children responded. Total fixation durations were computed for each AOI by summing durations of all fixations within the AOI. Outliers of total fixation duration on the whole stimulus were removed from further analyses (3 $SD$s beyond the mean, 1.46% of the data points). Proportional fixation durations were calculated by dividing total fixation time on each AOI by total fixation time on the whole face (excluding fixations on areas beyond the oval overlay contouring the face).

### Data-driven approach

We used the iMAP Matlab Toolbox (Caldara & Miellet, 2011) to generate heatmaps for each group of children and difference maps for comparisons between groups. With this procedure, we first computed fixation maps by summing the fixation duration on fixation location coordinates, across all valid trials for each group × face type condition, thereby weighting the importance of a fixation as a function of its duration. The iMAP applies a Gaussian kernel function to spatially smooth each fixation map. $Z$ scores were then computed for each map to normalize data. To reveal the difference of fixation patterns between groups and for different face types, we subtracted one difference map from another and $Z$ scored the resulting difference maps prior to the statistical comparison. Instead of requiring a priori subjective segmentation of face

stimuli into AOIs, the iMAP toolbox computes the statistical maps of fixations on any location in the visual stimuli at the pixel level. Since the resulting maps contain thousands of pixels and generate a large number of statistical comparisons, the iMAP corrects for this problem of multiple comparisons by applying a robust statistical Random Field Theory (RFT) approach, which is widely used in functional magnetic resonance imaging (fMRI). Specifically, the iMAP Toolbox applies the statistical Pixel test from the Stat4Ci toolbox (Chauvin, Worsley, Schyns, Arguin, & Gosselin, 2005). To establish significance, the iMAP used a one-tailed Pixel test ($p < 0.05$) for maps of each condition and a two-tailed Pixel test ($p < 0.05$) for each difference map. Also, a fixation position alignment procedure was conducted prior to iMAP analysis, to ensure that major facial features of the face stimuli (e.g., eyes, nose, and mouth) aligned across all face stimulus images.

### Saccade path analysis

We developed an in-house Scanpath Matlab Toolbox that counted frequencies of gaze shifts from one AOI area to another (Bahill et al., 1981; Salvucci & Goldberg, 2000). These paths included any shifts between the two eyes, eyes and nose, eyes and mouth, and nose and mouth, and between the eyes (left and right eyes combined), nose, and mouth (any eye movement that shifted consecutively across eyes, nose, and mouth in any order was counted as one scan). The proportional frequencies of saccade paths were calculated by dividing the counts of each saccade path by the total counts of saccade paths on the whole stimulus.

## Results

### Accuracy

Table 2 shows means and $SD$s of accuracy (%) for ASD and TD children's face recognition. One-sample $t$ tests showed that age- and IQ-matched TD children recognized faces significantly above chance (i.e., 50%), $t(20) = 10.44$, $p < 0.001$, $\eta^2 = 0.85$, and $t(19) = 5.85$, $p < 0.001$, $\eta^2 = 0.64$, respectively, but ASD children did not, $t(19) = 0.30$, $p = 0.77$, $\eta^2 = 0.005$. An ANOVA revealed a significant group effect, $F(2, 58) = 19.69$, $p < 0.001$, $\eta^2 = 0.40$. A priori contrasts showed that ASD children recognized faces significantly less accurately than age- and IQ-matched TD children, $p < 0.001$, and $p = 0.001$, respectively.

To examine whether accuracy was improved over trials, we conducted Spearman correlations between

|  | ASD | Age-matched TD | IQ-matched TD |
|---|---|---|---|
| Behavioral performance | | | |
|   Accuracy (%) | 51.15 (16.17) | 79.10 (12.78) | 66.25 (12.43) |
| Total fixation durations (ms) | | | |
|   Whole face | 2253.57 (699.23) | 3083.26 (642.88) | 3004.69 (908.03) |
| Proportional fixation durations | | | |
|   Right eye | 0.11 (0.09) | 0.19 (0.12) | 0.20 (0.09) |
|   Left eye | 0.17 (0.11) | 0.16 (0.09) | 0.12 (0.08) |
|   Nose | 0.29 (0.12) | 0.26 (0.12) | 0.23 (0.12) |
|   Mouth | 0.14 (0.09) | 0.18 (0.13) | 0.12 (0.08) |
| Proportional frequencies of saccade paths (%) | | | |
|   Between eyes | 2.47 (3.71) | 7.47 (6.99) | 3.52 (4.18) |
|   Eyes-nose | 7.42 (5.02) | 13.08 (6.34) | 9.94 (6.93) |
|   Eyes-mouth | 2.72 (2.37) | 4.60 (4.77) | 3.34 (3.69) |
|   Nose-mouth | 4.26 (2.95) | 11.67 (10.48) | 5.25 (6.40) |
|   Face-nonface | 17.23 (6.26) | 5.70 (3.51) | 13.73 (5.02) |

Table 2. Means and *SD*s of accuracy, total and proportional fixation durations, and proportional frequencies of saccade paths between AOIs, for ASD, age-matched TD, and IQ-matched TD children. *Note.* Standard deviations are shown in parentheses.

trial and accuracy for each group. Results showed an improvement of accuracy over trials for both age- and IQ-matched TD groups, $r_s = 0.13$, $p = 0.013$, $r_s = 0.20$, $p < 0.001$, respectively. There was no improvement over trials for children with ASD, $r_s = 0.001$, $p = 0.99$.

## Total fixation durations and counts

Preliminary analyses revealed highly similar data patterns for fixations on target faces during the familiarization, test, and review phases, and foil faces during the test phase. Therefore, all fixations on a face during all the phases were combined. Also, similar data patterns were obtained for target and foil faces. Thus, fixation data for both types of faces were summed to calculate total fixation durations for each child. In addition, statistical results based on fixation counts were nearly identical to those based on fixation durations. To avoid redundancy, results will only be reported based on the latter.

Table 2 shows group means and standard deviations of total fixation duration within the face. An ANOVA showed a significant group effect on total fixation time on the face, $F(2, 58) = 7.40$, $p = 0.001$, $\eta^2 = 0.20$. A priori contrasts showed that ASD children fixated significantly less on the face than age-matched and IQ-matched TD children, $p = 0.001$, and $p = 0.003$, respectively.

To examine whether children showed different scanning patterns for correct and incorrect trials, we performed additional analyses on the eye movement index using a 3 (Group: ASD, age- and IQ-matched TD) × 2 (Performance: correct vs. incorrect) mixed-design ANOVA. Results showed a significant perfor-

mance effect on the total face looking time, $F(1, 56) = 12.41$, $p = 0.001$, $\eta^2 = 0.18$, a group effect, $F(2, 56) = 8.16$, $p = 0.001$, $\eta^2 = 0.23$, and a face × group interaction, $F(2, 56) = 4.17$, $p = 0.021$, $\eta^2 = 0.13$. Simple effect analyses showed that for the ASD group, there was no effect of performance on the face-looking time, $F(1, 56) = 0.10$, $p = 0.76$; age- and IQ-matched TD children both looked at the face longer on correct trials than on incorrect trials, $F(1, 56) = 10.96$, $p = 0.002$, $F(1, 56) = 9.42$, $p = 0.003$, respectively.

## Proportional fixation duration on individual AOIs

Because ASD children fixated less on the face area than the age- and IQ-matched TD children, to examine whether ASD and TD children also fixated on the major face features differently, we calculated proportional fixation durations within each AOI (each eye, nose, and mouth) with total fixation time on the face area controlled. Table 2 shows the resultant means and standard deviations.

ANOVAs were performed on ASD and TD children's proportional fixation durations on each AOI. When we combined results from both eyes, as is typical in the literature (e.g., Falck-Ytter, 2008; Jones et al., 2008; Pelphrey et al., 2002; Speer et al., 2007), group differences in proportional fixation durations were not significant, $F(2, 58) = 0.86$, $p = 0.43$, $\eta^2 = 0.03$. There were also no significant group differences in looking time on the nose or mouth, $F(2, 58) = 1.40$, $p = 0.26$, $\eta^2 = 0.05$, $F(2, 58) = 1.82$, $p = 0.17$, $\eta^2 = 0.06$, respectively.

When we examined proportional fixation durations on each of the two eyes, the group effect was significant on the
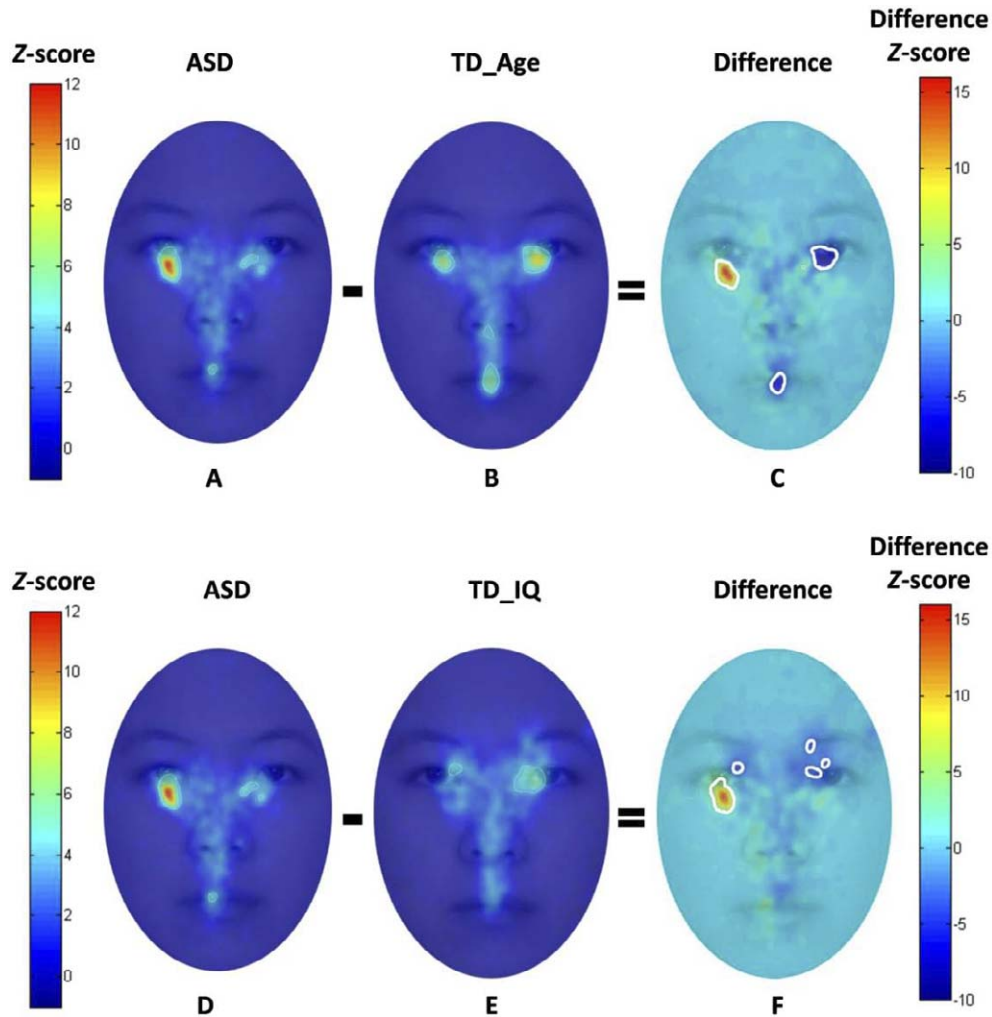
Figure 2. Heat maps for ASD and age-matched TD children (A, B) and the difference map (C), and mean saliency maps for ASD and IQ-matched TD children (D, E) and the difference map (F). The colors represent *Z* scores of fixation duration, with warm colors denoting longer fixation duration and cold colors denoting shorter fixation duration. White contours in the difference maps indicate regions of significant difference (at the alpha level of 0.05, two-tailed). Note that the left and right temperature scales are different.

right eye (from the observer's perspective), $F(2, 58) = 4.58$, $p = 0.014$, $\eta^2 = 0.14$. A priori contrasts revealed that ASD children looked less at the right eye than age- and IQ-matched TD children, $p = 0.019$ and $p = 0.007$, respectively. No significance of group difference was found for the left eye, $F(2, 58) = 1.99$, $p = 0.15$, $\eta^2 = 0.06$.

Additional analyses with a 3 (Group) × 2 (Performance: correct vs. incorrect) mixed-design ANOVA revealed no effects of performance or group × performance interaction for the proportional fixation durations on the core facial features, $ps > 0.05$.

## Data-driven analysis

The results of the data-driven analysis are shown in Figure 2. Figures 2A and 2B illustrate ASD and age-

matched TD children's fixation distributions during face recognition as well as their differences by subtracting the fixation map for age-matched TD children from ASD children (Figure 2C). Figures 2D and 2E illustrate ASD and IQ-matched TD children's fixation distributions during face recognition, as well as their differences by subtracting the fixation map for IQ-matched TD children from ASD children (Figure 2F). Significant difference areas are marked by white borders, $p < 0.05$, corrected.

As shown, most fixations for both ASD and TD children fell in the central triangular area of the face. However, there were also marked differences between ASD and TD children. When compared to baseline, both groups of TD children fixated mostly around the eye, mouth, and nose regions. For ASD children, there was only one significantly fixated area: the left eye (from the observer's perspective).
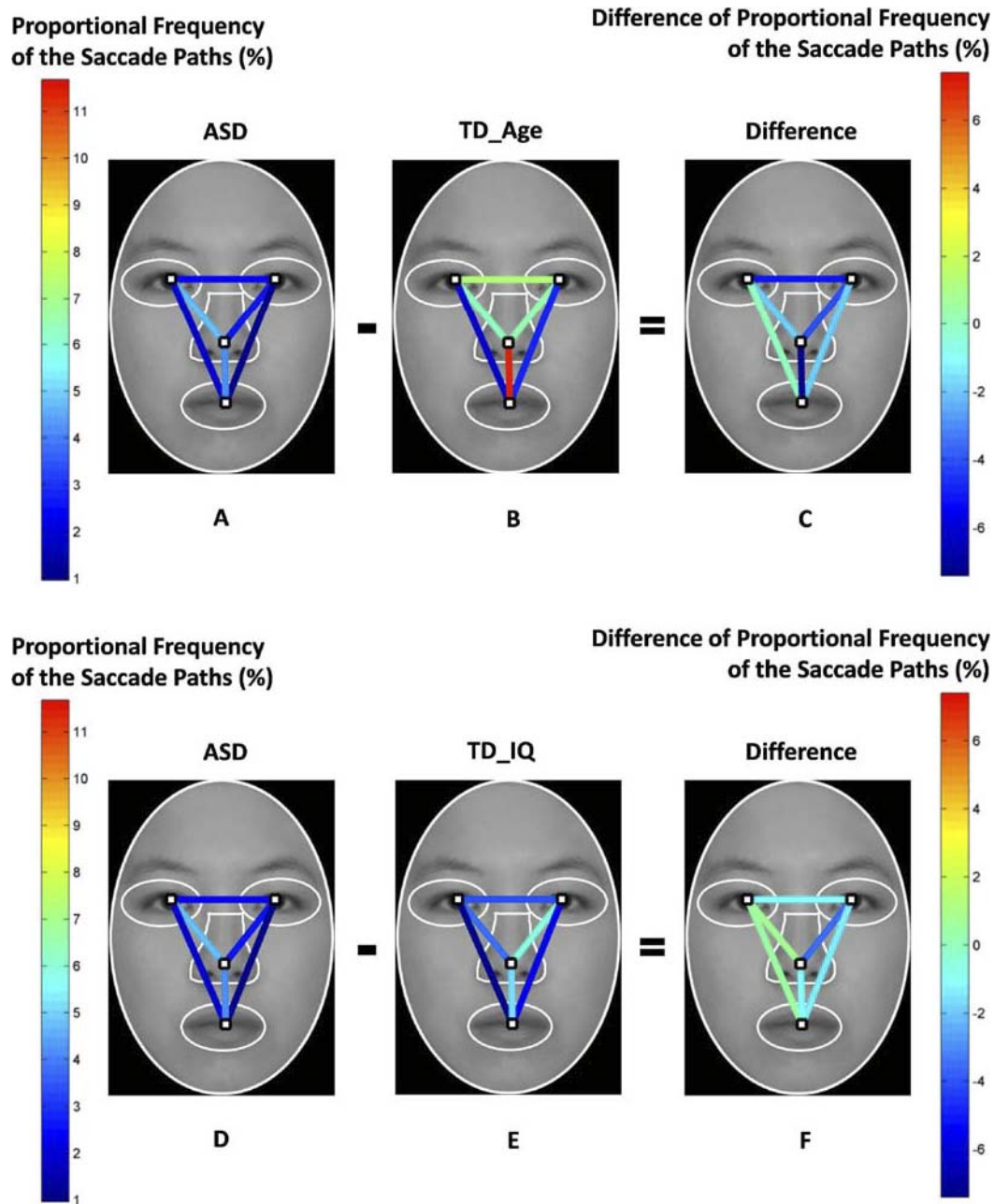
Figure 3. Saccade path maps for ASD and age-matched TD observers looking at faces (A, B) and the difference map (C), and mean proportional saccade path maps for ASD and IQ-matched TD observers (D, E) and the difference map (F). The six lines in each map represent paths between eyes, left eye and nose, right eye and nose, left eye and mouth, right eye and mouth, and nose and mouth, respectively. The color of the lines refers to the proportional saccade path within each region, with warm colors denoting more proportional saccade paths and cold colors denoting fewer proportional saccade paths. Note that the left and right temperature scales are different.

When fixation maps of the groups were contrasted statistically, ASD children looked significantly longer at the left eye of the face, but significantly shorter at the right eye. Furthermore, although children with ASD looked longer at the left eye, such prolonged fixations were actually below and outside of the eye itself. Finally, ASD children looked significantly less at the central mouth area than age-matched TD children.

## Saccade path analysis

We calculated the proportional frequencies of saccade paths by dividing the frequency of each saccade path by the total number of saccade paths on the whole stimulus. Table 2 lists the means and SDs of the proportional frequencies of saccade paths. Figure 3 represents maps for proportional saccade paths for

ASD children, age- and IQ-matched TD children, and the differences between ASD and TD children. Figures 3A and 3B illustrate scan path maps for the proportional saccade path for ASD and age-matched TD children during face recognition, whereas Figure 3C illustrates their differences by subtracting the path map for age-matched TD children from ASD children. Figures 3D, 3E, and 3F illustrate comparable scan path maps for proportional saccade path for ASD and IQ-matched TD children and their differences.

One-way ANOVAs revealed significant group effects on proportional frequencies of saccade paths between the eyes, $F(2, 58) = 5.29$, $p = 0.008$, $\eta^2 = 0.15$, between eyes and nose, $F(2, 58) = 4.37$, $p = 0.017$, $\eta^2 = 0.13$, between nose and mouth, $F(2, 58) = 6.17$, $p = 0.004$, $\eta^2 = 0.18$, and between the face and non-face areas, $F(2, 58) = 28.41$, $p < 0.001$, $\eta^2 = 0.50$. A priori contrasts revealed that ASD children scanned significantly less often than age-matched TD children between the eyes, $p = 0.003$, between eyes and nose, $p = 0.005$, and between nose and mouth, $p = 0.002$. No significant differences were found in the contrast between ASD children and IQ-matched children for the above paths. However, children with ASD scanned more often between the face and non-face paths than the age- or IQ-matched TD children, $p < 0.001$, $p = 0.032$, respectively.

The 3 (Group) × 2 (Performance: correct vs. incorrect) mixed-design ANOVAs revealed significant performance effects on the proportional saccade paths between the eyes and nose, $F(1, 57) = 9.923$, $p = 0.003$, $\eta^2 = 0.15$, indicating that children scanned the eyes and nose less often on correct trials than on incorrect trials. No performance × Group interaction was found for any saccade paths.

## Correlations between accuracy and eye movement measures

We calculated the Pearson correlations between face recognition performance and eye movement measures for ASD, age-, and IQ-matched TD children separately. For the ASD children, no significant correlations were found between their face recognition performance and eye movement measures, which might be due to their chance level face recognition performance. For the TD groups, the face recognition performance was also not significantly correlated with most of the eye movement measures. For the IQ-matched TD group, recognition accuracy positively correlated only with the proportional fixation duration of the left eye, $r_p(20) = 0.57$, $p = 0.009$.

## Discussion

Consistent with existing behavioral findings, ASD children recognized faces significantly more poorly than age- and IQ-matched children. Eye tracking results from the AOI approach found that children with ASD fixated less on faces than age- and IQ-matched TD children. This result is also consistent with the existing eye tracking findings (e.g., Chawarska & Shic, 2009; Dewit, Falck-Ytter, & von Hofsten, 2008). When we controlled for total fixation time differences on the whole face using proportional fixation duration measures, ASD children did not significantly differ from either group of TD children in proportional fixation durations on the eyes (both combined), nose, and mouth. These findings, based on the AOI approach, are consistent with the results of some previous studies that also analyzed the eye region by combining fixations on the two eyes (e.g., Chawarska & Shic, 2009; Dewit et al., 2008; Nakano et al., 2010; Van Der Geest et al., 2002; see Bal et al., 2010; Jones et al., 2008, for findings to the contrary). However, when we separated proportional fixation durations on the right and left eyes (from the observer's perspective), ASD children's durations were significantly shorter on the right eye relative to those of both TD groups.

Data-driven analyses confirmed these findings. Heat maps of the fixation point distributions for each group and the contrast between ASD and TD groups showed that age-matched TD children's fixations concentrated on the pupils of both eyes, whereas ASD children's fixations were biased towards the left eye, and IQ-matched TD children's fixations were biased towards the right eye. Also, ASD children spent significantly less time on the right eye than both TD groups. Previous research has reported an asymmetry in facial expression that the right side of the face (from the observer's view) is more emotionally expressive than the left side (from the observer's view), reflecting a right cerebral hemispheric superiority in the production of emotional expressions (see Powell & Schirillo, 2009, for a review). Our findings of the left eye bias (from the observer's view) in children with ASD suggest that they may avoid fixating on the more emotionally expressive side of the face. This result is in accord with the deficits in understanding facial expressions and emotions reported in previous studies (e.g., Baron-Cohen et al., 1999; Dalton et al., 2005; Hobson, Ouston, & Lee, 1988). Similar patterns of left eye bias have been reported in adults with high AQ scores (E. Shimojo, Wu, & S. Shimojo, 2013) and in infants at high-risk for ASD (Dundas, Gastgeb, & Strauss, 2012).

The data-driven approach also revealed several novel findings. First, most fixations of ASD and TD children were similarly scattered around the triangular areas between the eyes and mouth, and few landed outside this

area. Second, when fixation data from ASD children were contrasted with those from age- and IQ-matched TD children, ASD children fixated significantly more on the left eye. This significant area, marked with a white contour in Figure 2, was actually not on the left eye itself, but below it. In contrast, when fixating on the same left eye, TD children's fixations centered around the pupil region. This marked difference between ASD and TD children might result from ASD children's strong tendency to avoid direct eye contact with another person (Bal et al., 2010; Jones et al., 2008). The data-driven approach also showed that ASD children looked significantly less at the center of the mouth than did the age-matched TD children, but not the IQ-matched TD children. This reduction in ASD children's fixation on the mouth may be due to a developmental delay, rather than an ASD-specific characteristic.

Saccade path analysis, which has never been previously used for analyzing TD and ASD children's face scanning data, provided additional new insights. However, for the saccade paths (eye-eye, eyes-nose, nose-mouth), although ASD children made markedly different gaze shifts relative to age-matched TD children, their saccade paths were comparable to IQ-matched children. Thus, the reduced proportional saccade paths for ASD children might not be ASD-specific, but rather reflect a developmental delay.

Findings from the three analytic approaches, taken together, strongly suggest that when compared to age- and IQ-matched TD children, ASD children do not have a pervasive and general abnormality in face scanning. After controlling for the difference in fixation time on the whole face, except for the eye regions, ASD children's fixations on key face parts were largely comparable either to age-matched TD or IQ-matched TD groups. Also, proportional saccade paths for ASD children were comparable to IQ-matched TD children.

In contrast, in the eye region, ASD children's scanning differed significantly from that of TD children in a highly specific manner. First, ASD children fixated significantly less on the right eye than did both TD groups. Second, unlike both TD groups, ASD children's fixations on the two eyes were more biased towards the left eye region. Third, their fixations to the left eye region differed from those of both TD groups: Whereas TD children fixated on the pupil region, ASD children tended to fixate below the left eye as though trying to avoid direct eye contact. We speculate that ASD children's tendency to avoid eye contact might contribute to their poor face recognition performance as the eyes are central in typical face processing in children and adults (e.g., Jones, Carr, & Klin, 2008; Klin et al., 2002). Limited scanning of the eye regions might have led to poor representation of the encountered faces in memory. Thus, when we consider the developmental origins of ASD children's face processing deficits, we must not just

focus on cognitive issues such as executive functioning, memory, and perceptual discrimination abilities, but also on social factors such as interpersonal interaction involving mutual eye contact.

Future research efforts should, like the present study, take advantage of the rich data provided by the eye tracking technique and use multiple approaches to analyze the data from not only elementary-school aged ASD children, but preschoolers and adolescents with ASD. Only through such systematic and multi-approach studies can we gain enriched understanding of how atypical face scanning in ASD children emerges and cascades to lead to severe face recognition impairments in adulthood. Such understanding will eventually help clinicians to develop evidence-based, guided eye-tracking training programs to improve face processing skills in ASD individuals.

## Conclusions

The present study investigated ASD and age- and IQ-matched TD children's scanning of faces. We used a novel multi-method approach that included the traditional AOI approach, the new data-driven iMAP approach, and the scanpath approach. We found that ASD children spent less time looking at the whole face generally. After controlling for this difference, ASD children's fixations of the other face parts, except for the eye region, and their scanning paths between face parts were comparable either to the age-matched or IQ-matched TD groups. In contrast, in the eye region, ASD children's scanning differed significantly from that of both TD groups in a highly specific manner. First, ASD children fixated significantly less on the right eye than both TD groups. Second, unlike both TD groups, ASD children's fixations were more biased towards the left eye region. Third, their fixations to the left eye region were different from those of both TD groups: Whereas TD children fixated on the pupil region of the eye, ASD children fixated below the left eye as though they were trying to avoid direct eye contact. We thus conclude that ASD children do not have a general and pervasive abnormality in face scanning. Rather, their abnormality is limited only to the eye region, likely due to their strong tendency to avoid eye contact.

*Keywords: autism spectrum disorder, face processing, face recognition, eye movements, eye tracking*

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# References

American Psychiatric Association. (1994). *Diagnostic and statistical manual of mental disorders* (4th ed.), Washington, DC: American Psychiatric Press.

Auyeung, B., Baron-Cohen, S., Wheelwright, S., & Allison, C. (2008). The Autism Spectrum Quotient: Children's Version (AQ-Child). *Journal of Autism and Developmental Disorders, 38,* 1230–1240. doi:10.1007/s10803-007-0504-z.

Bahill, A. T., Brockenbrough, A., & Troost, B. T. (1981). Variability and development of a normative data base for saccadic eye movements. *Investigative Ophthalmology & Visual Science, 21,* 116–125, http://www.iovs.org/content/21/1/116. [PubMed] [Article]

Bal, E., Harden, E., Lamb, D., Van Hecke, A. V., Denver, J. W., & Porges, S. W. (2010). Emotion recognition in children with autism spectrum disorders: Relations to eye gaze and autonomic state. *Journal of Autism and Developmental Disorders, 40,* 358–370. doi:10.1007/s10803-009-0884-3.

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,* 131–137. doi:10.1007/s10803-005-0046-1.

Baron-Cohen, S., Ring, H. A., Wheelwright, S., Bullmore, E. T., Brammer, M. J., Simmons, A., et al. (1999). Social intelligence in the normal and autistic brain: An fMRI study. *European Journal of Neuroscience, 11,* 1891–1898.

Caldara, R., & Miellet, S. (2011). iMap: A novel method for statistical fixation mapping of eye movement data. *Behavior Research Methods, 43,* 864–878. doi:10.3758/s13428-011-0092-x.

Chauvin, A., Worsley, K. J., Schyns, P. G., Arguin, M., & Gosselin, F. (2005). Accurate statistical tests for smooth classification images. *Journal of Vision, 5*(9):1, 659–667, http://www.journalofvision.org/content/5/9/1, doi:10.1167/5.9.1. [PubMed] [Article]

Chawarska, K., & Shic, F. (2009). Looking but not seeing: Atypical visual scanning and recognition of faces in 2 and 4-year-old children with autism spectrum disorder. *Journal of Autism and Developmental Disorders, 39,* 1663–1672. doi:10.1007/s10803-009-0803-7.

Chawarska, K., Volkmar, F., & Klin, A. (2010). Limited attentional bias for faces in toddlers with autism spectrum disorders. *Archives of General Psychiatry, 67,* 178–185. doi:10.1001/archgenpsychiatry.2009.194.

Corden, B., Chilvers, R., & Skuse, D. (2008). Avoidance of emotionally arousing stimuli predicts social–perceptual impairment in Asperger's syndrome. *Neuropsychologia, 46,* 137–147. doi:10.1016/j.neuropsychologia.2007.08.005.

Dalton, K. M., Nacewicz, B. M., Johnstone, T., Schaefer, H. S., Gernsbacher, M. A., Goldsmith, H. H., et al. (2005). Gaze fixation and the neural circuitry of face processing in autism. *Nature Neuroscience, 8,* 519–526. doi:10.1038/nn1421.

Dawson, G., Carver, L., Meltzoff, A. N., Panagiotides, H., McPartland, J., & Webb, S. J. (2002). Neural correlates of face and object recognition in young children with autism spectrum disorder, developmental delay, and typical development. *Child Development, 73,* 700–717. doi:10.1111/1467-8624.00433.

Dawson, G., Webb, S. J., & McPartland, J. (2005). Understanding the nature of face processing impairment in autism: Insights from behavioral and electrophysiological studies. *Developmental Neuropsychology, 27,* 403–424. doi:10.1207/s15326942dn2703_6.

Dewit, T., Falck-Ytter, T., & von Hofsten, C. (2008). Young children with autism spectrum disorder look differently at positive versus negative emotional faces. *Research in Autism Spectrum Disorders, 2,* 651–659. doi:10.1016/j.rasd.2008.01.004.

Dundas, E., Gastgeb, H., & Strauss, M. S. (2012). Left visual field biases when infants process faces: A comparison of infants at high- and low-risk for autism spectrum disorder. *Journal of Autism and Developmental Disorders, 42,* 2659–2668. doi:10.1007/s10803-012-1523-y.

Falck-Ytter, T. (2008). Face inversion effects in autism: A combined looking time and pupillometric study. *Autism Research, 1,* 297–306. doi:10.1002/aur.45.

Falck-Ytter, T., & von Hofsten, C. (2011). How special is social looking in ASD: A review. *Progress in Brain Research, 189,* 209–222. doi:10.1016/B978-0-444-53884-0.00026-9.

Falck-Ytter, T., Fernell, E., Gillberg, C., & von Hofsten, C. (2010). Face scanning distinguishes social from communication impairments in autism. *Developmental Science, 13,* 864–875. doi:10.1111/j.1467-7687.2009.00942.x.

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,* 248–257. doi:10.1016/j.neuropsychologia.2008.07.016.

Happe, F., & Frith, U. (2006). The weak coherence account: Detail-focused cognitive style in autism spectrum disorders. *Journal of Autism and Developmental Disorders, 36,* 5–25.

Hernandez, N., Metzger, A., Magné, R., Bonnet-Brilhault, F., Roux, S., Barthelemy, C., et al. (2009). Exploration of core features of a human face by healthy and autistic adults analyzed by visual scanning. *Neuropsychologia, 47,* 1004–1012. doi:10.1016/j.neuropsychologia.2008.10.023.

Hobson, R. P., Ouston, L., & Lee, A. (1988). Emotion recognition in autism: Coordinating faces and voices. *Psychological Medicine, 18,* 911–923.

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,* 946–954. doi:10.1001/archpsyc.65.8.946.

Joseph, R. M., & Tanaka, J. (2003). Holistic and part-based face recognition in children with autism. *Journal of Child Psychology and Psychiatry, 44,* 529–542.

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,* 809–816. doi:10.1001/archpsyc.59.9.809.

Klin, A., Sparrow, S. S., de Bildt, A., Cicchetti, D. V., Cohen, D. J., & Volkmar, F. R. (1999). A normed study of face recognition in autism and related disorders. *Journal of Autism and Developmental Disorders, 29,* 499–508. doi:10.1023/A:1022299920240.

Langdell, T. (1978). Recognition of faces: An approach to the study of autism. *Journal of Child Psychology and Psychiatry, 19,* 255–268.

Le Couteur, A., Rutter, M., Lord, C., Rios, P., Robertson, S., Holdgrafer, M., et al. (1989). Autism diagnostic interview: A standardized investigator-based instrument. *Journal of Autism and Developmental Disorders, 19,* 363–387. doi:10.1007/BF02212936.

Lord, C., Risi, S., Lambrecht, L., Cook, E. H., Leventhal, B. L., DiLavore, P. C., 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,* 205–223. doi:10.1023/A:1005592401947.

Lord, C., Rutter, M., & Le Couteur, A. (1994). Autism Diagnostic Interview-Revised: A revised version of a diagnostic interview for caregivers of individuals with possible pervasive developmental disorders. *Journal of Autism and Developmental Disorders, 24,* 659–685. doi:10.1007/BF02172145.

McPartland, J., Dawson, G., Webb, S. J., Panagiotides, H., & Carver, L. J. (2004). Event-related brain potentials reveal anomalies in temporal processing of faces in autism spectrum disorder. *Journal of Child Psychology and Psychiatry, 45,* 1235–1245. doi:10.1111/j.1469-7610.2004.00318.x.

Monk, C. S., Weng, S.-J., Wiggins, J. L., Kurapati, N., Louro, H. M. C., Carrasco, M., et al. (2010). Neural circuitry of emotional face processing in autism spectrum disorders. *Journal of Psychiatry & Neuroscience, 35,* 105–114. doi:10.1503/jpn.090085.

Morita, T., Kosaka, H., Saito, D. N., Ishitobi, M., Munesue, T., Itakura, S., et al. (2012). Emotional responses associated with self-face processing in individuals with autism spectrum disorders: An fMRI study. *Social Neuroscience, 7,* 223–239. doi:10.1080/17470919.2011.598945.

Nakano, T., Tanaka, K., Endo, Y., Yamane, Y., Yamamoto, T., Nakano, Y., et al. (2010). Atypical gaze patterns in children and adults with autism spectrum disorders dissociated from developmental changes in gaze behaviour. *Proceedings of the Royal Society B: Biological Sciences, 277,* 2935–2943. doi:10.1098/rspb.2010.0587.

Pellicano, E., Jeffery, L., Burr, D., & Rhodes, G.

(2007). Abnormal adaptive face-coding mechanisms in children with autism spectrum disorder. *Current Biology, 17,* 1508–1512. doi:10.1016/j.cub.2007.07.065.

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,* 249–261. doi:10.1023/A:1016374617369.

Pierce, K., Müller, R. A., Ambrose, J., Allen, G., & Courchesne, E. (2001). Face processing occurs outside the fusiform "face area" in autism: Evidence from functional MRI. *Brain, 124,* 2059–2073. doi:10.1093/brain/124.10.2059.

Powell, W. R., & Schirillo, J. A. (2009). Asymmetrical facial expressions in portraits and hemispheric laterality: A literature review. *Laterality, 14,* 545–572.

Rutherford, M. D., & Towns, A. M. (2009). Scan path differences and similarities during emotion perception in those with and without autism spectrum disorders. *Journal of Autism and Developmental Disorders, 38,* 1371–1381. doi:10.1007/s10803-007-0525-7.

Salvucci, D. D., & Goldberg, J. H. (2000). Identifying fixations and saccades in eye-tracking protocols. In *Proceedings of the Eye Tracking Research and Applications Symposium* (pp. 71–78). New York: ACM Press.

Shimojo, E., Wu, D.-A., & Shimojo, S. (2013). *Don't look at the face – social inhibition task reveals latent avoidance of social stimuli in gaze orientation in subjects with high Autism Quotient scores*. Poster presented at the 13th Annual Meeting of Vision Science Society, Naples, FL.

Speer, L. L., Cook, A. E., McMahon, W. M., & Clark, E. (2007). Face processing in children with autism: Effects of stimulus contents and type. *Autism, 11,* 265–277. doi:10.1177/1362361307076925.

Van Der Geest, J. N., Kemner, C., Camfferman, G., Verbaten, M. N., & Van Engeland, H. (2002). Looking at images with human figures: Comparison between autistic and normal children. *Journal of Autism and Developmental Disorders, 32,* 69–75. doi:10.1023/A:1014832420206.

Vlamings, P. H. J. M., Jonkman, L. M., & Kemner, C. (2010). An eye for detail: An event-related potential study of the rapid processing of fearful facial expressions in children. *Child Development, 81,* 1304–1319. doi:10.1111/j.1467-8624.2010.01470.x.

Weigelt, S., Koldewyn, K., & Kanwisher, N. (2011). Face identity recognition in autism spectrum disorders: A review of behavioral studies. *Neuroscience & Biobehavioral Reviews, 36,* 1060–1084. doi:10.1016/j.neubiorev.2011.12.008.