Do Individuals with and without Autism Spectrum Disorder Scan Faces Differently? A New Multi-Method Look at an Existing Controversy

Li Yi, Cong Feng, Paul C. Quinn, Haiyan Ding, Jiao Li, Yubing Liu, and Kang Lee

Individuals with autism spectrum disorder (ASD) are known to process faces atypically. However, there has been considerable controversy regarding whether ASD individuals also scan faces differently from typical adults. Here we compared ASD individuals' face-scanning patterns with those of typically developing (TD) controls and intellectually disabled (ID) but non-ASD individuals with the use of an eye tracker and multiple approaches to analyze eye-tracking data. First, we analyzed the eye movement data with a traditional approach, measuring fixation duration on each area of interest within the face. We found that compared with TD and ID individuals, ASD individuals looked significantly shorter at the right eye. Second, we used a data-driven method that analyzes fixations on each pixel of the face stimulus and found that individuals with ASD looked more at the central nasal area than TD and ID individuals. Third, we used a novel saccade path analysis that measures frequencies of saccades between major face areas. We found that ASD individuals scanned less often between core facial features than TD individuals but did not differ from ID individuals. Findings from the multi-method approaches show that individuals with ASD appear not to have a pervasive ASD-specific atypicality in visual attention toward the face. The ASD-specific atypical face-scanning patterns were shown to be limited to fixations on the eyes and nose. ***Autism Res*** *2014, 7: 72–83*. © 2013 International Society for Autism Research, Wiley Periodicals, Inc.

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It is well known that individuals with autism spectrum disorder (ASD) show atypical face processing [e.g. Boucher & Lewis, 1992; Boucher, Lewis, & Collis, 1998; Dawson, Webb, & McPartland, 2005; Gepner, de Gelder, & de Schonen, 1996; Klin et al., 1999; Langdell, 1978; McPartland, Dawson, Webb, Panagiotides, & Carver, 2004; Wolf et al., 2008]. Studies using neuroimaging techniques have also found specific neural correlates of such atypicality [e.g. Dawson et al., 2002; Grice et al., 2001; Hall, Doyle, Goldberg, West, & Szatmari, 2010; Monk et al., 2010; Morita et al., 2011; Pierce, Müller, Ambrose, Allen, & Courchesne, 2001; Schultz et al., 2003; South & Diehl, 2011; Webb, Dawson, Bernier, & Panagiotides, 2006; Weng et al., 2011; see Dawson et al., 2005, for a review]. However, these findings have been challenged in terms of the existence and nature of the face-processing deficits in ASD. For example, Jemel, Mottron, and Dawson [2006] argued that face-processing ability in individuals with ASD has been underestimated in the current literature and that arguments for deficits of face processing in ASD are still inconclusive in the absence of strong and consistent empirical evidence.

In recent years, eye-tracking techniques have increasingly been used to examine ASD individuals' scanning patterns when they look at faces. The existing eye-tracking studies have reported controversial findings. Some studies have found reduced attention to the face and its core features (eyes, nose, and mouth) in ASD individuals compared with typically developing (TD) individuals, especially the eyes [Corden, Chilvers, & Skuse, 2008; Falck-Ytter, 2008; Hernandez et al., 2009; Jones, Carr, & Klin, 2008; Klin & Jones, 2008; Klin, Jones, Schultz, Volkmar, & Cohen, 2002; Pelphrey et al., 2002; Speer, Cook, McMahon, & Clark, 2007; Trepagnier, Sebrechts, & Peterson, 2002]. However, other studies failed to find different patterns for ASD individuals

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relative to TD individuals [e.g. Falck-Ytter, Fernell, Gillberg, & von Hofsten, 2010; Fletcher-Watson, Leekam, Benson, Frank, & Findlay, 2009; Rutherford & Towns, 2008; van der Geest, Kemner, Verbaten, & van Engeland, 2002]. The controversy may stem from the use of different tasks [Rutherford & Towns, 2008], or stimuli [e.g. Falck-Ytter et al., 2010; Speer et al., 2007; Van der Geest et al., 2002], or inconsistencies or limitations in data analytic methods [e.g. different ways of defining areas of interest: Falck-Ytter, 2008; Hernandez et al., 2009; Jones et al., 2008; Klin et al., 2002].

All of the eye-tracking findings mentioned above were based on the area of interest (AOI) approach, which measures the number and duration of fixations within predefined regions. Typical AOIs defined in face-processing studies involve the eyes, nose, mouth, and other facial areas. The AOI approach has been widely used in eye-tracking research because of its simplicity and convenience. In addition, assembling fixation points within an AOI gives rise to abundant fixation data and thus the possibility of obtaining a relatively reliable and stable estimation of observers' gaze at a particular AOI. However, the AOI-based approach treats all fixation points falling in an AOI homogeneously and customarily adds them up. Consequently, it could fail to reveal differences between ASD and TD individuals with respect to fixation patterns within the AOI (e.g. individuals with ASD may pay more attention to peripheral eye areas, while TD individuals may fixate more on central eye areas). Additionally, a fixation point is usually defined as a sustained look that falls in an AOI above a certain preset time threshold (e.g. 100 ms). As such, useful information about fixations below the threshold may be inappropriately discarded.

Limitations of the AOI approach can be minimized by using complementary methods of data analysis. One alternative method is the data-driven approach [Caldara & Miellet, 2011]. Instead of using a predefined AOI, this approach includes all fixation points into analysis regardless of their duration. Fixation points on any part of the stimuli will be summed according to their spatial location and be statistically compared between groups or conditions. Although this data-driven approach may fail to reveal significant differences in fixation of some facial areas due to few fixation points clustering around them, it serves as an informative supplement to the AOI approach by providing a better spatial resolution, through which differences between distinct groups or conditions in spatial distribution of fixation points can be found.

Although the eye-tracking technique provides rich information about both fixations and saccades associated with face scanning, another limitation of the AOI approach is its exclusive focus on fixations while omitting information on saccades. Thus, its overuse in eye-tracking research hinders identification of saccade path differences between ASD and TD individuals in face scanning [see Pelphrey et al., 2002 and Rutherford & Towns, 2008 for exceptions with ASD adults].

Another important issue is the control group, to which ASD individuals are compared. Some eye-tracking studies used individuals with high-functioning autism, whose IQ did not differ from the TD group [e.g. Klin et al., 2002; Pelphrey et al., 2002; Speer et al., 2007]. However, most studies matched ASD and TD groups by only chronological ages, not general mental ability [Chawarska & Shic, 2009; Corden et al., 2008; Dalton et al., 2005; Hernandez et al., 2009; van der Geest et al., 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 group of individuals with intellectual disability (ID) to match the ASD group's IQ.

The current investigation aimed to address limitations associated with predominant use of the traditional AOI approach by employing three different but complementary approaches concurrently to analyze eye movement data. First, the AOI approach was adopted to investigate whether ASD, TD, and ID individuals look at different core face features (e.g. eyes, mouth, and nose) differently. Second, the data-driven analysis was used to reveal whether there exist any reliable group differences over all pixels of the face. Third, with a novel Scanpath method, we analyzed saccade paths between core face features (e.g. between eyes, eyes and nose, and eyes and mouth) for all three groups, and compared their disparities in saccade path frequencies. By analyzing eye movement data with these three approaches simultaneously, we expected to clarify similarities and differences between ASD and TD or ID individuals in face scanning, something that has been highly controversial because of the reliance on the traditional AOI-based approach alone.

In the current study, eye tracking was used to examine performance of ASD, TD, and ID individuals in a face recognition task. We employed an old–new face recognition paradigm, in which participants were required to memorize a series of faces and were tested with familiar and novel faces afterward. Given the results of previous behavioral studies, we expected significantly poorer performance in individuals with ASD than those without. Due to the current controversies regarding the visual-scanning patterns of individuals with ASD during face processing, two possible outcomes could arise out of the traditional AOI approach: (a) individuals with ASD would look at the core facial features less than TD and ID individuals or (b) no difference would be found in looking time at the core face features between ASD and the two control groups. However, we expected the data-driven approach to provide more detailed information about the distribution of fixations around the major facial features.

Table 1. Participant Characteristics in Each Group

		N	Male (female)	Mean age	Original IQ	GARS	GARS range
ASD		19	14 (5)	20.84 (3.27)	23.67 (9.36)	102.93 (12.31)	85–130
TD		28	22 (6)	20.61 (2.90)	67.57 (5.17)	62.64 (11.01)	41–74
ID		22	18 (4)	23.59 (3.08)	23.82 (8.63)	57.45 (12.36)	41–83
Difference (*t*-test)	ASD vs. TD	N/A	N/A	0.26	–18.20**	10.98**	N/A
	ASD vs. ID	N/A	N/A	–2.77*	–0.05	11.01**	N/A
	ID vs. TD	N/A	N/A	3.52*	–21.00**	–1.57	N/A

Note. Standard deviations are shown in parentheses. ASD, autism spectrum disorder; GARS, Gilliam Autism Rating Scale; ID, intellectually disabled; TD, typically developing.
*$P < 0.01$; **$P < 0.001$.

We also expected to see group differences in terms of face-scanning patterns. In particular, we anticipated that individuals with ASD would display fewer saccade paths between the core facial features than TD individuals and perhaps also ID individuals.

Method

Participants

Participants were 19 ASD and 22 IQ-matched ID adolescents and young adults from community centers for individuals with ASD and ID in Guangzhou, China, and 28 age-matched TD adolescents and young adults recruited from communities in the same city (Table 1). All ASD participants were previously diagnosed by professional clinicians and satisfied the diagnostic criteria for autism according to the DSM-IV (American Psychiatric Association, 1994). 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 and widely used in China. Therefore, we confirmed diagnosis of ASD using the Chinese version of the Gilliam Autism Rating Scale–Second Edition [Gilliam, 2006]. The ID individuals were also previously diagnosed by professional clinicians according to the criteria of the DSM-IV [American Psychiatric Association, 1994] as suffering from ID of unknown causes and not autism. The ASD and TD groups were matched by their chronological age, ($t(45) = 0.26$, $P = 0.80$). The ID group was recruited to match ASD group's IQ ($t(38) = –0.05$, $P = 0.96$), which was assessed with the use of the Combined Raven Test.

Stimuli and Procedure

We used 36 images of frontal-view grey-scale Chinese faces with neutral facial expressions (width: 500 pixels, height: 700 pixels, resolution: 72 pixels per inch, 18 male faces). The faces were normalized to the same face template such that their eyes, nose, and mouth were located approximately in the same physical location. All faces were normalized in terms of the locations of the eyes, nose, and mouth, and they were overlaid with the same elliptical shape to control for hairstyle differences (Fig. 1).

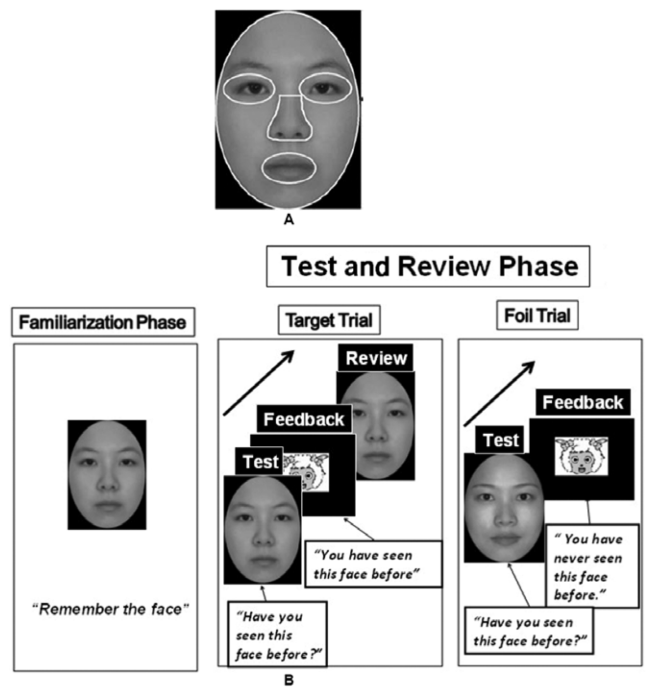

Figure 1. Sample area of interest (AOI) plots (A) and schematic representation of the experimental design (B).

Face images were presented on the 17″ (height = 25.8 cm; width = 34.4 cm) monitor of a Tobii T120 eye tracker (Tobii Technology AB, Danderyd, Sweden) with a resolution of 1024 × 768 pixels. Tobii Studio 1.5 software (Tobii Technology AB, Danderyd, Sweden) was used to control the presentation of the stimuli. Participants sat in front of the Tobii eye tracker at a viewing distance of approximately 60 cm away from the screen. The face pictures subtended a visual angle of 15.94° (width) × 22.18° (height).

Before the experiment, calibration was conducted using the Tobii calibration program (Tobii Technology AB, Danderyd, Sweden). Calibrations were considered successful when all five points showed good fit in the computed mapping for both eyes. Afterward, participants proceeded with the familiarization and test phases (Fig. 1B). In the familiarization phase, participants were asked to memorize six target faces (three for each sex), which appeared mixed with foil faces in each test phase. Each target face was presented for 3 sec. Then, five test phases followed, during which participants judged whether the face displayed was "seen before" or "never seen before." There were 18 trials in each test phase, including six target trials (the same six target faces used in the familiarization phase), and six foil trials (matched for gender), which were never seen before and were never shown again in the subsequent test phases once they were shown. All target and foil faces were shown sequentially and participants responded by key pressing. Each test trial was presented until the key press. The interstimulus interval was 3 sec with a cartoon character (188×143 pixels) in the center of the screen, saying "look at the next picture." After key pressing to indicate whether a face was seen before or not, the face disappeared and feedback was given to indicate whether the participant had responded correctly (Fig. 1). If the preceding face was a target face, it was shown again for participants to review for 3 sec; if it was a foil face, the face was not reviewed. Participants' responses were recorded manually on recording sheets and their eye movements were recorded by the eye tracker with a sampling rate of 60 Hz.

Data Analysis

We employed three approaches to analyze the eye movement data. For the AOI approach, we used five predefined AOIs including the whole face (i.e. area within the face contour), left eye, right eye, nose, and mouth (Fig. 1). The AOIs were defined as the entire face feature of interest plus an additional 50 pixels of edges. Considering the slight variability of the size of the face features even after normalization, we defined AOIs separately for each face. A fixation was defined as a sustained look at the AOI within a fixation radius of 50 pixels for more than 100 ms. Total fixation durations were computed for each AOI by summing durations of all fixations within the AOI. Outliers of total fixation durations on the whole stimulus were removed from further analyses (i.e. three standard deviations (SD) beyond the mean for each group, 1.38% of the data points). The proportional fixation durations were calculated by dividing the total fixation time on each AOI by the total fixation time on the whole face (excluding the fixations on areas beyond the oval overlaid on the face).

For the data-driven approach, the iMap MATLAB toolbox [Caldara & Miellet, 2011] was used to create heat maps for each condition and difference maps for comparisons between conditions. Instead of requiring a priori segmentation of faces into AOIs, the iMap toolbox computes the statistical maps of fixations based on the raw point-of-regard data on any location in the visual stimuli. Gaussian kernel was then implemented to spatially smooth each fixation map, and we Z-scored each map to normalize data after smoothing. To reveal the difference of fixation patterns between groups and for different face types, we subtracted each two different maps and Z-scored the resulting difference maps prior to the statistical comparison. Thus, 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 3-D fixation maps contain thousands of pixels, it generates a large number of statistical comparisons, possibly resulting in inflated type I error rates. The iMap overcomes this limitation by applying a robust statistical random field theory (RFT) approach, which is a recent advancement in applied statistics and has already been used successfully in functional magnetic resonance imaging data analysis to solve the similar problem of massive univariate statistical testing for the effect of interest in each brain voxel. The RFT approach firstly estimates the smoothness (spatial correlation) of the statistical maps, and then uses these smoothness values to determine the expected Euler characteristic at different thresholds. This procedure estimates the threshold at which 5% of equivalent statistical maps are expected to arise under the null hypothesis [Caldara & Miellet, 2011]. The iMap toolbox incorporates the RFT approach by applying 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.

For analyzing saccade paths, we developed a Scanpath MATLAB toolbox to count the frequencies of a participant's gaze shifts from one AOI to another. We calculated frequencies of paths involving two AOI between the eyes, eyes and nose, eyes and mouth, and nose and mouth. We also calculated frequencies of the more complex paths involving the three AOI between the eyes (left and right eyes combined), nose, and mouth.

Results

Accuracy

Table 2 presents the means and standard deviations of accuracy (%) for ASD, TD, and ID individuals. One-sample

Table 2. Means and Standard Deviations of Accuracy, Total and Proportional Fixation Durations, and Frequencies of Saccade Paths between Areas of Interest (AOIs)

		ASD	TD	ID
Behavioral performance	Accuracy (%)	0.52 (0.06)	0.81 (0.09)	0.59 (0.13)
Total fixation durations (ms)	Whole face	1964.80 (694.00)	1952.66 (397.42)	2085.21(511.10)
Proportional fixation durations	Right eye	0.07 (0.08)	0.16 (0.10)	0.13 (0.09)
	Left eye	0.07 (0.09)	0.12 (0.11)	0.10 (0.12)
	Nose	0.36 (0.19)	0.32 (0.16)	0.21 (0.15)
	Mouth	0.11 (0.10)	0.09 (0.07)	0.07 (0.09)
	Non-feature area	0.40 (0.15)	0.32 (0.11)	0.49 (0.20)
Frequencies of saccade paths	Between eyes	12.05 (25.04)	47.71 (48.13)	20.55 (35.11)
	Eyes–nose	37.74 (44.18)	58.00 (38.70)	28.09 (30.41)
	Eyes–mouth	3.58 (4.30)	13.39 (14.78)	7.32(10.21)
	Nose–mouth	21.84 (13.15)	41.86 (36.07)	15.55 (15.67)
	Eyes–nose–mouth	3.37 (2.63)	13.18 (10.77)	5.05 (8.23)

ASD, autism spectrum disorder; ID, intellectually disabled; TD, typically developing.

Table 3. Group Differences in Accuracy, Total and Proportional Fixation Durations, Data-Driven Analysis, and Frequencies of Saccade Paths between Areas of Interest (AOIs)

		ASD vs. TD	ASD vs. ID	ID vs. TD
Behavioral performance	Accuracy (%)	99.42***	4.48*	65.20***
Total fixation durations (ms)	Whole face	0.01	0.53	0.78
Proportional fixation durations	Right eye	9.88**	4.66*	0.82
	Left eye	2.98	0.69	0.41
	Nose	0.57	7.36**	4.83*
	Mouth	1.06	2.57	0.47
	Non-feature area	3.13	3.44	15.09***
Data-driven analysis	Right eye	ASD < TD, $P < 0.05$	ASD < ID, $P < 0.05$	ID > TD, $P < 0.05$
	Left eye	$P > 0.05$	$P > 0.05$	$P > 0.05$
	Nose	ASD > TD, $P < 0.05$	ASD > ID, $P < 0.05$	ID < TD, $P < 0.05$
	Mouth	$P > 0.05$	$P > 0.05$	$P > 0.05$
Frequencies of saccade paths	Between eyes	9.53*	0.49	6.02
	Between eyes and the nose	3.23	0.66	7.66*
	Between eyes and the mouth	8.54*	1.12	3.56
	Between the nose and the mouth	6.90	0.61	12.97**
	Eyes–nose–mouth	15.38**	0.40	11.50**

ASD, autism spectrum disorder; ID, intellectually disabled; TD, typically developing.
*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

t-tests showed that TD and ID participants' accuracies were significantly above chance (TD, 81%; $t(27) = 18.76$, $P < 0.001$, $\eta^2 = 0.93$; ID, 59%; $t(21) = 3.05$, $P = 0.006$, $\eta^2 = 0.31$), whereas ASD participants' accuracies did not differ from chance (52%; $t(18) = 1.66$, $P = 0.11$, $\eta^2 = 0.14$). A one-way independent-sample ANOVA showed a group difference in accuracy ($F(2, 66) = 58.81$, $P < 0.001$, $\eta^2 = 0.64$). A priori contrasts showed that ASD individuals' accuracies were significantly lower than TD participants ($F(1, 66) = 99.42$, $P < 0.001$, $\eta^2 = 0.54$), and ID participants ($F(1, 66) = 4.48$, $P = 0.038$, $\eta^2 = 0.02$); ID participants' accuracies were lower than TD participants ($F(1, 66) = 65.20$, $P < 0.001$, $\eta^2 = 0.36$), as shown in Table 3.

Total Fixation Duration

Highly similar data patterns for fixations on target faces during familiarization, test and review trials, and foil faces during test trials were observed during preliminary analyses. Thus, we combined all fixations of the target and foil faces during all phases for subsequent data analysis. Table 2 shows the means and standard deviations of the total fixation durations by group. A one-way ANOVA showed no significant group difference in total fixation durations on the whole face ($F(2, 66) = 0.44$, $P = 0.65$, $\eta^2 = 0.01$). We further examined the difference of total face fixation durations for hits, misses, false alarms, and correct rejection trials in the test phases using a 3 (Group) × 4 (Response Type) mixed-design analysis of variance (ANOVA). Results showed a main effect of Response Type ($F(3, 165) = 5.34$, $P = 0.002$, $\eta^2 = 0.088$). Post hoc analysis with Bonferroni correction revealed that participants spent significantly less time looking at the whole face during the correct rejection trials than the hit ($P = 0.02$), miss ($P = 0.006$), and false-alarm trials ($P = 0.034$).

Proportional Fixation Durations of Individual AOIs

The mean proportional fixation durations within each AOI (both eyes, nose, mouth, and non-feature areas) are listed in Table 2. To test for the group differences in proportional fixation duration on each core face feature area (AOI), independent-sample ANOVAs were performed between groups. Table 3 summarizes the group differences of different eye movement indices.

A one-way ANOVA showed significant group differences on the right eye (from the observer's perspective; $F(2, 66) = 5.05$, $P = 0.009$, $\eta^2 = 0.13$), and the nose ($F(2, 66) = 4.13$, $P = 0.02$, $\eta^2 = 0.11$). A priori contrasts showed that ASD individuals looked shorter at the right eye than TD individuals ($F(1, 66) = 9.88$, $P = 0.003$, $\eta^2 = 0.13$) and ID individuals ($F(1, 66) = 4.66$, $P = 0.03$, $\eta^2 = 0.06$). ID individuals looked shorter at the nose than ASD individuals ($F(1, 66) = 7.36$, $P = 0.009$, $\eta^2 = 0.10$) and TD individuals ($F(1, 66) = 4.83$, $P = 0.032$, $\eta^2 = 0.07$). There was no group difference in looking time on the left eye (from the observer's perspective) ($F(2, 66) = 1.51$, $P = 0.23$, $\eta^2 = 0.04$) and the mouth ($F(2, 66) = 1.29$, $P = 0.28$, $\eta^2 = 0.04$). Also, a group difference of looking time on the non-feature area was found ($F(2, 66) = 7.55$, $P = 0.001$, $\eta^2 = 0.19$): ID individuals looked at non-feature areas significantly longer than TD participants ($F(1, 66) = 15.09$, $P < 0.001$, $\eta^2 = 0.19$); individuals with ASD did not look at non-feature areas of faces significantly differently from TD individuals ($F(1, 66) = 3.13$, $P = 0.08$, $\eta^2 = 0.04$) or ID individuals ($F(1, 66) = 3.44$, $P = 0.06$, $\eta^2 = 0.04$).

The proportional fixation durations on the left and right eyes were compared using paired *t*-tests for each group. Results showed no difference between the proportional fixation durations on the left and right eyes for ASD, ID, and TD individuals (ASD: $t(18) = 0.00$, $P = 1.00$, $\eta^2 = 0.00$; ID; $t(21) = -1.49$, $P = 0.15$, $\eta^2 = 0.10$; TD: $t(27) = 1.88$, $P = 0.07$, $\eta^2 = 0.34$).

We also examined the difference of proportional fixation durations for hits, misses, false alarms, and correct rejection trials in the test and review phases using 3 (Group) × 4 (Response Type) mixed-design ANOVAs. A significant main effect of Response Type existed only in the non-feature area ($F(3, 165) = 2.81$, $P = 0.041$, $\eta^2 = 0.049$). Post hoc analysis with Bonferroni correction revealed that participants looked marginally longer during the miss trials than the false-alarm trials ($P = 0.069$).

Data-Driven Analysis

We conducted the data-driven analysis using the procedures with iMap MATLAB toolbox. Figure 2A and B show ASD and TD individuals' fixation distributions when scanning faces as well as their differences (Fig. 2C) by subtracting the fixation map for TD individuals from ASD individuals. Significant difference areas are marked by white contours ($P < 0.05$, corrected). As shown, most of the fixations for both ASD and TD individuals tended to fall in the central triangular area of the face. However, there were also marked differences between the groups. When the fixation maps of the groups were compared statistically, individuals with ASD looked at the central nasal area significantly longer than TD individuals. In contrast, TD individuals looked longer at the center of the right eye (from the observer's perspective) than ASD individuals.

Figure 2D and E show ASD and ID individuals' fixation distributions when scanning faces as well as their differences (Fig. 2F) by subtracting the fixation map for ID individuals from ASD individuals. As shown, most of the fixations for both ASD and ID individuals also tended to fall in the central triangular area of the face. The difference pattern is similar to the difference pattern between ASD and TD individuals: ASD individuals looked at the nose significantly longer than ID individuals. In contrast, ID individuals looked significantly longer at the right eye (from the observer's perspective) than ASD individuals. However, unlike the contrast between the maps between ASD and TD individuals, relative to the ASD individuals, ID individuals had significantly more fixations on the inner edge of the right eye.

Figure 2G and H show ID and TD individuals' fixation distributions when scanning faces as well as their differences (Fig. 2I) by subtracting the fixation map for TD individuals from ID individuals. As shown, TD individuals looked at the nose significantly longer than ID individuals. However, ID individuals looked longer at the right eye (from the observer's perspective) than TD individuals. Similar to the contrast between the maps between ASD and ID individuals, relative to the TD individuals, ID individuals had significantly more fixations on the inner edge of the right eye.

Analysis of Saccade Paths

Several saccade paths (between eyes, eyes–nose, eyes–mouth, nose–mouth, eyes–nose–mouth) were identified and their mean frequencies were calculated by group (Table 2). Figure 3A and B show the maps of frequencies of each saccade path for ASD and TD individuals during

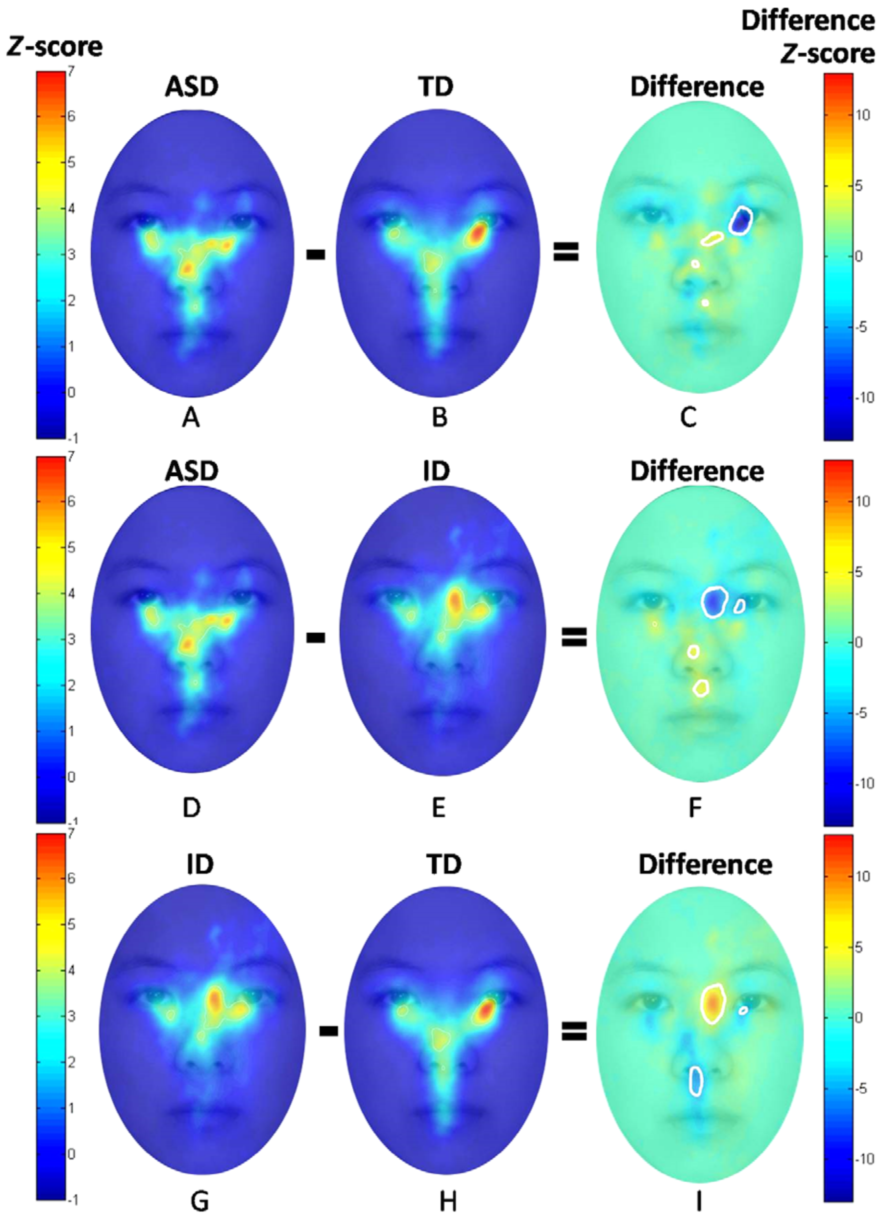

Figure 2. Heat maps for autism spectrum disorder (ASD) and typically developing (TD) individuals (A & B) and the difference map (C); heat maps for ASD and intellectually disabled (ID) individuals (D & E) and the difference map (F), and heat maps for ID and TD individuals (G & H) and the difference map (I). 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.

face scanning as well as their difference by subtracting the saccade path map for TD individuals from that for ASD individuals (Fig. 3C). Figure 3D and E show the maps of frequencies of each saccade path for ASD and ID individuals as well as their difference by subtracting the saccade path map for ID individuals from that for ASD individuals (Fig. 3F).

One-way ANOVAs found significant group differences in the total frequencies of saccade paths between the eyes ($F(2, 66) = 5.57$, $P = 0.03$, $\eta^2 = 0.14$), between the nose and the mouth ($F(2, 66) = 7.23$, $P = 0.02$, $\eta^2 = 0.18$), and between eyes–nose–mouth ($F(2, 66) = 9.53$, $P = 0.001$, $\eta^2 = 0.22$).

A priori contrasts showed that compared with TD individuals, individuals with ASD scanned significantly less often between the eyes ($F(1, 66) = 9.53$, $P = 0.015$, $\eta^2 = 0.12$), between the eyes and the mouth ($F(1, 66) = 8.54$, $P = 0.023$, $\eta^2 = 0.11$), and following an

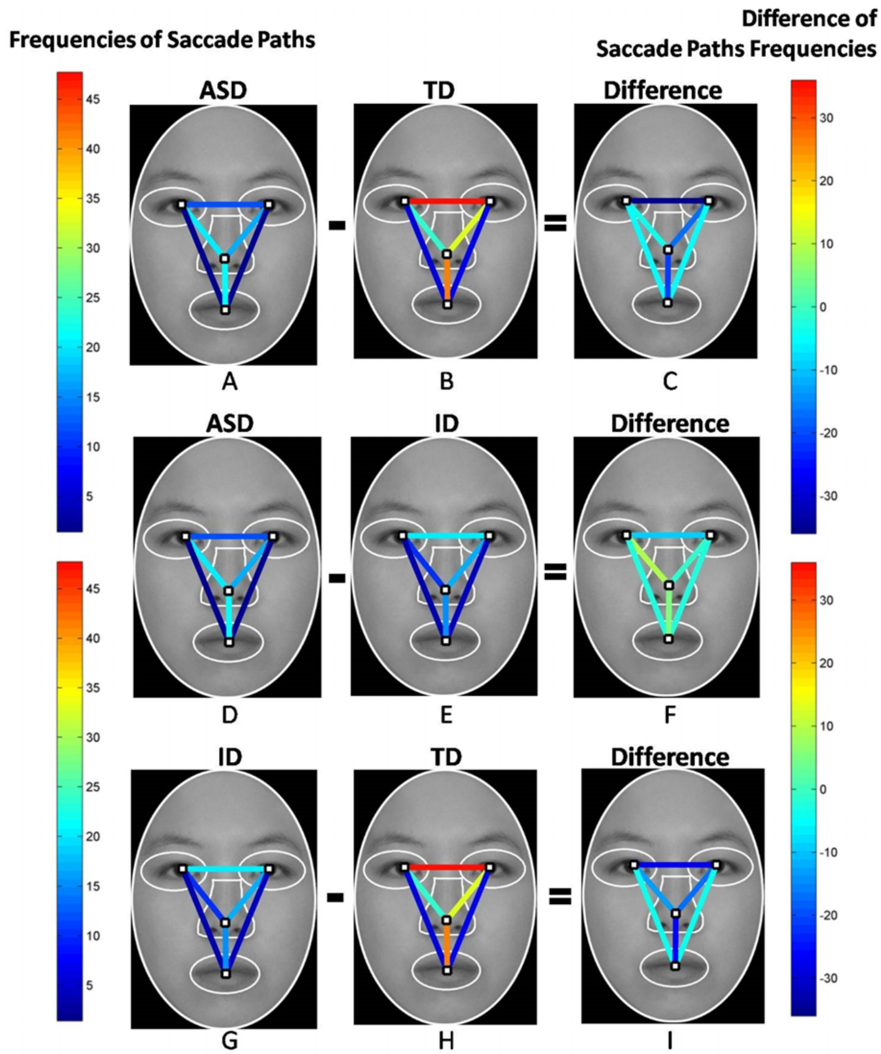

Figure 3. Saccade path maps for autism spectrum disorder (ASD) and typically developing (TD) observers looking at faces (A & B) and the difference map (C), saccade path maps for ASD and intellectually disabled (ID) observers (D & E) and the difference map (F), and saccade path maps for ID and TD observers (G & H) and the difference map (I). 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 saccade path counts within each region, with warm colors denoting more saccade path counts and cold colors denoting fewer counts. Note that the left and right temperature scales are different.

eye–nose–mouth path ($F(1, 66) = 15.38$, $P = 0.001$, $\eta^2 = 0.18$); there was a marginally significant difference of the path frequency between the nose and the mouth ($F(1, 66) = 6.90$, $P = 0.054$, $\eta^2 = 0.09$), but no difference between the eyes and the nose ($F(1, 66) = 3.23$, $P = 0.38$, $\eta^2 = 0.04$). However, we performed similar analyses and found no significant saccade path differences between ASD and ID individuals. The saccade paths of ID and TD individuals were also compared. Results showed that ID participants scanned significantly less often than TD participants between the eyes and the nose ($F(1, 66) = 7.66$, $P = 0.037$, $\eta^2 = 0.10$), between the nose and the mouth ($F(1, 66) = 12.97$, $P < 0.001$, $\eta^2 = 0.16$), and following an eye–nose–mouth path ($F(1, 66) = 11.50$, $P = 0.006$, $\eta^2 = 0.14$).

Discussion

We used eye tracking and three data-analytic approaches to investigate similarities and differences in face-scanning patterns among ASD, TD, and ID individuals. First, we used the AOI approach to compare face looking time between groups. Second, we employed a data-driven analysis that focused on each fixation point instead of summed fixation durations, thus providing an opportunity to examine group differences on each pixel of the face stimuli during processing. Finally, we analyzed saccade paths between core face features of ASD, TD, and ID individuals.

The AOI analysis revealed that the three groups spent similar amounts of time looking at faces. This finding is inconsistent with results from previous studies that individuals with ASD spent less time on the face than controls [e.g. Boucher & Lewis, 1992; Boucher et al., 1998; Dawson et al., 2005; Gepner et al., 1996; Klin et al., 1999; Langdell, 1978; McPartland et al., 2004; Wolf et al., 2008]. One possibility for this inconsistency was the nature of the face stimuli used. In the present study, in order to ascertain that our results about face scanning could be attributed to faces, we surrounded the face stimuli with a covering oval to prevent non-face features such as hairstyle from interfering with participants' visual attention toward faces. By contrast, the existing studies that reported reduced visual attention toward faces in ASD individuals tended to use face stimuli without such controls.

Moreover, when normalizing fixation duration according to total fixation duration on the faces, the AOI approach did not find ASD individuals' fixations on the left eye (from the observer's perspective) and mouth to be significantly different from those of TD and ID individuals. Also, although ASD individuals looked significantly longer at the nose region than ID individuals, their fixation durations on the nose were not significantly different from those of TD individuals. Finally, when we compared each group's fixation durations on the left vs. right eye AOIs, all three groups spent equal amounts of time on both eyes. The AOI approach only revealed ASD to be uniquely different from both TD and ID in terms of their visual attention to the right eye of the face (from the observer's perspective); that is, ASD individuals looked significantly less on the right eye of the face than both TD and ID individuals.

Data-driven analyses confirmed two main findings of the AOI approach: (a) there was little group difference at the left eye and the mouth; and (b) ASD individuals fixated less on the right eye than TD and ID individuals. However, there were additional novel findings revealed by the data-driven approach. First, relative to TD individuals, ASD individuals tended to fixate less on the circular area of the right eye where the pupil resided. The difference map between ASD and ID individuals in the eye region was similar to that between ASD and TD individuals: ASD individuals spent less time than ID individuals in the right eye region, but the major difference resided at the inner edge of the right eye. These findings suggest that relative to the TD and ID individuals, ASD individuals tended to avoid looking at the center or inner edge of the right eye.

The second novel finding from the iMap approach was that when the ASD fixation patterns were contrasted with those of TD and ID, ASD individuals spent more looking time on the central facial areas (i.e. the nose region) relative to TD and ID individuals. This finding added to the results of the AOI approach that only showed significant differences in looking time on the nose between ASD and ID individuals.

To take further advantage of the eye movement data, we adopted the saccade path analyses to examine saccade data between ASD and TD or ID individuals during face scanning, thus providing us with further new insights into the similarities and differences of face processing in the three groups. We found that ASD individuals indeed scanned significantly less than TD individuals between the core features of the face. However, this reduced scanning was not ASD-specific as evidenced by the fact that the frequencies of saccade paths between the core face features of ID individuals did not differ from those of ASD individuals. In other words, the apparent reduced saccades between core face features in ASD might be due to a deficit in general mental ability, not ASD per se.

Although the new methods provide richer data and more evidence for the face-scanning patterns in ASD, their main findings largely complemented the findings from the traditional AOI approach. Despite its limitations, the AOI approach is still a powerful, straightforward, and widely used method to analyze the face-scanning patterns. Additional analyses can be used to identify the subtleties and nuances of differences in face scanning in ASD. In particular, the AOI approach may mix possibly significant group difference areas with possibly no-difference areas. Specifically, when the potential significant area is much smaller than the AOI area, possibly significant group-differences may be obscured. Moreover, only part of the significant area may be at the edge of an AOI and thus may be excluded from the AOI analysis.

One limitation of the current study was the absence of strong and reliable confirmation of ASD diagnosis, such as ADOS or ADI-R. Since these two diagnostic scales have not been translated and validated in China, we used the Chinese version of the GARS scale to confirm the diagnosis of the ASD participants. Future studies with ASD individuals should use more reliable measures to confirm ASD diagnosis. Also, ASD individuals may show different eye gaze patterns of face processing depending on the type of stimuli and tasks [see Speer et al., 2007 for an example]. The face stimuli used should include not only static faces but also dynamic faces, and the task demands may need to vary from simple viewing to face detection and active processing (e.g. identifying the name of a face or categorizing a face by its gender).

Another limitation is that, because the current sample of ASD participants was at chance-level performance (52%) on the face recognition task, we do not know for sure how well they comprehended and engaged with the task.

Although ID participants also performed poorly in this task (59%), they performed significantly better than the ASD group and above chance, indicating that they understood the task, but their performance was limited by their cognitive function. It is also noteworthy that although face recognition accuracy showed that the ASD group performed more poorly than the ID group, the difference (7%) was not as great as the ASD–TD comparison (29%). Since the ASD and ID groups were matched by IQ scores, this pattern suggests that cognitive function is a contributor to face recognition ability. Future studies could be conducted to explore the relationship between cognitive function and face recognition in ASD.

Another issue is that the current study was based on a Chinese sample, so that cultural differences in face processing need to be considered when generalizing the conclusions to other populations, especially Westerners. Previous studies have provided evidence for East–West cultural differences in face-scanning patterns. For example, Blais, Jack, Scheepers, Fiset, and Caldara [2008] found that Western observers tend to fixate on the eye region, whereas Chinese observers tend to fixate on the nose. Fu, Hu, Wang, Quinn, and Lee [2012] further reported that Chinese observers looked longer at the nose and mouth of the Chinese faces and at the eyes of Caucasian faces. This is because, as explained by Fu et al. [2012], long-time direct eye contact is considered to be impolite and socially inappropriate in some Asian cultures [McCarthy, Lee, Itakura, & Muir, 2006; Yuki, Maddux, & Masuda, 2007]. As a result, socialized Chinese people attempt to avoid making eye contact in social situations. To date, no study has investigated cultural differences in face processing in individuals with ASD. However, we would expect that as a less socially engaged group, individuals with ASD may not display as much variation across cultures as do TD individuals. The current study found that, compared with TD Chinese participants, Chinese individuals with ASD looked less at the eye region and more on the nose. Thus, if we conduct this study with a Western sample, we may find similar patterns.

In summary, the results derived from three data analysis procedures used concurrently pinpoint focal and highly specific differences between ASD and non-ASD individuals in their visual scanning of the face. ASD individuals fixated less on the right eyes of the face but looked more at the central nasal area than TD and ID individuals. Other than these ASD-specific characteristics, ASD individuals' face-scanning patterns are either similar to ID individuals or TD individuals, or both, suggesting that ASD individuals do not have a general pervasive atypicality in visual attention toward the face.

Future investigations should take full advantage of the abundant data provided by the eye-tracking technique and analyze the data with multiple complementary approaches. Only through use of multi-approach analyses can we obtain a comprehensive understanding of the atypical face-processing patterns in ASD. Such understanding would eventually assist clinicians in developing evidence-based training programs that target ASD-specific deficits in face scanning, which in turn should enhance training programs' effectiveness and efficiency in improving ASD individuals' face-processing ability [see Tanaka et al., 2010, for an example]. We view the current research as representing an important step toward this goal.

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